

AN INVESTIGATION OF FUEL CELL ELECTRODE ACTIVITY  
INFLUENCED BY ALTERNATING CURRENT ELECTRIC FIELDS

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A Dissertation  
Presented to  
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In Partial Fulfillment  
of the Requirements for the Degree  
Master of Science

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by  
Gordon Henry Twedt

August 1968

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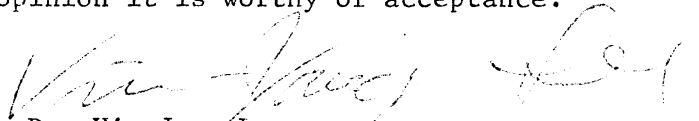
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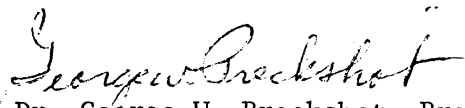
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presented by Gordon Henry Twedt

a candidate for the degree of Master of Science

and hereby certify that in their opinion it is worthy of acceptance.

  
Dr. Vin-Jang Lee  
Associate Professor, Chemical Engineering

  
Dr. George W. Preckshot, Professor  
Chairman, Dept. of Chemical Engineering

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ABSTRACT

Two methods of applying an alternating current electric field to the grid electrodes of the fuel cell systems were studied. Both methods were used to enhance the power output of the system. The alternating current electric field was applied to the grid electrodes to induce greater ionic motion, reduce the concentration polarization losses due to the ionic film double layer, and to desorb catalyst poisons and strongly adsorbed ions from the fuel cell electrode surfaces.

The enhancement of the fuel cell system power was found to be a function of the applied voltage and frequency. A greater applied alternating field voltage resulted in an increased power enhancement. In the first method, a maximum enhancement of 42,000 percent, at an applied voltage of 0.3 volt, was asymptotically approached as the frequency of the alternating current field was increased from 0.5 to 1000 cycles per second. This maximum enhancement corresponded to an output power of 3,000 microwatts. The input power from the alternating field was determined to be no greater than 3,000 microwatts. Also, a retention of the power enhancement for a short period after the removal of the applied alternating field was noticed and measured. In the second method, a maximum enhancement of 670 percent was obtained

at an applied voltage of 0.3 volt and a frequency of three cycles per second. A power input of 9,000 microwatts was needed to obtain the 670 percent enhancement. This power input was much greater than the enhanced power output obtained from the fuel cell system.

Grid electrodes were positioned in the gas phase behind the fuel cell electrodes and initial studies indicated that such a configuration consumed negligible input power while still producing an enhanced fuel cell power output.

When the effects of the semiconductive materials were investigated, a wafer of n-type silicon was used as the hydrogen electrode and a p-type silicon wafer was used as the oxygen electrode. The open circuit voltage of this configuration was 7.0 millivolts. An open circuit voltage of 4.5 millivolts was measured when the hydrogen electrode was p-type silicon and the oxygen electrode was n-type silicon. The difference between the two configurations indicated that, by assembling the fuel cell system in the same manner as the first configuration considered, an increase in open circuit voltage may be achieved.

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## CHAPTER I

## INTRODUCTION

Due to the unique needs of the military and space programs and attempts at pollution abatement, interest in fuel cells and fuel cell systems has been very great in recent years. The advancement of fuel cell technology has been rapid, but power from fuel cell systems is not yet commercially available. Factors hindering a commercial fuel cell system include: prohibitive cost and limited availability of catalyst materials, deterioration of the catalytic activity of the electrodes, many complex design problems, electrode poisoning due to chemisorption of an unreactive species, and lack of understanding of the processes of polarization and reaction mechanisms (10).

Relatively inexpensive nickel metal and semiconductive materials, such as nickel boride (26, 27) have been substituted for platinum and other noble metals as electrode catalysts. This has lowered the cost of fuel cell construction but the problems of chemisorption of poisons and the deterioration of the catalytic activity of the electrodes still hinder the commercial development of a fuel cell system. Schwabe has investigated the influence of gamma and beta emitters, deposited on an oxygen electrode, in increasing the activity of such electrodes. He indicates that the activity of the electrode surface is increased under the influence of the emitters (36). Other studies have indicated the beneficial effects of external radiation sources on electrode activity (22). Mechanical stirring and ultrasonics have also been used in attempts to increase fuel cell efficiency (2). Alternating current electric fields have been successfully employed to enhance the electrode

activity in a hydrogen--oxygen fuel system (37).

The fuel cell electrode and its catalysis have received the major portion of the fuel cell research effort, but attempt to improve upon the fuel cell output during actual operation, except by temperature and pressure changes, have received less attention.

The purpose and intent of this investigation was twofold. The study of the influence of an external alternating current electric field on the activity of a hydrogen--oxygen fuel cell system (32, 37) and the operation of the fuel cell with the extrinsic semiconductive material, silicon as electrodes. In the study of the alternating field effects, the alternating current field was applied to a single platinum grid electrode positioned between the two fuel cell electrodes. The complete system consisted of two identical fuel cells connected in parallel with one grid electrode positioned midway between the two electrodes of each cell. When the silicon semiconductive material was used in an attempt to study its electrocatalytic activity, only one fuel cell was employed as the system.

The completion of this investigation entailed: (I) the design and construction of an aqueous hydrogen--oxygen fuel cell system, (II) the application of an alternating current field to the grid electrode and the fuel cell electrodes, (III) the measurement of the power output of the system, (IV) the use of n-type and p-type silicon semiconductive material as fuel cell electrodes, and (V) the interpretation and analysis of the experimental results.

## CHAPTER II

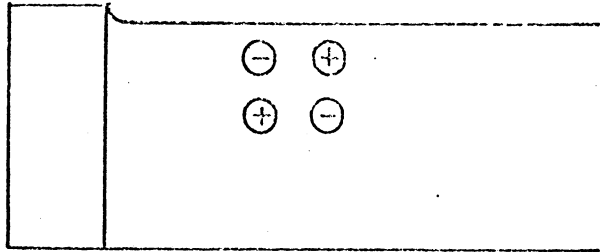
## THEORY OF THE EXPERIMENTAL METHOD

Many excellent reviews relating to fuel cell technology, electrode activity, and semiconductor processes are readily available. This discussion will, therefore, be limited to those basic concepts and fundamentals of fuel cell and semiconductor technology believed pertinent to the understanding of this experimental method.

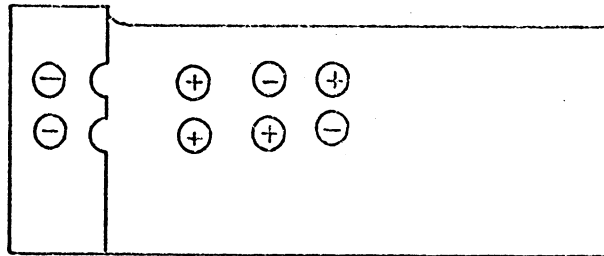
The Electrode Electrolyte Process

The development of a commercial fuel cell system depends upon how well engineering knowledge and ingenuity are employed to meet the kinetic demands of the fuel cell system. The purpose of this investigation was an improved method of solving the problem of concentration polarization caused by the capacitance effect arising from the formation of ionic film double layers at the fuel cell electrodes and the problem of the slow steady decay of the fuel cell electrode activity due to adsorbed catalyst poisons. Further, semiconductive materials were employed as electrodes to study their electrocatalytic effect on the activity of the fuel cell system.

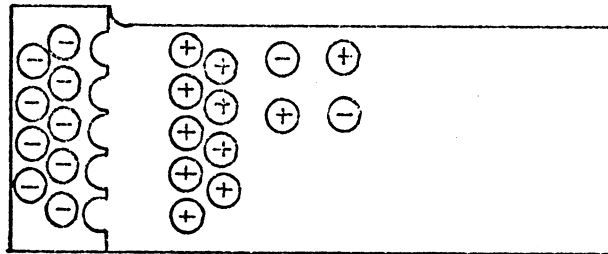
Ionic Film Double Layer. Most active metals, when placed in an ionic solution, enter the solution in the form of ions. This situation is illustrated by Figure 1. When a plate of active metal is placed in an ionized solution, such as aqueous potassium hydroxide, atoms of the metal will immediately give up an electron to the plate body and metal ions will enter into solution. This process causes the plate to become negatively charged and, therefore, the positively charged ions of the



1a. Initial Condition



1b. Metal Ions Dissolving

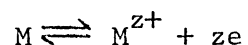


1c. Equilibrium Condition

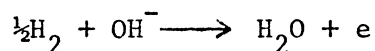
Figure 1. Metal Dissolution in Ionic Solution.



solution are attracted to the metal plate. A positively charged film is formed immediately adjacent to the negatively charged plate. This electrical, ionic double layer results in the formation of a potential barrier which limits further ionization of the metal and an equilibrium is established between the negative metal and the positive ions in the liquid phase (2).

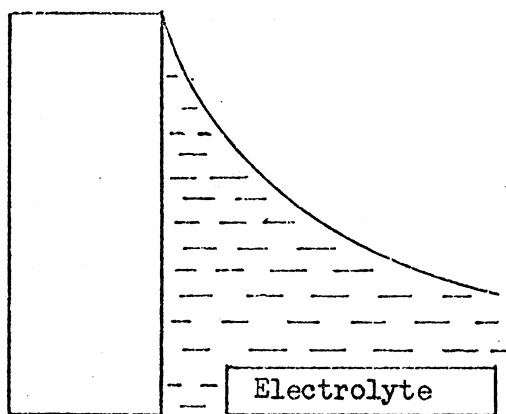


This idea is further illustrated by Figure 2. The ions leaving the electrode are attracted to the negatively charged electrode and are repulsed by the positively charged ionic film. Under these conditions, ions are formed only as rapidly as they are discharged or reacted. This equilibrium is maintained as long as no electrons are added to or taken from the electrode. In the case of a fuel cell, if the external circuit is completed by a finite load resistance electrons will flow through the external circuit, altering the equilibrium conditions. This change in the concentration of electrons, ions, and charged species results in a net oxidation or reduction until the equilibrium is once more established. Ideally, the electrodes of a fuel cell are inert with respect to the electrolyte solution and this theory of metal ionization may be generalized to any ionizable molecule or atom on the electrode surface. Absorbed molecules or atoms may undergo ionization and exchange electrons with the metal. The reaction at the hydrogen electrode of an aqueous alkaline electrolyte hydrogen-oxygen fuel cell.



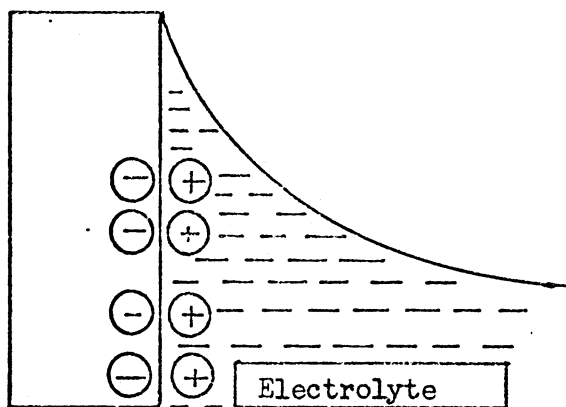
determines the potential as long as the electrode is electrochemically

Metal



2a. Metal in Electrolyte

Metal



2b. The Ionic Film Double Layer

Figure 2. Formation of the Ionic Film Double Layer.

inert (25). The slow transport of ions through the electrolyte solution results in an accumulation of the ionic double layer which produces a concentration polarization potential drop (6, 9). This slow transport of ions may be explained by the potential--distance diagram shown in Figure 3. As the reactive ions from the bulk electrolyte approach the electrode--electrolyte interface, the potential barrier through which they must travel increases very rapidly and hinders the migration of the ions to the electrode--electrolyte--gas interface. At low current densities, the concentration polarization contributes more to the reduction of the reversible electrode potential than does the activation polarization. The potential drop due to activation polarization is the potential loss that occurs when reactants of high activation energy are used in the fuel cell system.

Catalysts, higher temperature, and increased pressure may be used to reduce activation polarization, but these factors have little effect on the concentration polarization (1). Factors which may be easily adjusted to reduce concentration polarization are the ionic double layer and the surface coverage of adsorbed poisons and unreactive ions. Agitation has proven successful for planar electrodes (30). The application of an external alternating electric field has been successful for both porous carbon and solid nickel electrodes (37).

Electrode Poisoning. The fuel cell electrode process requires that the reactants be adsorbed on the catalytic electrode surface prior to their ionization and charge transfer. If the reactive electrode surface sites are covered with products that are difficult to desorb

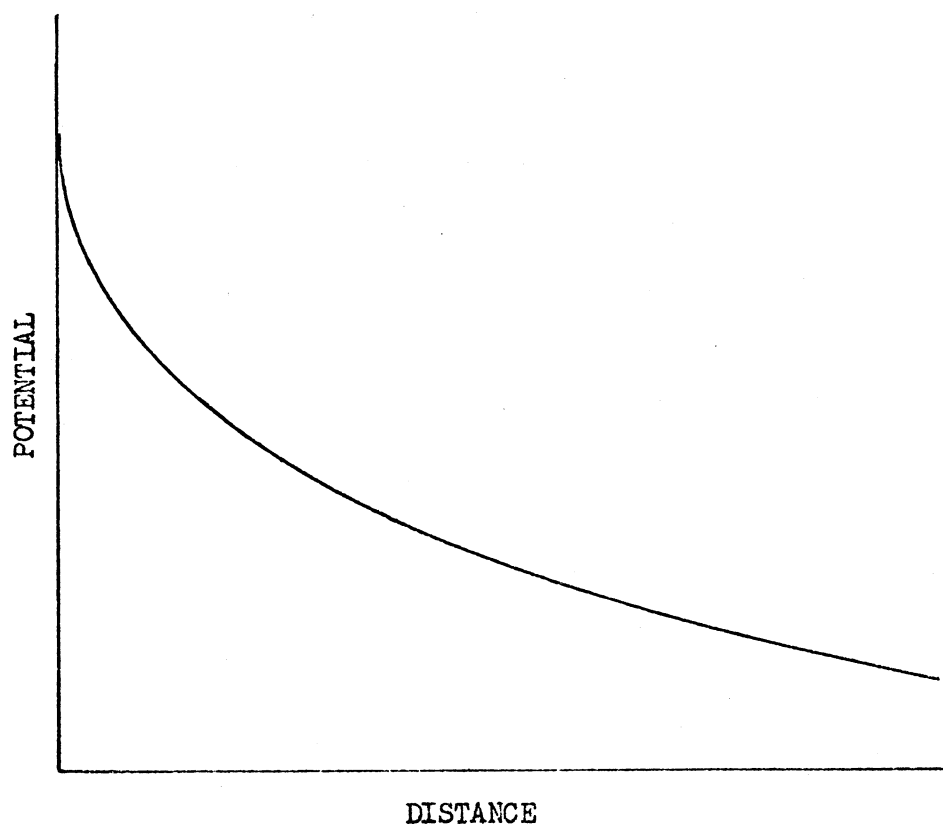


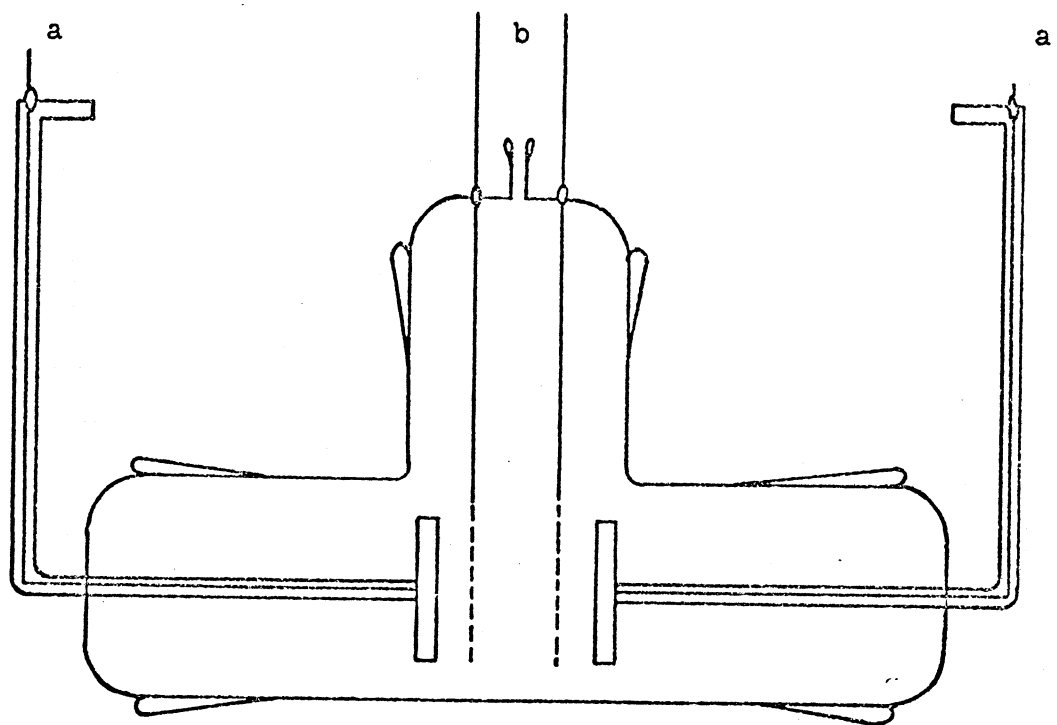
Figure 3. Potential--Distance Relation for the Electrode--Electrolyte Interface.

(6, 25) and unreactive species, oxides, or other poisons that reduce the number of available catalyst sites, the fuel cell will exhibit a reduction in power output. The application of an external alternating current electric field to the electrodes while the fuel cell is open circuited has been shown effective for the removal of adsorbed poisons (37).

Semiconductor Electrolyte Interface. Four factors distinguish the electrode processes at a semiconductor electrode surface from those at a metal electrode surface. These four factors are: (I) the low and readily variable electron density, (II) the possibility of having sizeable penetration of electric fields deep into the semiconductor, (III) the existence of an energy gap between the valence and conduction bands, (IV) the possibility of distinguishing two kinds of charge carriers, electrons and holes (20). A shift in the position of the Fermi level of the semiconductor results in a change in the potential drop between the bulk of the semiconductor and the bulk of the electrolyte. The various energy bands of the semiconductor (conduction and valence) and the Fermi level, for n-type and p-type materials are illustrated in Figure 8.

#### The Experimental Method

Two methods of applying an alternating current electric field in the hydrogen--oxygen fuel cell have been demonstrated. An alternating current field was applied to parallel grid electrodes contained in the electrolytic solution as shown in Figure 4. An enhancement in



a. Fuel Cell Terminals

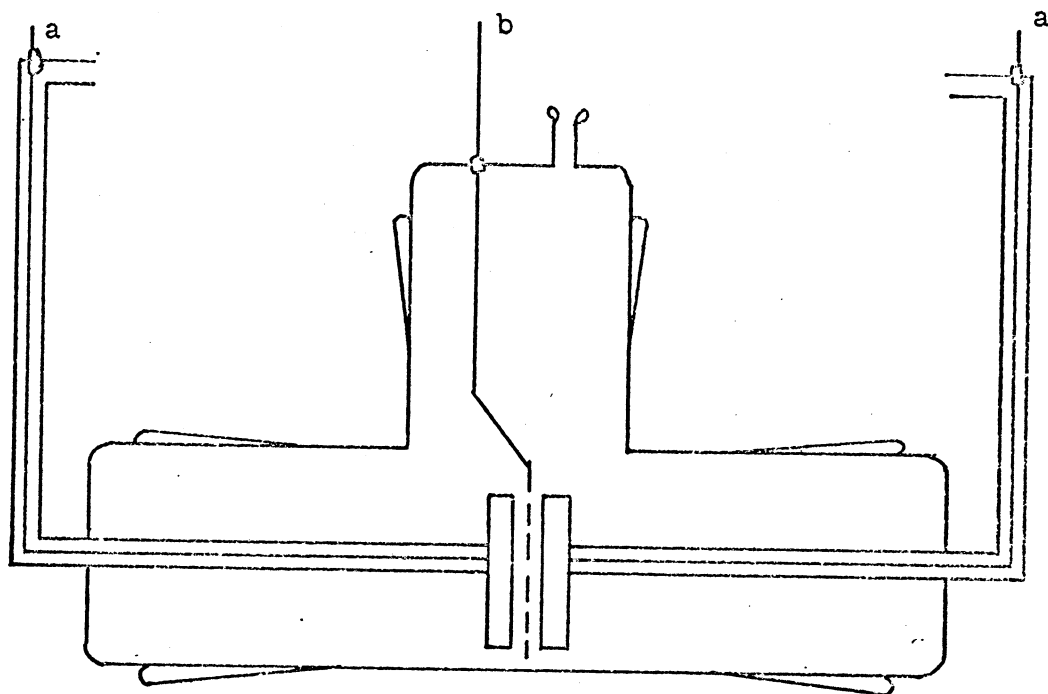
b. Grid Electrode Terminals

Figure 4. Fuel Cell Housing Containing Two Parallel Electrodes.

fuel cell output power was achieved by applying the alternating field during operation. Also, a regenerative effect was also noticed when the electric field was imposed on the system at open circuit. The cost of operating the electric field equipment was approximately five times greater than the 5,000 percent maximum enhancement. This power loss was attributed to the resistance effects of the electrolyte (37). A proposed improved method of alternating field application (32) was studied in this investigation:

Removal of the Ionic Double Layer by Grid Electrodes. A single platinum grid electrode was employed in each of the two parallel fuel cells. The grid electrode was placed in the electrolyte solution and centered between the two fuel cell electrodes, as shown in Figure 5. The alternating current electric field imposed upon the grid electrodes and the fuel cell electrodes induced greater ionic motion which hindered the accumulation of strongly adsorbed species and poisons on the catalytic electrode surfaces. High concentration polarization was avoided since the applied alternating current field disrupted the ionic double layer adjacent to the fuel cell electrodes.

Consideration of a triode vacuum tube, Figure 6, may be extremely helpful in the explanation of the function of the alternating current electric field applied to the fuel cell grid electrodes. In the triode vacuum tube, a negative space charge develops around the cathode. The individual electrons are attracted to the positively charged plate, having passed through the grid electrode. The grid electrode may be positively or negatively charged to control the flow of electrons between the cathode and the plate (28).



- a. Fuel Cell Terminals
- b. Grid Electrode Terminal

Figure 5. Fuel Cell Housing for Single Grid Electrode.



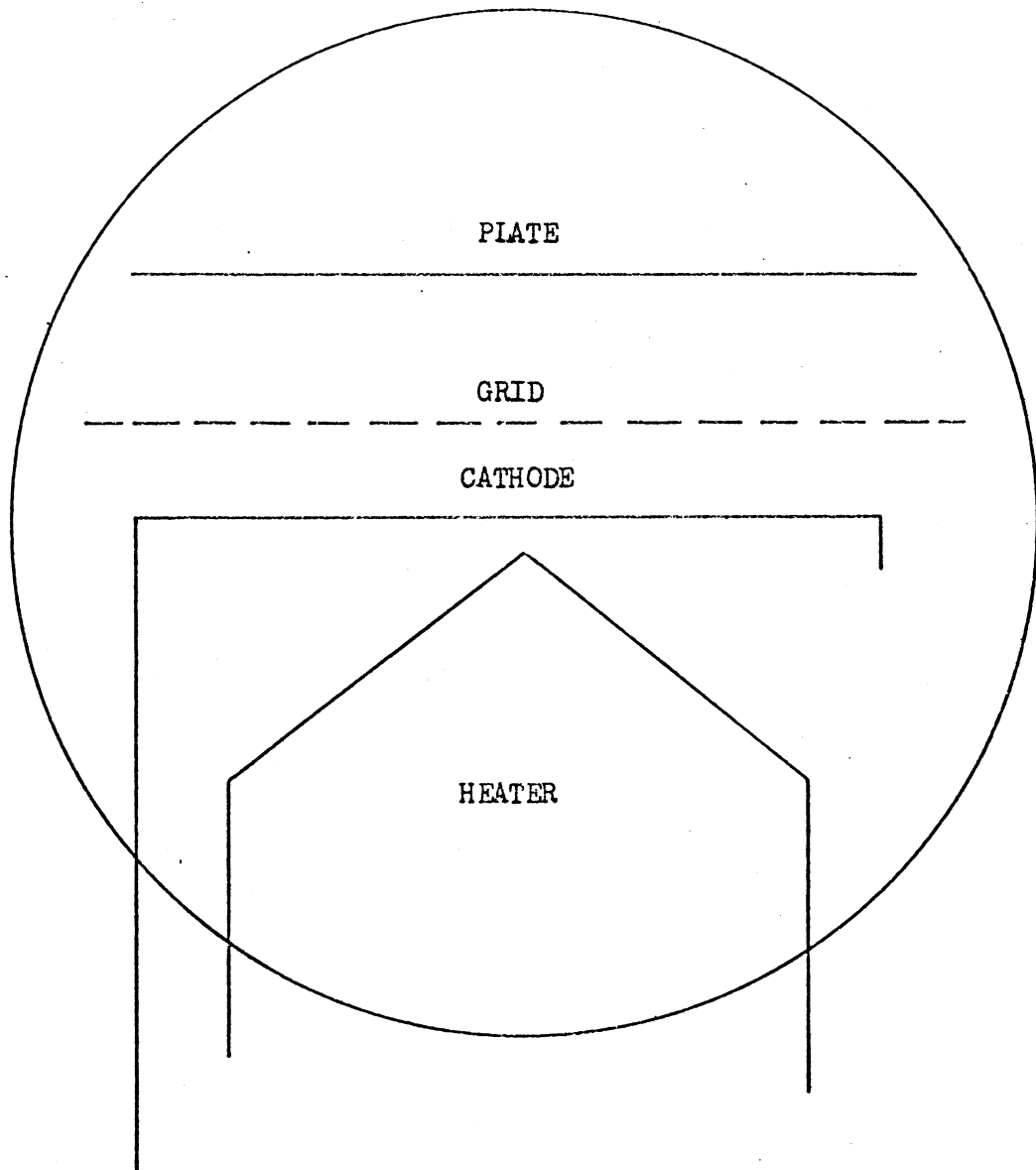


Figure 6. Triode Vacuum Tube.

The control imposed upon the electrons by the grid electrode may be explained by considering the position of the electrons in Figure 7. The electrons pass through the grid mesh and are influenced by the potential residing on the grid. If the grid is positively charged relative to the cathode, the indicated electrons will be subject to the influence of several forces. The forces acting on an electron in the position a are: first, the initial velocity of emission; second, the attraction back to the cathode by the image positive charge formed on the cathode; third, the influence of the negative space charge; fourth, the attraction due to the plate; fifth, the attraction due to the grid wires. The forces imposed by the grid are as indicated, but the resultant attractive force is toward the positive plate. An electron positioned at point b is influenced by its instantaneous velocity, the attraction of the plate and the resultant attraction of the grid wires, which is zero. The forces acting on an electron at point c are similar to those at points a and b, but the electron is attracted to the grid and does not travel to the plate (28).

Influence of Extrinsic Semiconductor Materials. The adsorbed molecules or atoms acting as acceptors or donors on the electrode surfaces are assumed to be in equilibrium with their ions. The concentration of these neutral and charged particles are determined by the Fermi energy level at the electrode surface. The energy band diagrams for n-type and p-type semiconductors before any donor or acceptor ionization has taken place are shown in Figure 8. When the adsorbed surface species become ionized, the energy bands of the semiconductor are in-

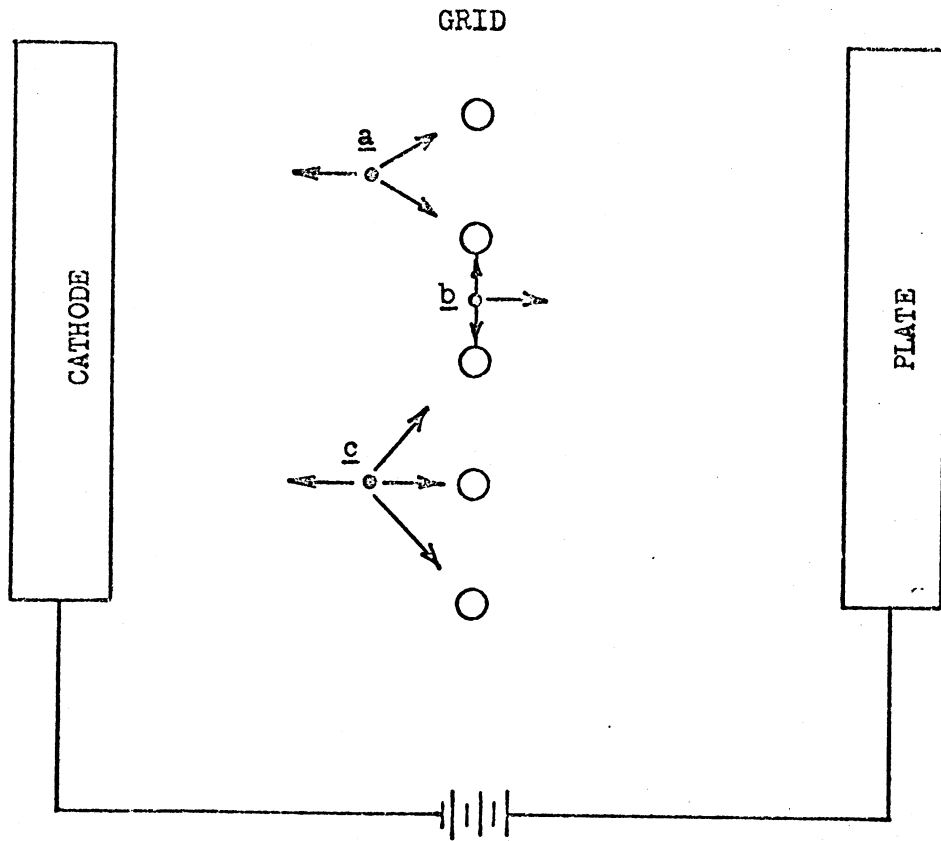


Figure 7. Grid Forces in a Triode Vacuum Tube.

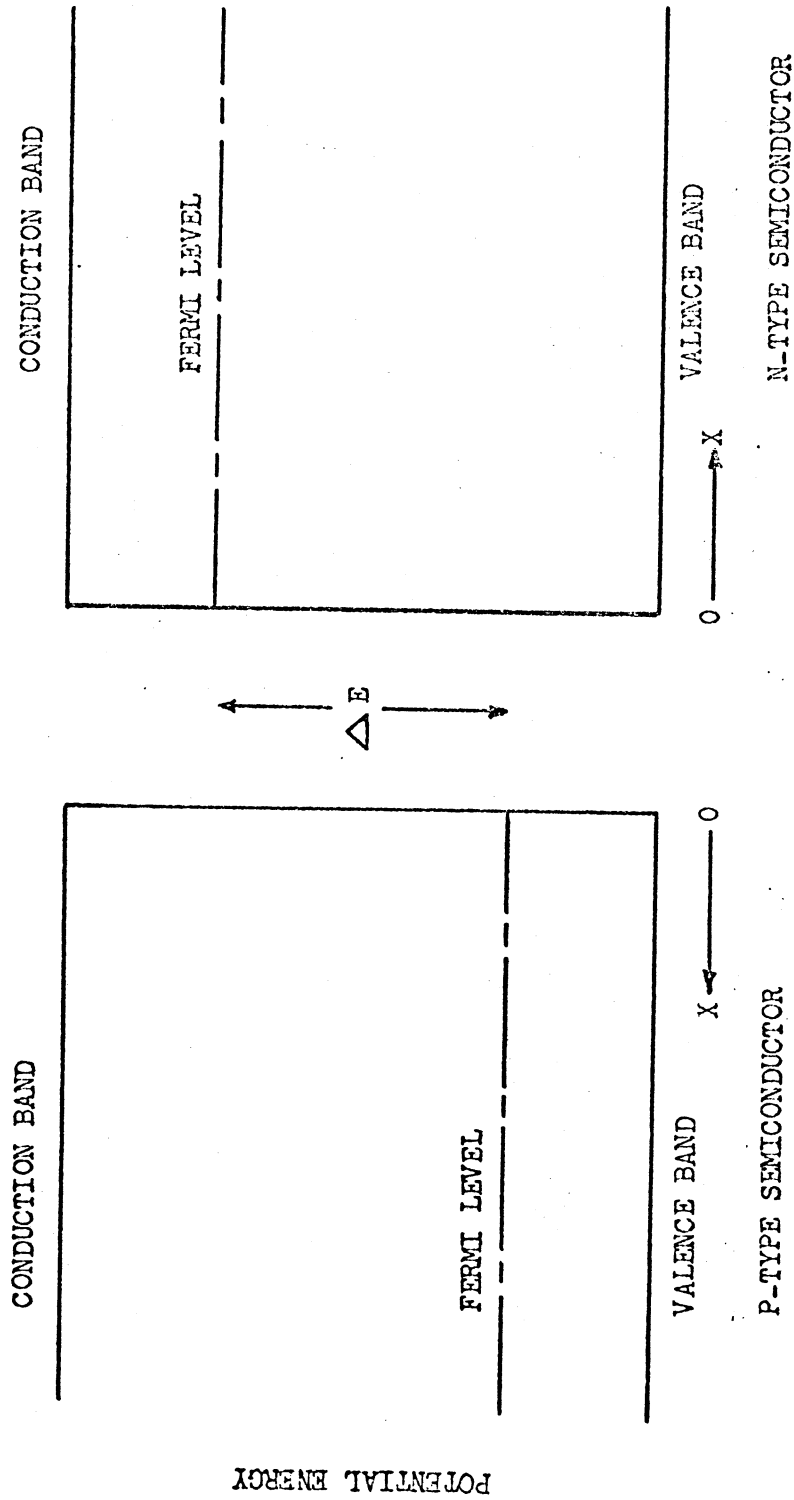


Figure 8. Initial Condition Before Donor or Acceptor Ionization.

fluenced. The energy band diagrams, shown in Figures 9 and 10 for the adsorption of acceptor and donor species have been proposed by Lee (34).

A consideration of the displacement of the Fermi energy level at the electrode surface indicates, that by the proper choice of materials and operating conditions, the potential between the two electrodes may be increased or decreased. A hydrogen--oxygen fuel cell system employing a p-type oxygen electrode and an n-type hydrogen electrode would be expected to experience an increase in potential between the two electrodes due to the effect of the acceptors on the oxygen electrode and the donors on the hydrogen electrode. This situation is illustrated in Figure 9. The opposite effect, a decrease in electrode potential, would be expected if the hydrogen electrode was a p-type semiconductor and the oxygen electrode was an n-type semiconductor. This condition is illustrated in Figure 10.

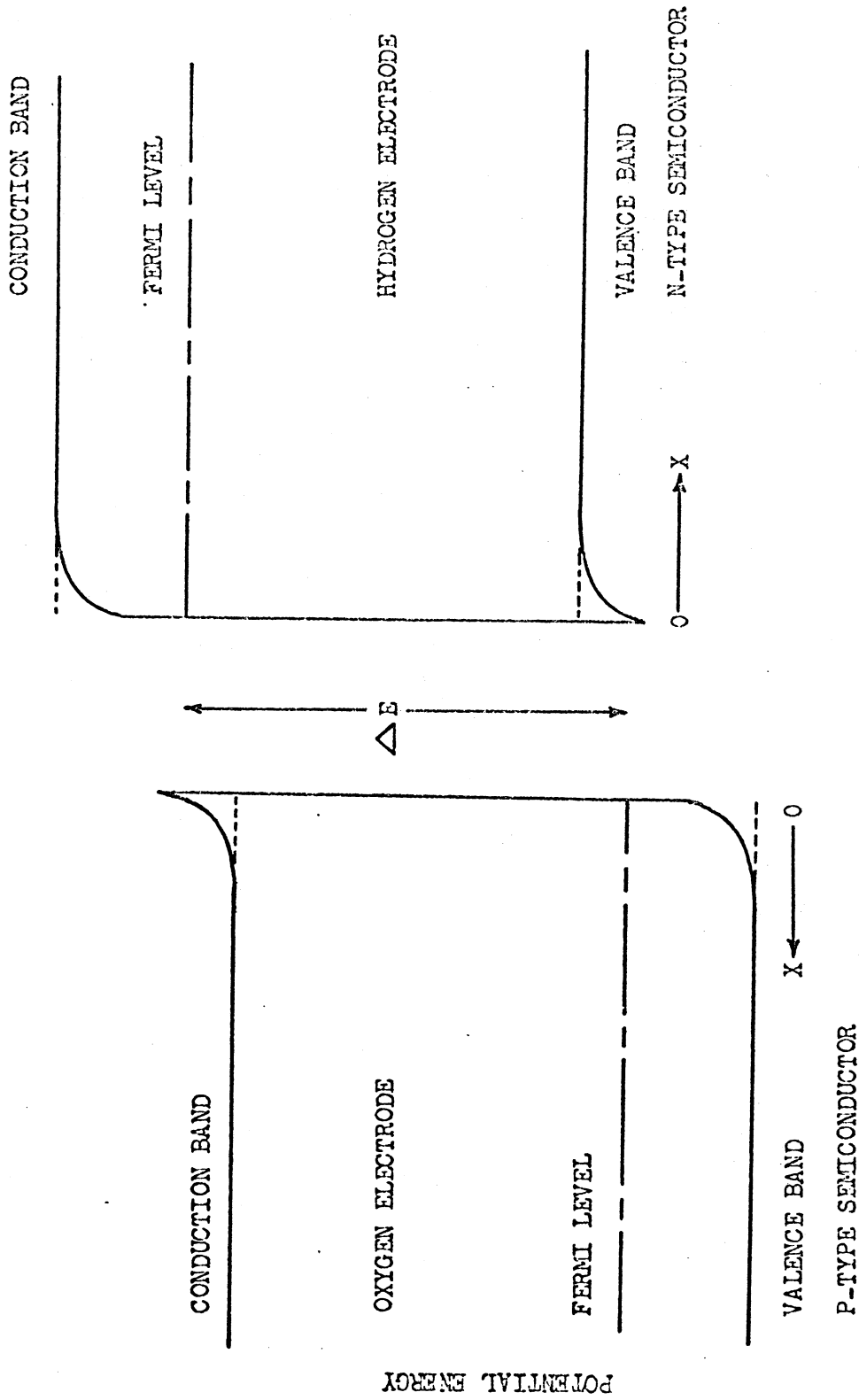


Figure 9. Potential Energy Increase After Adsorption.

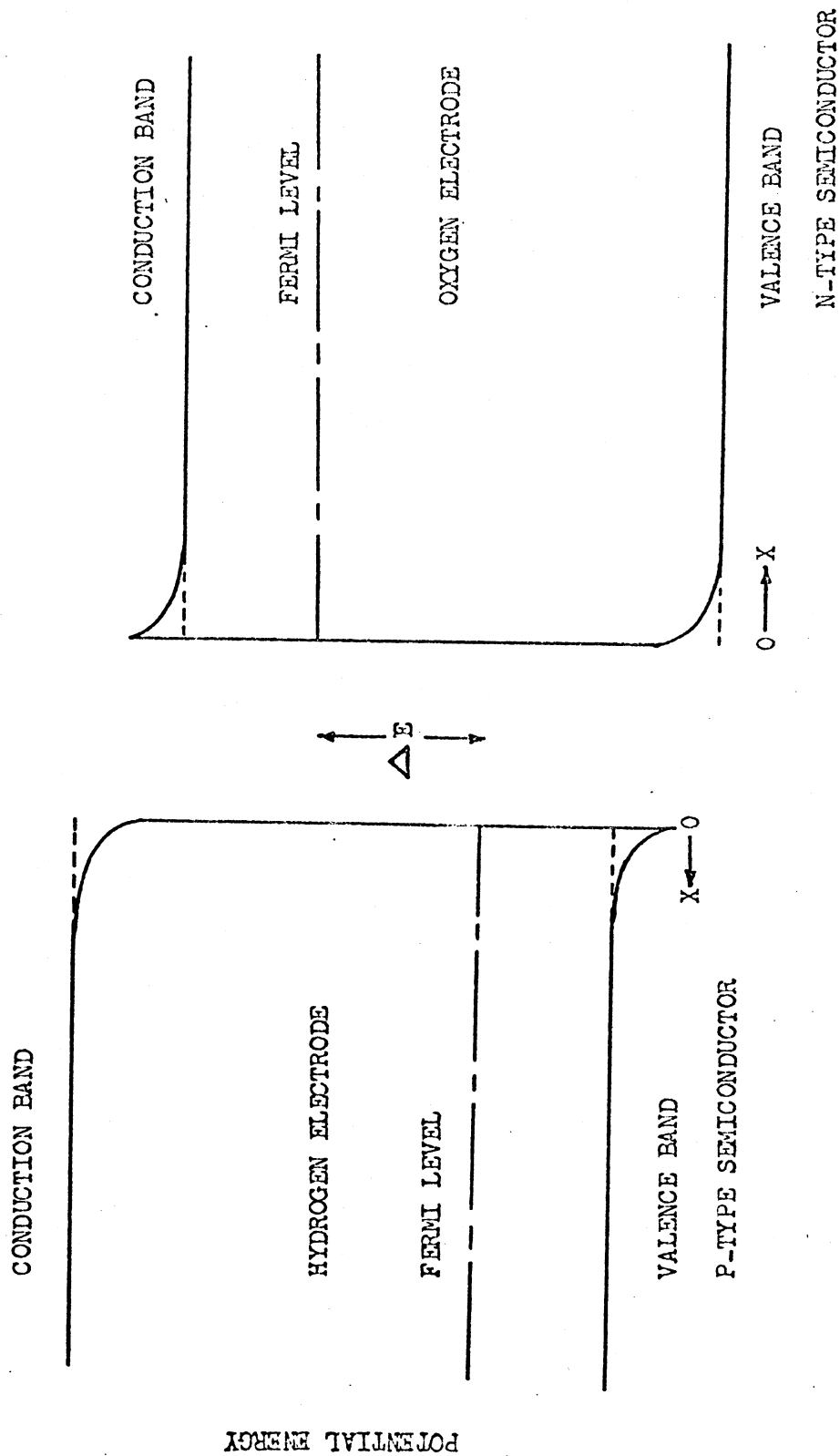


Figure 10. Potential Energy Decrease After Adsorption.

### CHAPTER III

#### EXPERIMENTAL

This investigation had as its purpose the study of the influence of an alternating current electric field upon the activity of platinum fuel cell electrodes and the operation of the fuel cell system with the semiconductive material, silicon, as electrodes. The completion of this investigation entailed: (I) the design and construction of an aqueous hydrogen--oxygen fuel cell system, (II) the application of an alternating current field to the grid electrode and the fuel cell electrodes, (III) the measurement of the power output of the system, (IV) the use of n-type and p-type silicon semiconductive material as fuel cell electrodes, and (V) the interpretation and analysis of the experimental results.

#### Equipment and Measurements

Schematic diagrams of the equipment configurations used in this experimental investigation are given in Figures 11, 12, and 13. Detailed drawings of the assembled fuel cell housing and the Teflon electrode assembly are shown in Figures 14 and 15, respectively.

Electrodes. Two types of fuel cell electrodes were employed in this investigation. Pure platinum solid foil was used to fashion electrodes which were 1.0 inch in diameter and 0.006 inch thick. Silicon single crystal wafers 1.0 inch in diameter and 0.003 inch thick were studied in the second phase of this investigation.

Fuel Cell Housing. Each fuel cell housing was constructed of



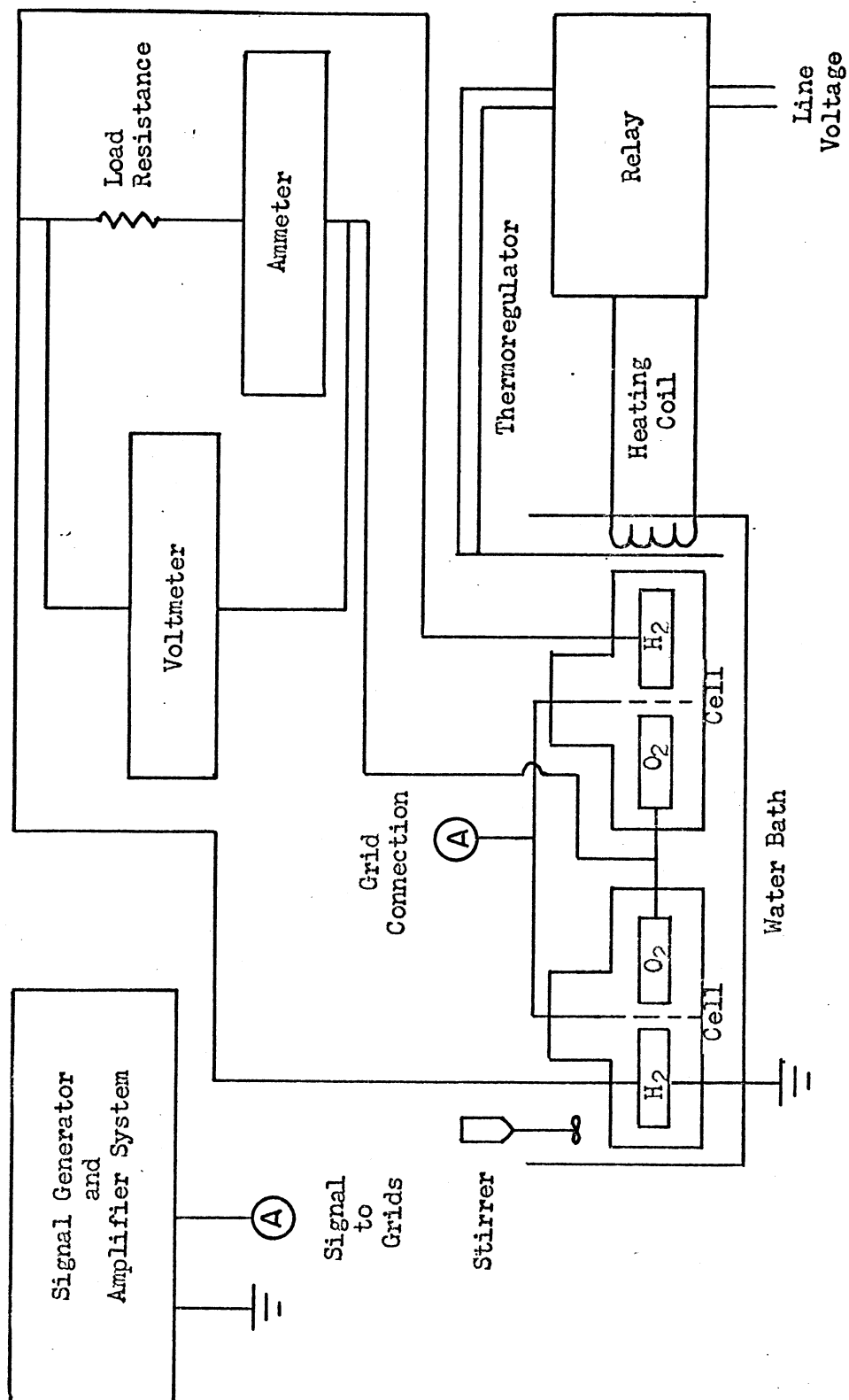


Figure 11. Schematic of Experimental System A.

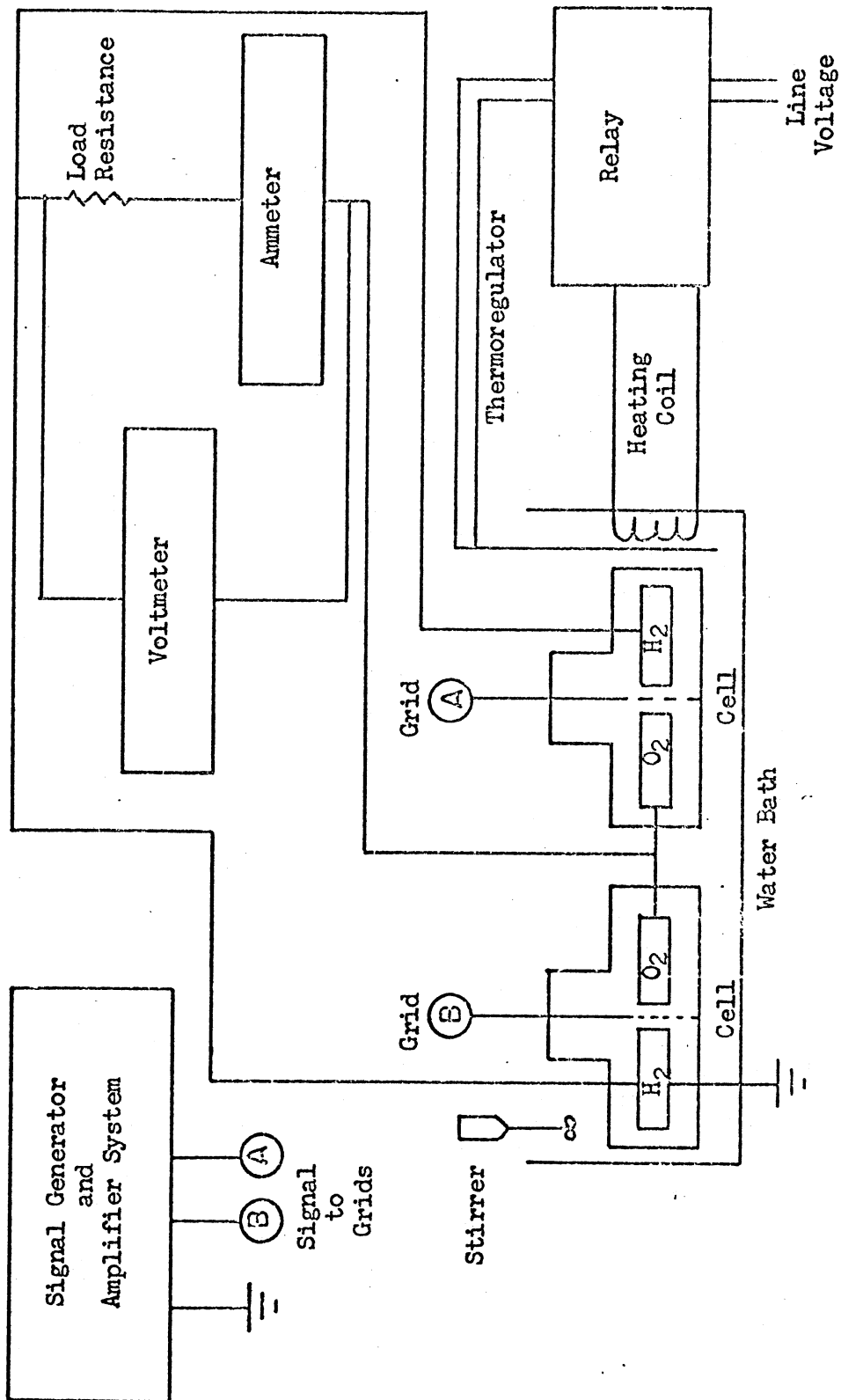


Figure 12. Schematic of Experimental System B.

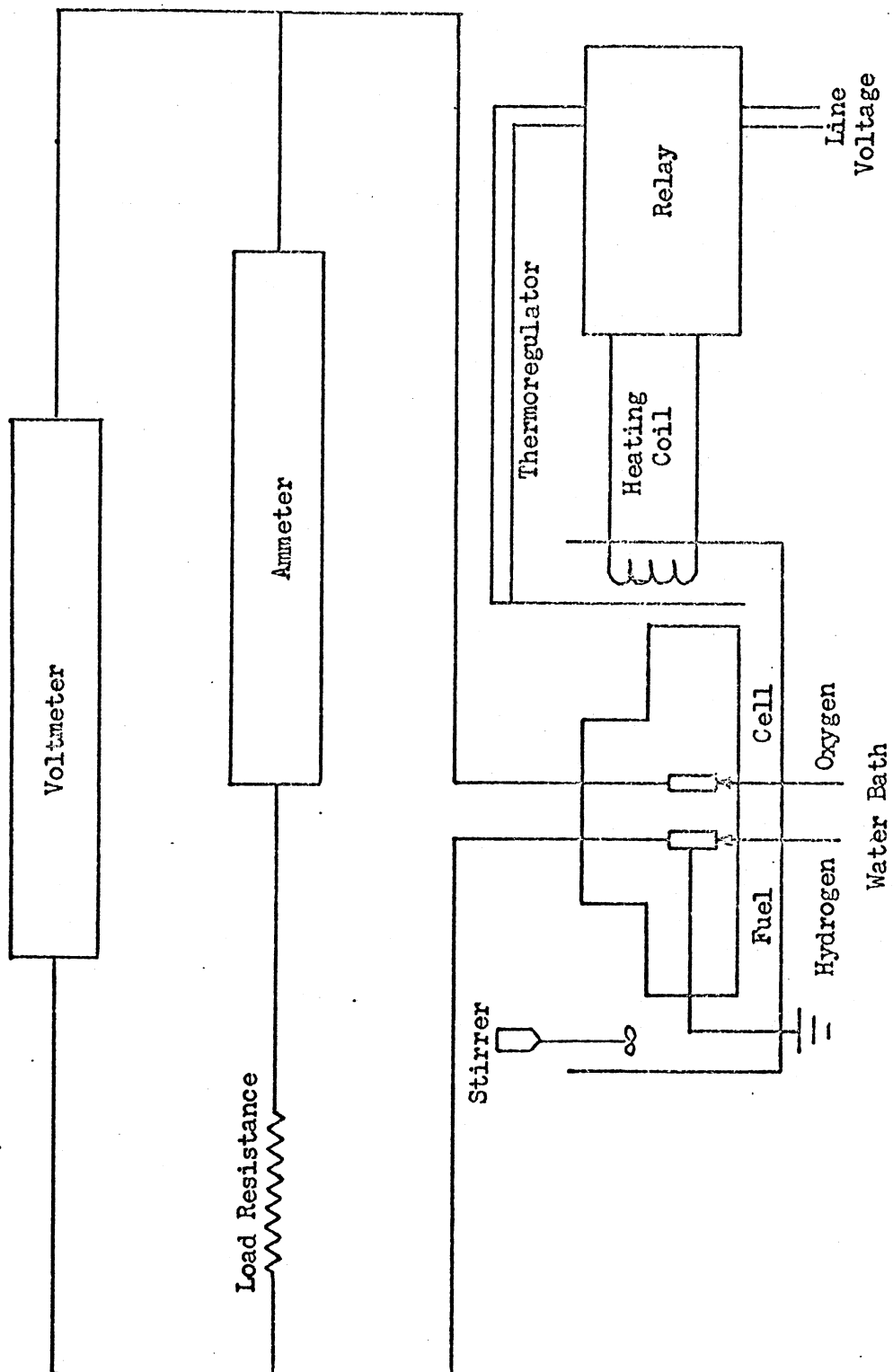
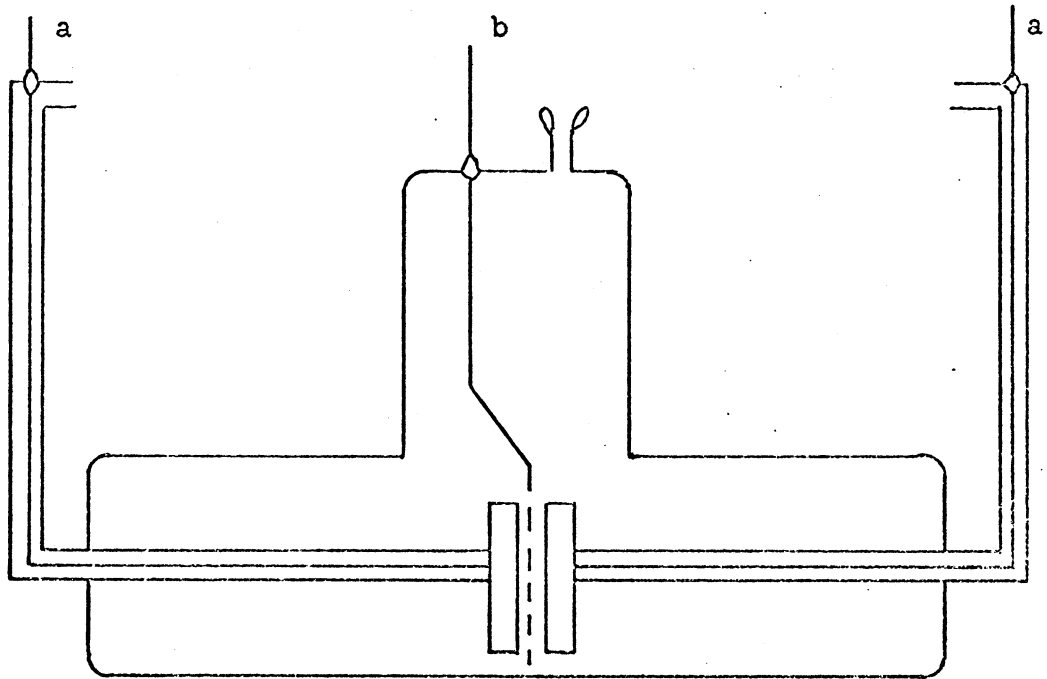


Figure 13. Schematic of Experimental System C.



- a. Fuel Cell Terminals
- b. Grid Electrode Terminal

Figure 14. Fuel Cell Housing with Terminal for Electric Field.

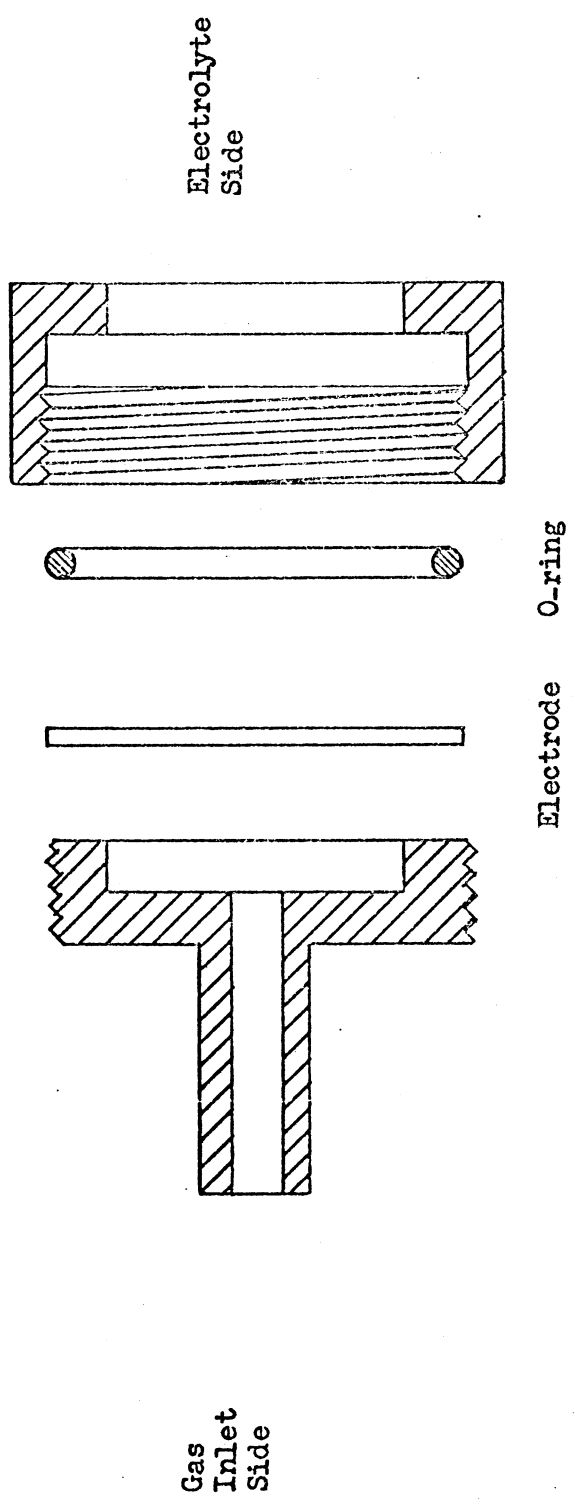


Figure 15. Teflon Electrode Assembly

three 45/50 Pyrex ground glass joints assembled as shown in Figure 14. The top joint was fitted with a standard taper glass thermometer joint and a single platinum wire to which a platinum wire gauze grid was attached. A 0.25 inch outside diameter glass tube was inserted into each of the side joints. This tube was oriented concentrically to the side joint and extended beyond the inner lip of the joint. The Teflon electrode holders were connected to the extended glass tube by Teflon Swagelok unions in such a manner that the electrode separation was 0.25 inch. The external ends of the glass tubes were connected to the compressed fuel and oxidant supply contained in pressurized cylinders.

The Teflon electrode holders and the manner in which the electrodes were assembled in them is illustrated in Figure 15. Dow Sealastic RTV 732 sealant was used to seal the threads of the electrode holder to prevent leakage of the feed gases to the electrolyte and the atmosphere. The fuel and oxidant gases entered at the back of the electrodes and a neoprene spacer distributed them to the rim of the electrodes. The gases then passed between an Auburn O-ring and the electrode surface, thereby forming a reactive electrode--electrolyte--gas interface.

Fuel. Hydrogen and oxygen gas were used as the fuel for the system. The gases, contained in pressurized cylinders, were delivered to the 0.25 inch outside diameter glass tube centered in the fuel cell side joints by a system of rubber and Tygon tubing. The glass tubing delivered the gases to the electrodes contained in the Teflon electrode holders. The pressure of both the hydrogen and oxygen gases was lower

than five pounds per square inch. The pressure used was high enough to supply the gas uniformly to the reactive electrode surface, but low enough to prohibit the formation of gas bubbles in the electrolyte solution.

Fuel Cell Temperature Control. A constant temperature water bath was used to maintain a constant fuel cell operating temperature of 30°C. The fuel cell system was immersed in the water bath. The water in the bath was kept in continuous circulation by a variable speed stirrer and the bath temperature was maintained by a 300 watt heating coil controlled by a relay and a thermoregulator.

Electric Field Source. The alternating current electric field was obtained by passing the signal from a Hewlett Packard function generator through a direct current operational amplifier. The signal was applied to the grid electrodes of both fuel cells during quasi steady state operation, as shown in Figures 11 and 12. The wave form and the voltage of the applied electric field was monitored and measured by a Tektronix oscilloscope and a Fluke Differential Multimeter.

Grid Position. The grid electrodes were placed between the hydrogen and oxygen electrodes of each fuel cell. The grid was centered 1/8 of an inch from each electrode surface. If the distance between the grid and the electrode surfaces is greater than or equal to twice the grid spacing, the force on the ions at the fuel cell electrodes is uniform. This distance was calculated by the formula

$$\phi(x, z) = F_n(z) \sin(2\pi nx/a)$$

where

$$F_n = A_n e^{(-z/z_0)}$$

$$z_0 = a/2\pi n$$

a is the grid spacing, and

n is the harmonic number (23).

The platinum wire gauze used in this investigation had grid spacings of 0.015 inch. Therefore, in all cases studied, the grid electrodes applied an entirely uniform force upon the ions at the surface of the electrodes.

Power Output Measurement System. The voltage and current output of the fuel cell system was continuously measured and recorded on a pair of Simpson 604 Multicorders. Figures 11, 12, and 13 indicate the electrical connections used in measuring the fuel cell power output.

Determination of the Effects of the Field. The fuel cell system was operated until a quasi steady state condition was attained before the alternating current electric field was applied to the grid electrodes. Any noticeable enhancement or abatement of the fuel cell power output, as measured by the fuel cell current and voltage, was attributed to the effects of the applied electrical field (37). The power enhancement or abatement was calculated as a percentage increase or decrease from the quasi steady state power.

Input Power Measurement. In the general case of an alternating electric current supplied to a system, the average power is determined as the product of the effective current, the effective voltage, and a power factor. The power factor may vary between the values of zero and unity, depending upon the circuit being considered. For the system studied in this investigation, an upper bound on the power input was determined by assuming a power factor of unity. The input power was



then calculated as the product of the voltage and current as measured by the apparatus indicated in Appendix F, Figure 22.

### Experimental Procedure

A direct soldered connection was used to join the output terminals to the solid fuel cell electrodes. When the semiconductor electrodes were used, a copper wire cloth was employed to collect the current from the electrodes and deliver it to the external circuit. The fuel cell housings, with the output electrical terminals connected as indicated earlier, were immersed in the constant temperature water bath and the one molar potassium hydroxide electrolyte was added. The fuel cells were connected in parallel and an ammeter and a load resistance were connected in series with the parallel fuel cell system. A voltmeter was then connected in parallel across the ammeter and the load resistance. The hydrogen and oxygen gas pressures were adjusted such that during the operation of the system no gas bubbles appeared at the electrode--electrolyte interface. The output voltage and current were measured and recorded, with the power output being calculated as the product of the corresponding output current and voltage.

System C, Figure 13, was used for the study of the influence of the extrinsic silicon semiconductor electrodes upon the fuel cell voltage output. Two semiconductor configurations were investigated in this study. First, the oxygen electrode was p-type and the hydrogen electrode was n-type; second, the oxygen electrode was n-type and the hydrogen

electrode was p-type. The first and second configurations are illustrated in Figures 9 and 10, respectively.

Enhancement During Operation by Grid Electrodes. The fuel cell system was operated until quasi steady state operating conditions were reached. The output voltage and current were then recorded. The quasi steady state power output of the fuel cell system during continuous operation is indicated by Table I and Figure 16. The quasi steady state operation of the system was necessary to permit the study of the enhancement of power output under the influence of the grid electrodes.

An alternating current electric field of known frequency and measured voltage was then applied to the grid electrodes. The voltage and current of the system were given sufficient time to reach an equable value. The output voltage and current oscillated about a mean value and this mean value was measured and recorded, together with the frequency and voltage of the applied alternating field. Any variation of the fuel cell system output was attributed to the alternating current electric field. These variations were calculated as percentage increases or decreases from the original quasi steady state values.

If the fuel cell system circuit was opened for a period and then closed, the power output would increase and then decay to the value obtained before the open circuit condition.

Influence of Semiconductor Electrodes. When the silicon semiconductive material was used as the electrodes of the fuel cell system, the first configuration investigated consisted of n-type silicon as the hydrogen electrode and p-type silicon as the oxygen electrode. The sec-

TABLE I  
POWER DECAY AFTER COMPLETION OF EXTERNAL CIRCUIT  
WITH NO FIELD APPLIED  
DATA OF JULY 1, 1968

Time (minutes)	Voltage (millivolts)	Current (milliamperes)	Power (microwatts)
0	225	8.00	1800
5	215	7.00	1500
10	160	5.00	800
15	125	4.50	560
20	120	4.00	480
25	100	2.75	280
30	75	2.75	210
35	75	2.25	170
40	60	2.00	120
45	40	1.25	50
50	35	1.00	35
55	25	0.75	19
60	20	0.50	10
65	15	0.50	7.5
70	15	0.50	7.5
75	15	0.50	7.5
80	15	0.50	7.5
85	10	0.25	2.5
90	10	0.25	2.5
95	10	0.25	2.5
100	10	0.25	2.5

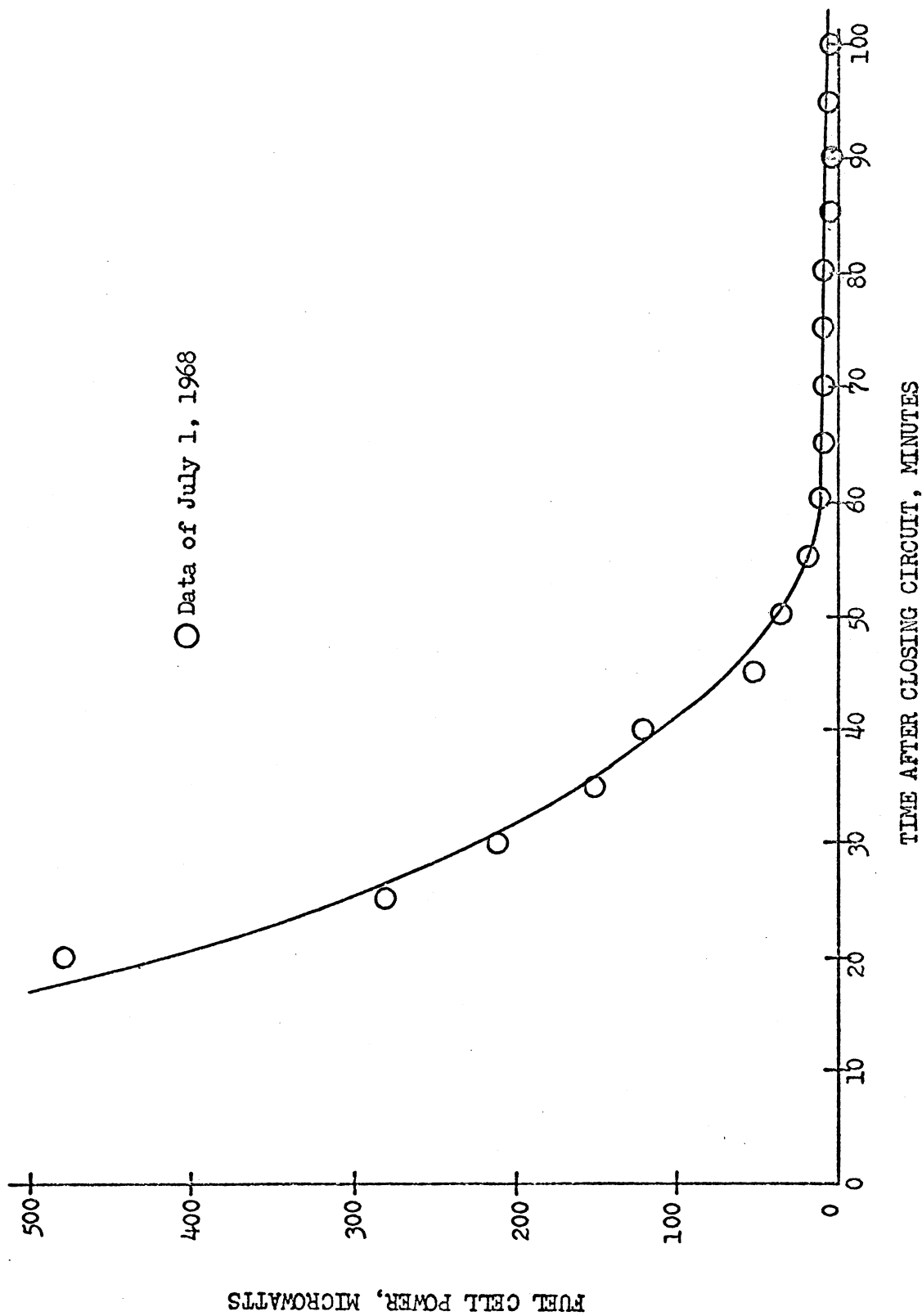


Figure 16. Power Decay After Completion of External Circuit with No Field Applied.

ond configuration used n-type silicon as the oxygen electrode and p-type silicon as the hydrogen electrode. The objective of the investigation was the determination of any differences that may have existed between the operating currents and voltages of the first and second configurations. This could lead to a better understanding of how semiconductive materials could be better used in a fuel cell system.

## CHAPTER IV

## RESULTS AND DISCUSSION

The results of this investigation of the effects of an alternating current electric field upon the operation of an aqueous electrolyte hydrogen--oxygen fuel cell system and the study of the use of semiconductive materials as electrodes of such a system are discussed in this chapter.

Enhancement, System A. Some extremely interesting phenomena were observed during the experiments with an alternating current electric field applied to the grid electrodes positioned between the fuel cell electrodes of System A, as shown in Figure 11. The main purpose of the tests was the study of the enhancement of the fuel cell system power output under the influence of an applied alternating current field. Also, the effect of using extrinsic semiconductive materials as fuel cell electrodes was investigated. The use of the alternating field to increase the power output of the fuel cell system was a study of the field effect catalysis of the electrode surfaces. The applied field increased the catalytic activity of the electrodes and induced ionic motion in the electrolyte. It was hoped that in this investigation an enhancement of the fuel cell system power output could be achieved with little or no power input from the applied alternating current field. Previous work has indicated that the enhancement of fuel cell power output by the application of an alternating current field was possible. The power input to the previous system was reported to be five times greater than the maximum power enhancement

achieved. This excessive power loss was attributed to the resistance of the electrolyte to the flow of ions (37). The present study employed solid platinum electrodes which were closely spaced in an effort to reduce the potential loss due to the internal resistance of the electrolyte. Also, only one grid electrode was inserted in each fuel cell in an attempt to reduce or eliminate the current flow between grid electrodes. This current flow was experienced when two grid electrodes were placed in the same fuel cell, as indicated in Figure 4 (37).

The open circuit voltage of the system was 0.70 to 0.75 volt. The external circuit of the system was completed and the fuel cell system was allowed to reach a quasi steady state operating condition before the alternating field was applied to the platinum grid electrodes. With the solid platinum electrode fuel cell system, a sinusoidal wave field with a frequency of 0.5 to 1000 cycles per second was applied to the grid electrodes. The voltage of the applied field was 0.1, 0.2, and 0.3 volt. An increase in the system current and voltage outputs was observed at all frequencies and applied voltages which were investigated. The output current and voltage oscillated widely, about a mean value, at frequencies between 0.5 and 3 cycles per second. At frequencies above three cycles per second, the system outputs fluctuated very little but, in all cases, the mean values of the output current and voltage were measured and recorded. At frequencies above 50 cycles per second, the enhancement of the fuel cell system power asymptotically approached a maximum value which depended upon the voltage of the applied alternating current electrical field. This phenomenon is illustrated by Table II

TABLE II  
ENHANCED POWER OBTAINED BY THE APPLICATION OF 0.3 VOLTS  
TO THE GRID ELECTRODES OF SYSTEM A  
DATA OF JUNE 28 AND JULY 1, 1968

Trial	Frequency (cy/sec)	Enhanced Power (microwatts)
538	0.5	850
537	1	1300
533	5	1900
564	10	2600
568	50	3000
573	100	3000
577	500	3000
578	1000	3000



TABLE II (continued)

ENHANCED POWER OBTAINED BY THE APPLICATION OF 0.2 VOLTS  
TO THE GRID ELECTRODES OF SYSTEM A  
DATA OF JUNE 28 AND JULY 1, 1968

Trial	Frequency (cy/sec)	Enhanced Power (microwatts)
549	0.5	680
548	1	910
541	5	1600
596	10	1800
600	50	2300
605	100	2300
609	500	2300
610	1000	2400

TABLE II (continued)  
ENHANCED POWER OBTAINED BY THE APPLICATION OF 0.1 VOLTS  
TO THE GRID ELECTRODES OF SYSTEM A  
DATA OF JUNE 28 AND JULY 1, 1968

Trial	Frequency (cy/sec)	Enhanced Power (microwatts)
561	0.5	260
560	1	350
556	5	510
551	10	580
629	50	760
634	100	790
638	500	880
639	1000	880

and Figure 17 which contain values of the enhanced power obtained and Table III and Figure 18 which contain values of the percentage power enhancement obtained by the application of the alternating current field. These tables and figures illustrate the asymptotic behavior of the power output of the system at higher applied field frequencies.

A maximum power output of 3,000 microwatts was obtained at an applied voltage of 0.3 volt and at frequencies above 50 cycles per second. This maximum power increase corresponded to a 42,000 percent enhancement or increase in the fuel cell power output. This enhancement was achieved by the expenditure of a maximum power input of 3,000 microwatts, as calculated in Appendix F. This dramatic improvement in the fuel cell system operation was attributed to the catalytic effects of the applied alternating current field and the enhanced ionic motion of the electrolyte.

When System A was studied, the major factor contributing to the system power enhancement was considered to be the catalytic effect of the alternating field upon the fuel cell electrode surfaces. The applied alternating field resulted in a cleansing of the reactive electrode surfaces. Strongly adsorbed ions and catalyst poisons were removed by the forces applied by the field, thereby, providing a greater catalytic electrode surface area upon which reaction could occur. This is the same effect noticed in the regeneration of a hydrogen--oxygen fuel cell system, at open circuit, by the application of an alternating current field (37).

Desorption Effects. The removal of strongly adsorbed ions and

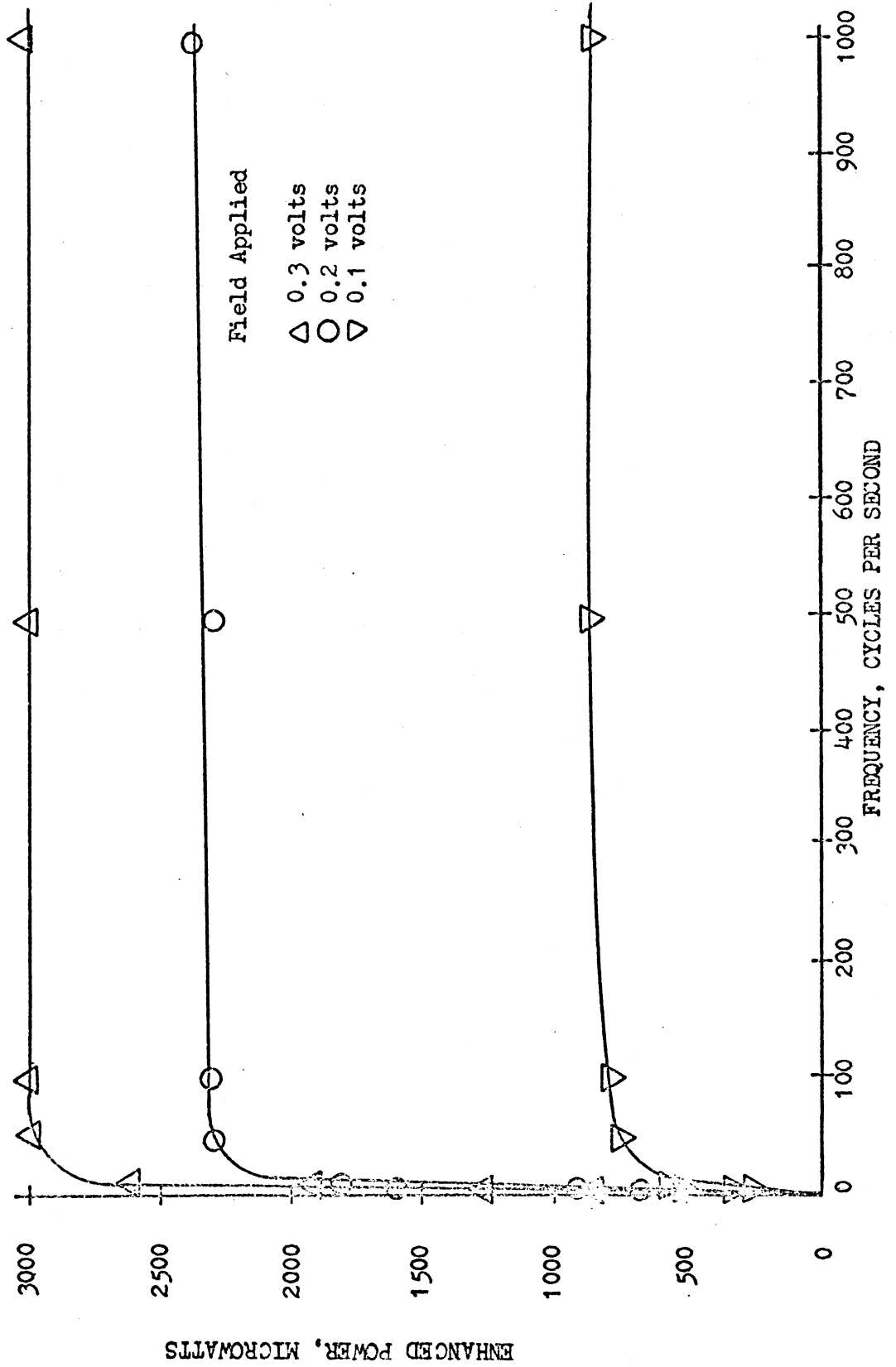


Figure 17. Enhanced Power with Grid Electrodes, System A.

TABLE III  
POWER ENHANCEMENT OBTAINED BY APPLICATION OF 0.3 VOLTS  
TO THE GRID ELECTRODES OF SYSTEM A  
DATA OF JUNE 28 AND JULY 1, 1968

Trial	Frequency (cy/sec)	Enhancement (percent)
538	0.5	11,000
537	1	17,000
533	5	26,000
564	10	34,000
568	50	42,000
573	100	42,000
577	500	42,000
578	1000	42,000

TABLE III (continued)  
POWER ENHANCEMENT OBTAINED BY APPLICATION OF 0.2 VOLTS  
TO THE GRID ELECTRODES OF SYSTEM A  
DATA OF JUNE 28 AND JULY 1, 1968

Trial	Frequency (cy/sec)	Enhancement (percent)
549	0.5	8,900
548	1	12,000
541	5	21,000
596	10	24,000
600	50	30,000
605	100	30,000
609	500	31,000
610	1000	32,000

TABLE III (continued)  
POWER ENHANCEMENT OBTAINED BY APPLICATION OF 0.1 VOLTS  
TO THE GRID ELECTRODES OF SYSTEM A  
DATA OF JUNE 28 AND JULY 1, 1968

Trial	Frequency (cy/sec)	Enhancement (percent)
561	0.5	3,300
560	1	4,600
556	5	6,700
551	10	7,600
629	50	10,000
634	100	10,000
637	500	12,000
638	1000	12,000

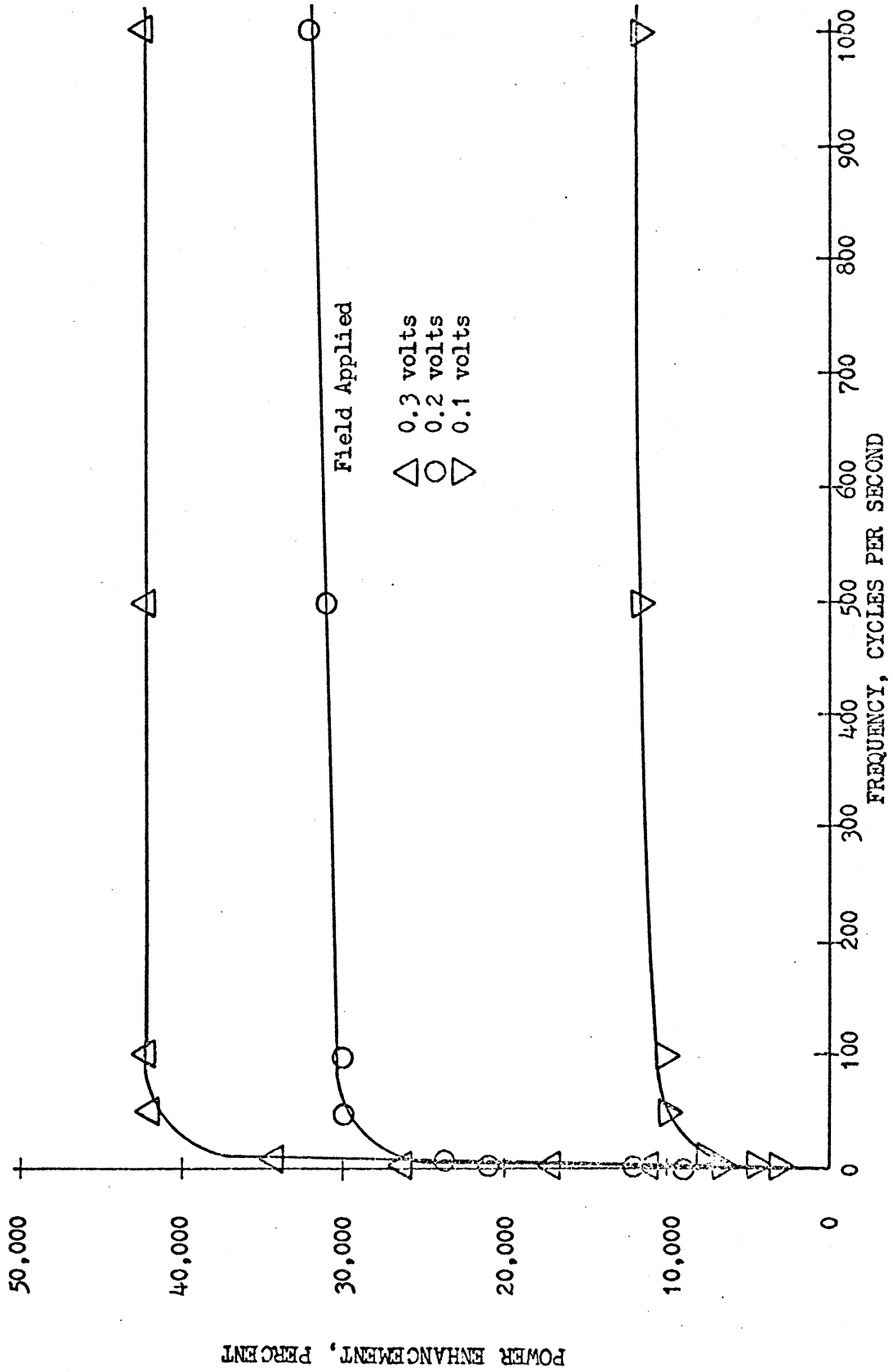


Figure 18. Power Enhancement with Grid Electrodes, System A.



catalyst poisons was evidenced by the continued increase in the fuel cell system power output after the removal of the applied alternating current field. The output current and voltage of the system, after removal of the applied field, slowly dropped from their maximum values to their values before the application of the alternating field. The duration of the decay time needed to attain initial conditions after the application of the alternating field was found to be a function of the applied voltage and frequency. The values of the decay time asymptotically approached maximum values as the frequency was increased. A maximum decay time of 225 seconds at frequencies greater than 100 cycles per second and an applied field of 0.3 volt was measured. To obtain the decay time measurements contained in Table IV and Figure 19, the alternating current electric field was applied to the fuel cell system for thirty seconds and then removed.

Enhancement, System B. An enhancement of the fuel cell power was also achieved with System B. Table V and Figure 20 contained enhanced power information. Table VI and Figure 21 present values of the percentage enhancement in fuel cell system power output. These tables and figures indicate that the enhancement of the fuel cell system power output was a function of the applied voltage and frequency. A voltage of 0.30 to 0.35 volt was measured when the circuit was open. A maximum enhancement of 670 percent at three cycles per second was attained with 0.3 volt applied to the grid electrodes. This enhancement corresponded to a power output of 2.6 microwatts, but the maximum input power, as calculated in Appendix F, was 9,000 microwatts. Again, any increased

TABLE IV  
DECAY TIME AFTER APPLICATION OF 0.3 VOLTS TO THE GRID  
ELECTRODES OF SYSTEM A FOR THIRTY SECONDS  
DATA OF JULY 2, 1968

Trial	Frequency (cy/sec)	Decay Time (seconds)
53	1	120
54	3	140
55	5	165
56	7	180
57	9	180
58	20	195
59	40	210
60	100	225
61	500	225

TABLE IV (continued)  
DECAY TIME AFTER APPLICATION OF 0.2 VOLTS TO THE GRID  
ELECTRODES OF SYSTEM A FOR THIRTY SECONDS  
DATA OF JULY 2, 1968

Trial	Frequency (cy/sec)	Decay Time (seconds)
35	1	120
36	3	135
37	5	165
38	7	190
39	9	200
40	20	210
41	40	210
42	100	215
43	500	215

TABLE IV (continued)  
DECAY TIME AFTER APPLICATION OF 0.1 VOLTS TO THE GRID  
ELECTRODES OF SYSTEM A FOR THIRTY SECONDS  
DATA OF JULY 2, 1968

Trial	Frequency (cy/sec)	Decay Time (seconds)
71	1	45
72	3	55
73	5	60
74	7	65
75	9	70
76	20	74
77	40	75
78	100	75
79	500	75

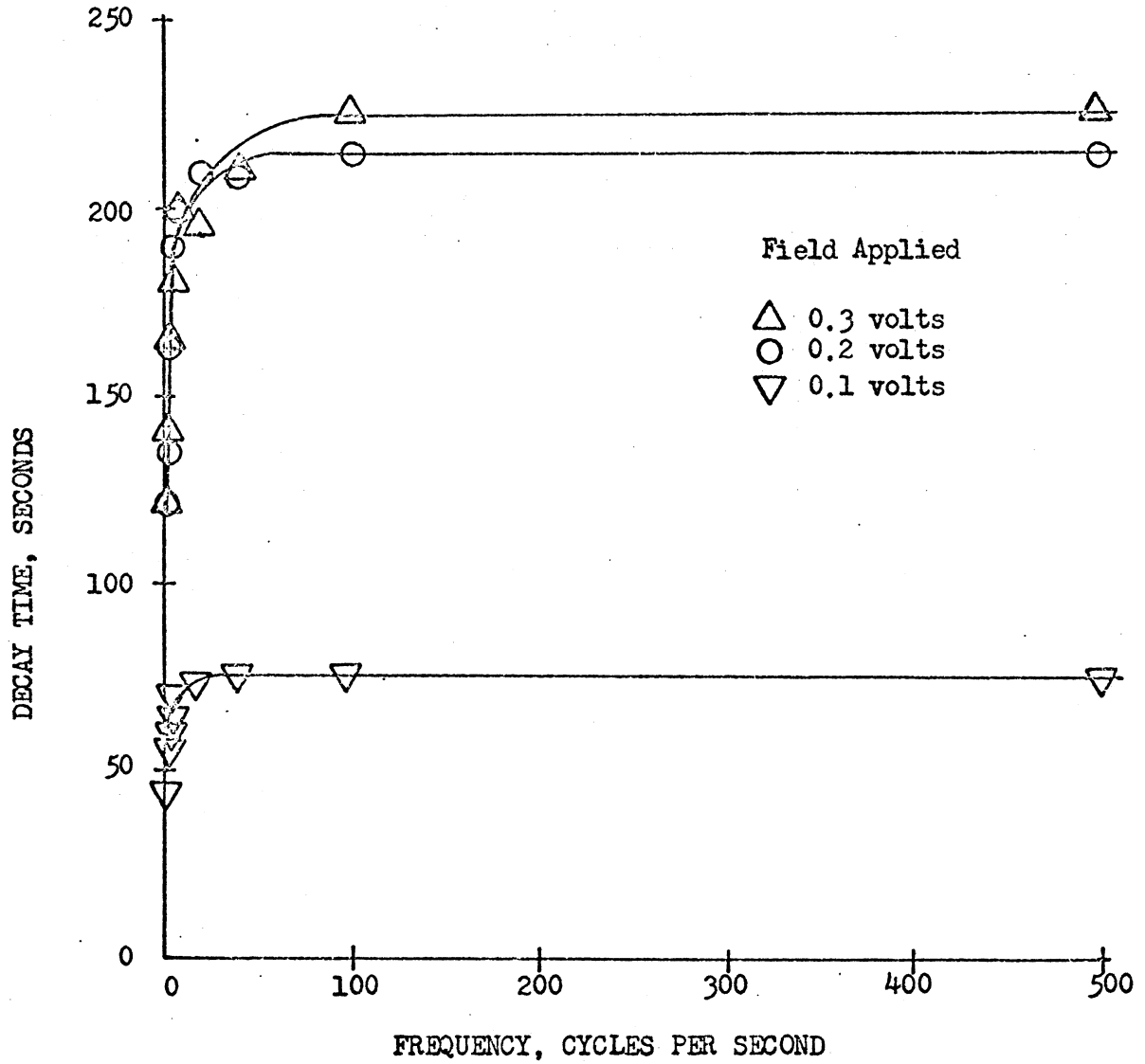


Figure 19. Decay Time after Thirty Second Application of Field to System A.

TABLE V  
ENHANCED POWER OBTAINED BY THE APPLICATION OF 0.3 VOLTS  
TO THE GRID ELECTRODES OF SYSTEM B  
DATA OF JULY 17, 1968

Trial	Frequency (cy/sec)	Enhanced Power (microwatts)
57	1	2.5
58	2	2.6
59	3	2.6
60	4	2.4
61	5	2.4
62	10	2.1
63	50	1.5
64	100	1.2

TABLE V (continued)  
ENHANCED POWER BY THE APPLICATION OF 0.2 VOLTS  
TO THE GRID ELECTRODES OF SYSTEM B  
DATA OF JULY 17, 1968

Trial	Frequency (cy/sec)	Enhanced Power (microwatts)
65	1	0.88
66	2	0.92
67	3	0.95
68	4	0.82
69	5	0.80
70	10	0.72
71	50	0.65
72	100	0.58

TABLE V (continued)

ENHANCED POWER OBTAINED BY THE APPLICATION OF 0.1 VOLTS

TO THE GRID ELECTRODES OF SYSTEM B

DATA OF JULY 17, 1968

Trial	Frequency (cy/sec)	Enhanced Power (microwatts)
73	1	0.38
74	2	0.39
75	3	0.39
76	4	0.38
77	5	0.36
78	10	0.36
79	50	0.34
80	100	0.34



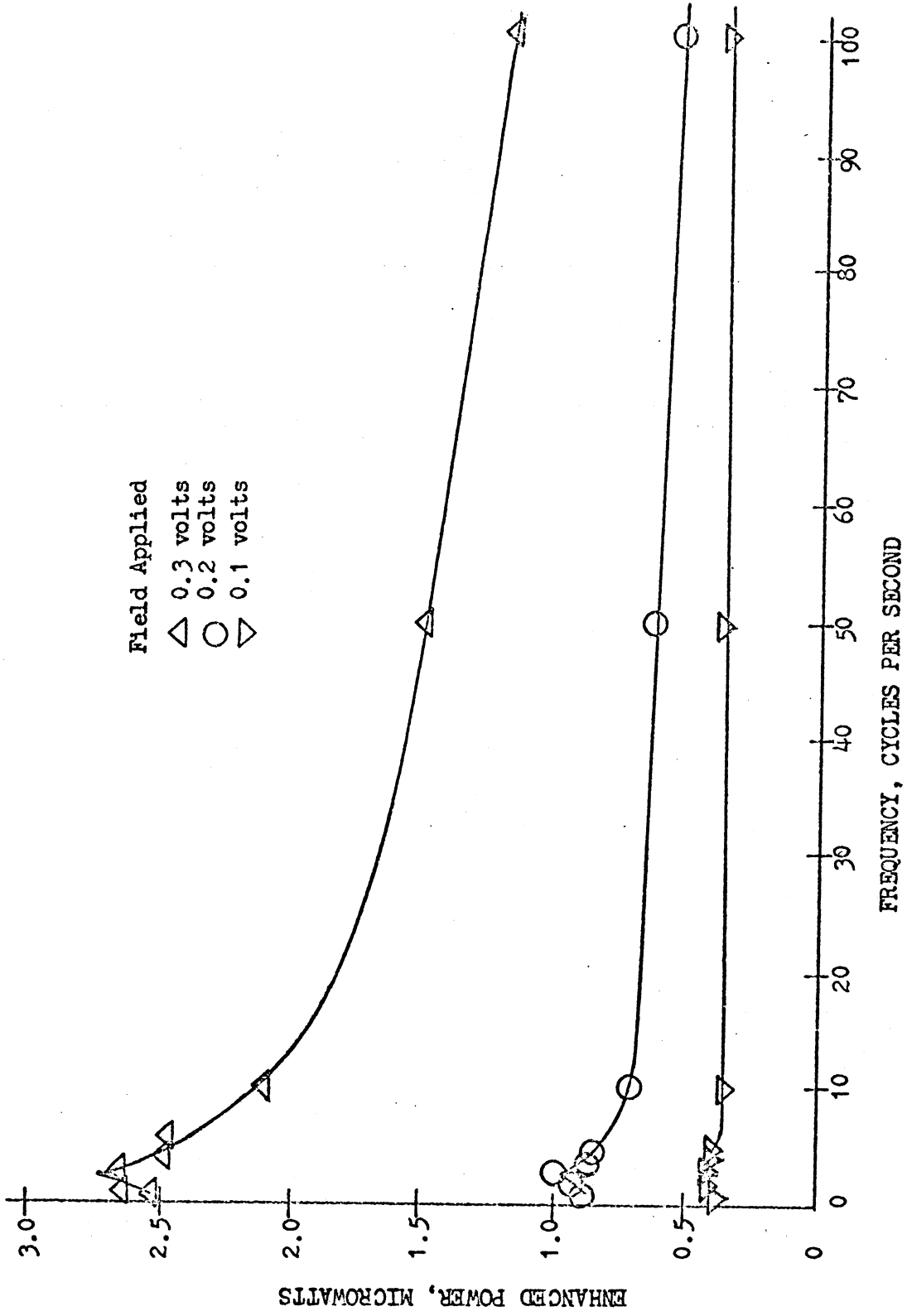


Figure 20. Enhanced Power with Grid Electrodes, System B.

TABLE VI  
POWER ENHANCEMENT OBTAINED BY APPLICATION OF 0.3 VOLTS  
TO THE GRID ELECTRODES OF SYSTEM B  
DATA OF JULY 17, 1968

Trial	Frequency (cy/sec)	Enhancement (percent)
57	1	640
58	2	660
59	3	670
60	4	610
61	5	590
62	10	520
63	50	340
64	100	230

TABLE VI (continued)  
POWER ENHANCEMENT OBTAINED BY APPLICATION OF 0.2 VOLTS  
TO THE GRID ELECTRODES OF SYSTEM B  
DATA OF JULY 17, 1968

Trial	Frequency (cy/sec)	Enhancement (percent)
65	1	160
66	2	170
67	3	180
68	4	140
69	5	140
70	10	110
71	50	90
72	100	70

TABLE VI (continued)  
POWER ENHANCEMENT OBTAINED BY APPLICATION OF 0.1 VOLTS  
TO THE GRID ELECTRODES OF SYSTEM B  
DATA OF JULY 17, 1968

Trial	Frequency (cy/sec)	Enhancement (percent)
73	1	11
74	2	15
75	3	15
76	4	11
77	5	7.4
78	10	7.4
79	50	0.0
80	100	0.0

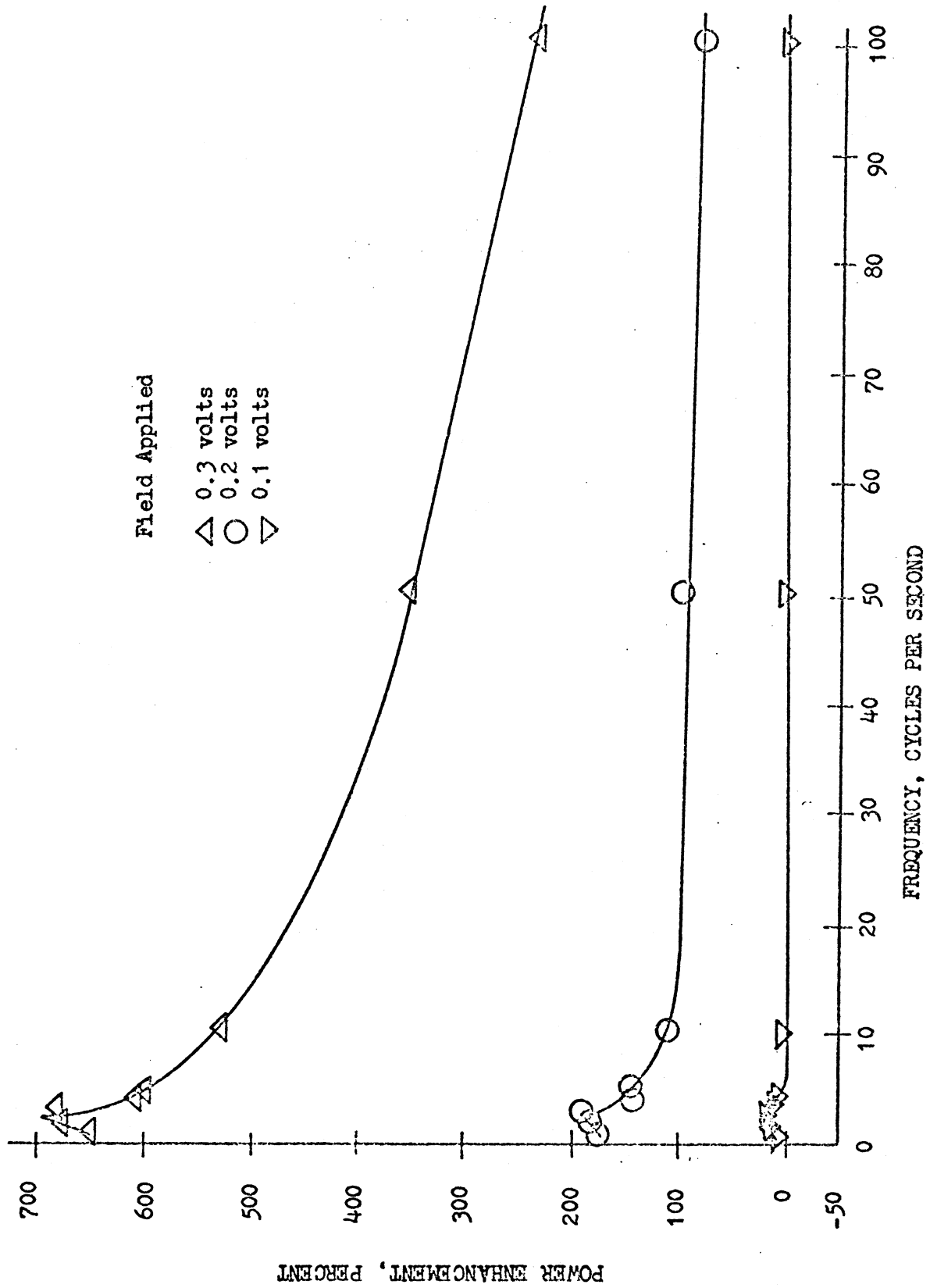


Figure 21. Power Enhancement with Grid Electrodes, System B.

voltage and increased current flow was attributed to the effects of the applied alternating field. Figure 21 indicates the relationship between the percent enhancement and the frequency and voltage of the applied alternating field. The increased power output was attributed to the enhanced ionic motion and the catalytic effect of the alternating field. No linger time or decay time was measurable with System B and, therefore, the major enhancement effect was attributed to the increased ionic motion in the electrolyte. It is also this ionic motion that explains the limiting values of the system power outputs. As an example, at higher frequencies when the grid electrode is positively charged, the negative ions in the electrolyte attempt to move toward the grid electrode, but before the negative ions can move, the grid becomes negatively charged and the ions are repelled instead of being attracted. This process is continually repeated and the ions are unable to increase their motion above a certain limiting value.

This same mechanism of decreasing or increasing the output current occurs in a triode amplifier circuit. The amplifier output will contain a component of fixed value and a component of fluctuating value, if a sinusoidal wave is impressed on the grid of the triode (12).

When a field of 0.1 volt was applied to the grid electrodes of System B, very little power enhancement was measured. This lack of enhancement was attributed to the inability of such a low voltage field to influence the ionic motion. The force applied by the 0.1 volt field was not strong enough to induce any appreciable motion. An improvement in fuel cell system operation could be obtained by applying higher volt-

ages, as indicated by the effects measured with 0.2 and 0.3 volt applied to the grid electrodes. This improvement could also be obtained by positioning the grid electrodes even closer to the fuel cell electrodes. For example, with one volt applied on a grid electrode 0.2 centimeter from the electrode surface, the applied field would be 5 volts per centimeter. If the grid electrode was placed 0.1 centimeter from the electrode surface, the applied field would be 10 volts per centimeter with the same one volt applied to the grid electrode. This increase in applied signal would provide greater enhancement of the fuel cell system power output.

The rapid evolution of gas bubbles from the hydrogen anode was observed when the alternating current field was applied to the platinum grid electrodes in the aqueous potassium hydroxide electrolyte. This phenomenon occurred at applied voltages above 0.3 volt and to a much lesser extent at an applied voltage of 0.3 volt. A slight dissolution of the grid electrodes was indicated by the formation of a slightly discolored area on the grid surface. Also, when the fuel cell system was inspected, a slight corrosion of the platinum electrodes at the gas--electrolyte--electrode interface was noticed. Therefore, the fuel cell system was not operated at an applied voltage greater than 0.3 volt.

The phenomena of increased dissolution of a metal by the application of an alternating current electric field was demonstrated by Tomashov and Strukov (39) and it is this phenomena that aids in the explanation of the enhancement of the fuel cell system operation by desorbing poisons

and strongly adsorbed ions on the electrode surface.

The voltage of the applied alternating current field was measured between the grid electrodes and the grounded hydrogen electrodes by both a Tektronix oscilloscope and a Fluke differential multimeter. The wave forms obtained on the oscilloscope indicated that both System A and System B were quite nonlinear.

The applied alternating current electric field contributed a component to the fuel cell system output as was evidenced by the oscillating output current and output voltage of the system.

Semiconductor Effects. Different configurations of semiconductive electrodes were used in the fuel cell of System C in an investigation of the effects of such electrodes on the output voltage and current of the fuel cell. The first configuration studied consisted of n-type silicon as the hydrogen electrode and p-type silicon as the oxygen electrode. The operating values of the current and voltage were so small that they could not be measured when the external circuit was completed. This low reactivity was attributed to the formation of oxides and surface poisons on the semiconductor electrode surfaces. Therefore, the fuel cell was operated at open circuit and the equilibrium values of the open circuit voltages were used to compare the effects of the various configurations upon the output of the fuel cell system. The open circuit voltage of the first configuration was 7.0 millivolts. The second configuration used n-type silicon as the oxygen electrode and p-type silicon as the hydrogen electrode. It was expected that the output voltage of the second configuration would be less than the first



configuration. The open circuit voltage of the second configuration was 4.5 millivolts. This was a difference of 2.5 millivolts between the two configurations and this was a 36 percent variation in output if based on the 7.0 millivolt output of the first configuration.

## CHAPTER V

## SUMMARY AND CONCLUSIONS

An aqueous electrolyte hydrogen--oxygen fuel cell system was designed and constructed for use in the experimental investigation of the field effect catalysis of the system. An enhancement of the fuel cell system power output was achieved by the application of an alternating current electric field to the grid electrodes positioned between the fuel cell electrodes. Solid platinum electrodes were used in the fuel cells. Also, electrodes composed of extrinsic silicon semiconductive material were used in the study in order to investigate their effect upon the operation of the fuel cell system.

The system consisted of two identical fuel cells, each containing a single grid electrode, connected in parallel. An alternating current electric field was obtained from a Hewlett Packard function generator. The sinusoidal signal from the function generator was passed through a D. C. amplifier and applied to the fuel cell system by two methods. In the first method, the signal was applied to the grid electrodes which had been connected together as shown in Figure 11. The alternating field applied to the grid electrodes in this manner produced a cleaning or desorption effect upon the fuel cell electrodes and it helped to induce greater ionic motion in the electrolyte. The alternating field produced a decrease in the high concentration polarization losses at the fuel cell electrodes by decreasing the ionic double layer formed at each electrode surface.

The maximum applied voltage was 0.3 volt. A maximum power en-

hancement of 42,000 percent was obtained with an applied field of 0.3 volt at frequencies greater than 50 cycles per second. The maximum enhanced power output was 3,000 microwatts and this enhancement was achieved by the expenditure of a maximum of 3,000 microwatts of input power. As the frequency was increased, the power enhancement asymptotically approached a maximum value and as the frequency was lowered, the power enhancement would decline. If the voltage of the applied alternating field was lowered, the fuel cell system power output and percentage power enhancement decreased. The decrease of enhancement at the lowered voltages was caused by the applied field lacking sufficient force to move the ions in the electrolyte and to desorb the ions and poisons on the electrode surfaces.

The desorption effect of the applied field was evidenced by a retention of a portion of the power enhancement after the removal of the applied alternating field. The power output of the fuel cell system would slowly decline from its maximum enhanced value to its initial value before the application of the field. The maximum value of this decay time was measured to be 225 seconds. This value was obtained after the application, for thirty seconds, of an alternating current field of 0.3 volt at frequencies greater than 100 cycles per second. The decay time was a function of the frequency and the applied voltage of the field. The decay time asymptotically approached a maximum value as the frequency of the applied field was increased. Lowering the voltage of the applied alternating field decreased the decay time.

In the second method, a dual channel D. C. amplifier was used

to apply the sinusoidal signal separately to each grid electrode. The experimental system is illustrated in Figure 12. Again, the alternating field had a catalytic effect upon the operation of the fuel cell system. A maximum enhancement of 670 percent was achieved with a maximum applied voltage of 0.3 volt at a frequency of three cycles per second. The maximum input power to the system was 9,000 microwatts and this was much greater than the enhancement obtained from the applied field. The enhancement would decrease as the frequency was increased or decreased from the value of three cycles per second. At low applied field voltages the power enhancement was quite small. This is explained by the inability of the low force field to move the ions in the electrolyte. Also, no measureable decay time was noticed in System B. This indicated that very little desorption of the surface poisons and ions had occurred during the application of the alternating current electric field.

The maximum alternating current field applied to the grid electrodes was 0.3 volt. At applied voltages greater than 0.3 volt, a rapid evolution of bubbles took place at the hydrogen anode. The electric field applied to the grids could enhance the rate of dissolution of the metal and for this reason higher voltages were not applied to the grid electrodes.

The alternating field applied to the fuel cell electrodes could be increased by reducing the distance between the fuel cell electrodes while keeping the grid electrode centered between them. This would reduce the power required to apply the signals, but still result in a power enhancement. A possible method of reducing the power input from

the applied field would be the coating of the grid electrodes with an electrically insulating surface coating. The enhancement of the fuel cell system power may also be accomplished, with very little or no power input, by designing a system with the grid electrodes positioned in the gas phase behind the fuel cell electrodes. Initial studies of this method are contained in Appendix I.

The enhancement of the fuel cell system power output was determined to be a function of the voltage and the frequency of the applied alternating current electric field.

The method of applying an alternating current electric field to grid electrodes placed in a fuel cell system has been shown to be effective in improving the power putput of the system. This method may be used to cause a continuous increase in the system power output. It may also be used to increase the fuel cell system power output for short periods of peak power demand in the same manner as an automobile accelerator is depressed when passing another automobile.

Two electrode configurations of extrinsic silicon semiconductor electrodes were studied in this investigation. The first configuration used n-type material as the hydrogen electrode and p-type material as the oxygen electrode. The second configuration used n-type material as the oxygen electrode and p-type material as the hydrogen electrode. The equilibrium open circuit voltages were used to indicate the effects of the different configurations upon the output of the fuel cell. In all cases studied, the first configuration had higher open circuit voltages than the second configuration.

Studies of the first configuration under the influence of an applied alternating current field could possibly produce interesting results which would provide further information on the behavior and effect of semiconductive materials as fuel cell electrodes.

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APPENDICES

## APPENDIX A

## MATERIALS AND APPARATUS

Materials

The following is a list of the materials and reagents used in this experimental investigation. A detailed analysis of a specific reagent may be obtained by consulting the catalogue of the respective supplier.

1. Gases. Hydrogen and oxygen of 99 plus percent purity was obtained from the University of Missouri.
2. Kel-F Stopcock Grease. Chemical Rubber Company, Cleveland, Ohio.
3. O-Rings. Teflon (Auburn 11-19 and 11-20), Auburn Manufacturing Company, Middletown, Connecticut.
4. Platinum Foil. Fisher No. 13-755 (thickness, 0.006 inch), Fisher Scientific Company, St. Louis, Missouri.
5. Platinum Wire. Fisher No. 13-765 (guage, 24; diameter, 0.020 inch), Fisher Scientific Company, St. Louis, Missouri.
6. Platinum Wire Gauze. Fisher No. 13-760 (45 mesh, 0.0085 inch wire), Fisher Scientific Company, St. Louis, Missouri.
7. Potassium Hydroxide. Reagent grade, meets ACS specifications, Fisher Scientific Company, St. Louis, Missouri.
8. Sealant. Silicon Rubber (Commercial-RTV 732), Dow Corning Corporation, Midland, Michigan.
9. Silicon Single Crystals. N-type, phosphorous doped, resistivity of 0.16--0.24 ohm--cm; P-type, boron doped, resistivity

of 0.041--0.079 ohm--cm; Monsanto Chemical Company, St. Louis, Missouri.

10. Unions. Jackson Supply Company (Part No. 400-6-4-Teflon), Ferguson, Missouri.

The following is a list of the principal components of the apparatus used in this investigation.

#### Constant Temperature Water Bath System

1. Immersion Heater. Power--300 watt, Fisher Scientific Company, St. Louis, Missouri.
2. Pyrex Bath. Size K, 18 inch diameter, 12 inches high, Fisher Scientific Company, St. Louis, Missouri.
3. Relay. Chemical Rubber Company (CRC Monitrol Relay), Cleveland, Ohio.
4. Stirring Motor. Sargent Cone Drive Stirring Motor, E. H. Sargent and Company, Chicago, Illinois.
5. Thermoregulator. Range 0 to 50°C. Chemical Rubber Company, Cleveland, Ohio.

#### Fuel Cell System

1. Electrode Holder. Made of Teflon by the University of Missouri Scientific Instrument Shop. Shown in Figure 15.
2. Fuel Cell Housing. Made of Pyrex glass (45/50) by the University of Missouri Glassblowing Service. Shown in Figure 14.

#### Power Output Measurement System

1. Microammeter. Model 604 Simpson Multicorder, Simpson Electric Company, Chicago, Illinois.

2. Milliammeter. Model 604 Simpson Multicorder, Simpson Electric Company, Chicago, Illinois.

3. Potentiometer. Model 604 Simpson Multicorder, Simpson Electric Company, Chicago, Illinois.

#### Electric Field System

1. D. C. Amplifier. Made by the Electrical Engineering Department of the University of Missouri.

2. D. C. Amplifier. Dual channel amplifier, (D. C. to 100 Hz.), made by the Electrical Engineering Department of the University of Missouri.

3. Differential Multimeter. Model 853 A Fluke Differential Multimeter, John Fluke Manufacturing Company, Inc., Seattle, Washington.

4. Function Generator. Low frequency (0.01 to 1200 cycles per second), sine, triangular and square wave, Model 202 A, Hewlett Packard Company, Loveland, Colorado.

5. Oscilloscope. Model 503, Tektronix, Inc., Beaverton, Oregon.

6. Power Supply. Model 407d, Fluke Power Supply, John Fluke Manufacturing Company, Inc., Seattle, Washington.

#### Miscellaneous

1. Balances. Various types used for preparing electrolyte solutions.

2. Graduated Cylinders. Various sizes for measuring electrolyte solutions.

3. Regulators. Various gas cylinder pressure regulators were

used.

4. Thermometers. Range - 10--110°C, 0.1°C. divisions, 10/30 cone, used to measure fuel cell temperature.

5. Tubing. Glass, Tygon, and rubber tubing was used for the feed gases.

## APPENDIX B

DATA OF SYSTEM POWER DECAY AFTER COMPLETION OF EXTERNAL  
CIRCUIT WITH NO FIELD APPLIED

Table VII contains power decay data for System A and Table VIII contains power decay data for System B. The external circuit of the fuel cell system was completed and the system voltage and current was continuously measured and recorded. The system initially had a large power output but this output decreased with the passage of time until a quasi steady state power output was attained.

TABLE VII

## POWER DECAY OF SYSTEM A AFTER COMPLETION OF EXTERNAL CIRCUIT

WITH NO FIELD APPLIED

DATA OF JUNE 21, 1968  
(morning)

Time (minutes)	Voltage (millivolts)	Current (milliamperes)	Power (microwatts)
0	78	1.00	78
15	32	0.65	21
30	30	0.60	18
45	25	0.50	12
60	25	0.50	12
75	25	0.50	12
90	24	0.45	11
105	22	0.42	9.2
120	21	0.42	8.8
135	21	0.42	8.8
150	21	0.42	8.8
165	25	0.50	12
180	14	0.30	4.2
195	14	0.20	2.8
210	10	0.20	2.8
225	10	0.20	2.0

DATA OF JUNE 21, 1968  
(afternoon)

0	54	1.00	54
15	30	0.60	18
30	33	0.65	20
45	30	0.60	18
60	30	0.55	16
75	28	0.55	15
90	27	0.55	15
105	26	0.50	13
120	25	0.50	12
135	24	0.50	12
150	24	0.45	11
165	23	0.45	10
180	22	0.45	9.9
195	22	0.42	9.2
210	22	0.42	9.2
225	22	0.40	8.8
240	21	0.40	8.4
255	19	0.35	6.6
270	13	0.25	3.2
285	13	0.25	3.2
300	9	0.20	1.8



TABLE VII (continued)

Time (minutes)	Voltage (millivolts)	Current (milliamperes)	Power (microwatts)
315	9	0.20	1.8
330	8	0.20	1.8

DATA OF JUNE 27, 1968  
(morning)

0	215	7.50	1600
3	25	4.75	120
6	20	2.50	50
9	15	0.75	11
12	15	0.50	7.5
15	15	0.50	7.5
18	15	0.50	7.5
21	15	0.50	7.5
24	15	0.50	7.5

DATA OF JUNE 27, 1968  
(afternoon)

0	190	7.00	1300
3	20	3.00	60
6	20	0.75	15
9	20	0.75	15
12	20	0.75	15
15	15	0.75	11
18	15	0.50	7.5
21	15	0.50	7.5

DATA OF JUNE 28, 1968  
(morning)

0	215	7.50	1600
5	105	4.00	420
10	50	3.00	150
15	25	1.00	25
20	25	1.00	25
25	30	1.25	38
30	15	0.50	7.5
35	15	0.50	7.5

DATA OF JUNE 28, 1968  
(afternoon)

0	190	7.00	1300
5	50	2.50	120
10	30	1.25	38
15	35	1.25	44
20	45	1.75	87

TABLE VII (continued)

Time (minutes)	Voltage (millivolts)	Current (milliamperes)	Power (microwatts)
25	20	0.75	15
30	15	0.50	7.5
35	15	0.50	7.5
40	15	0.50	7.5

DATA OF JULY 1, 1968

0	170	6.50	1100
5	150	5.50	820
10	130	5.75	750
15	130	5.50	720
20	120	5.50	660
25	110	4.00	440
30	95	3.50	330
35	80	3.00	240
40	70	2.75	190
45	65	2.50	160
50	65	2.50	160
55	70	2.50	180
60	95	4.00	380
65	85	3.00	260
70	75	2.75	210
75	90	2.75	250
80	85	3.25	280
85	85	3.00	260
90	80	3.00	240
95	80	3.00	240
100	70	2.50	180
105	70	2.50	180
110	65	2.25	150
115	65	2.25	150
120	65	2.25	150
125	60	2.00	120
130	55	2.00	110
135	55	2.00	110
140	50	1.50	75
145	40	1.50	60
150	40	1.50	60
155	40	1.50	60
160	40	6.50	260
165	70	1.75	120
170	45	1.50	68
175	40	1.50	60
180	40	1.50	60
185	40	1.50	60
190	40	1.75	70
195	50	2.00	100
200	55	2.25	120
205	50	1.25	62

TABLE VII (continued)

Time (minutes)	Voltage (millivolts)	Current (milliamperes)	Power (microwatts)
210	35	1.25	44
215	30	1.00	30
220	20	0.75	15
225	10	0.50	5.0
230	10	0.50	5.0
235	10	0.50	5.0
240	10	0.50	5.0

## DATA OF JULY 2, 1968

0	200	7.50	1500
5	20	1.00	20
10	10	0.50	5.0
15	10	0.50	5.0
20	10	0.50	5.0
25	10	0.50	5.0
30	10	0.50	5.0
35	10	0.50	5.0

## DATA OF JULY 3, 1968

0	225	8.00	1800
5	215	7.00	1500
10	160	5.00	800
15	125	4.50	560
20	120	4.00	480
25	100	2.75	280
30	75	2.75	210
35	75	2.25	170
40	60	2.00	120
45	40	1.25	50
50	35	1.00	35
55	25	0.75	19
60	20	0.50	10
65	15	0.50	7.5
70	15	0.50	7.5
75	15	0.50	7.5
80	15	0.50	7.5
85	10	0.25	2.5
90	10	0.25	2.5
95	10	0.25	2.5
100	10	0.25	2.5

TABLE VIII

POWER DECAY OF SYSTEM B AFTER COMPLETION OF EXTERNAL CIRCUIT

WITH NO FIELD APPLIED

DATA OF JULY 16, 1968

Time (minutes)	Voltage (millivolts)	Current (milliamperes)	Power (microwatts)
0	30	0.18	5.4
5	24	0.14	3.4
10	22	0.12	2.6
15	19	0.10	1.9
20	18	0.10	1.8
25	17	0.10	1.7
30	17	0.10	1.7
35	16	0.10	1.6
40	17	0.10	1.7
45	17	0.11	1.9
50	17	0.10	1.7

DATA OF JULY 17, 1968

0	50	0.0250	1.20
5	32	0.0160	0.51
10	28	0.0140	0.39
15	32	0.0165	0.53
20	27	0.0140	0.38
25	27	0.0135	0.36
30	26	0.0130	0.34
35	26	0.0130	0.34
40	26	0.0130	0.34
45	26	0.0130	0.34
50	26	0.0130	0.34
55	26	0.0130	0.34
60	25	0.0125	0.31

## APPENDIX C

DATA OF VOLTAGE AND CURRENT ENHANCEMENT BY APPLICATION OF ALTERNATING  
ELECTRIC FIELD TO GRID ELECTRODES DURING FUEL CELL OPERATION

Table IX contains voltage and current enhancement data for System A and Table X contains voltage and current enhancement data for System B. The fuel cell system was operated until it attained quasi steady state conditions. An alternating current electric field was applied to the grid electrodes of the system and the variations of the voltage and current from the quasi steady state values were measured and recorded. This procedure was followed for various values of the voltage and frequency of the applied alternating current field. The values of the voltage and current thus measured were used in the calculation of the enhanced power output of the fuel cell system.

TABLE IX  
 VOLTAGE AND CURRENT ENHANCEMENT BY APPLICATION OF ALTERNATING CURRENT ELECTRIC  
 FIELD TO GRID ELECTRODES OF SYSTEM A DURING FUEL CELL OPERATION

DATA OF JUNE 27, 1968

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Voltage (millivolts)	Enhanced Voltage (millivolts)	Initial Current (milliamperes)	Enhanced Current (milliamperes)
371	5	0.3	15	230	0.5	8.00
372	6	0.3	15	240	0.5	8.50
373	7	0.3	15	250	0.5	8.50
374	8	0.3	15	260	0.5	9.00
375	9	0.3	15	260	0.5	9.00
376	10	0.3	15	275	0.5	9.50
377	6	0.3	15	250	0.5	8.50
378	5	0.3	15	240	0.5	8.00
379	4	0.3	15	235	0.5	8.00
380	3	0.3	15	215	0.5	7.50
381	2	0.3	15	200	0.5	7.00
382	7	0.3	15	250	0.5	8.75
383	8	0.3	15	260	0.5	9.00
384	2	0.3	15	220	0.5	7.50
385	1	0.3	15	200	0.5	6.75
386	0.8	0.3	15	200	0.5	6.00
387	3	0.3	15	215	0.5	7.50
388	4	0.3	15	225	0.5	7.75
389	5	0.3	15	230	0.5	8.00
390	6	0.3	15	230	0.5	8.00
391	7	0.3	15	235	0.5	8.00
392	8	0.3	15	235	0.5	8.25
393	9	0.3	15	235	0.5	8.25
394	10	0.3	15	235	0.5	8.25
395	5	0.3	15	220	0.5	7.75

TABLE IX (continued)

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Voltage (millivolts)	Enhanced Voltage (millivolts)	Initial Current (milliamperes)	Enhanced Current (milliamperes)
396	6	0.3	15	225	0.5	7.75
397	7	0.3	15	225	0.5	8.00
398	4	0.3	15	210	0.5	7.25
399	3	0.3	15	200	0.5	7.25
400	2	0.3	15	200	0.5	7.00
401	3	0.3	15	220	0.5	7.25
402	4	0.3	15	230	0.5	8.00
403	5	0.3	15	240	0.5	8.25
404	6	0.3	15	245	0.5	8.50
405	7	0.3	15	250	0.5	8.25
406	8	0.3	15	260	0.5	9.00
407	9	0.3	15	260	0.5	9.00
408	10	0.3	15	265	0.5	9.25
409	3	0.2	15	190	0.5	6.50
410	2	0.2	15	170	0.5	6.00
411	3	0.2	15	185	0.5	6.50
412	4	0.2	15	200	0.5	7.00
413	5	0.2	15	205	0.5	7.00
414	6	0.2	15	215	0.5	7.50
415	7	0.2	15	215	0.5	7.50
416	8	0.2	15	220	0.5	7.50
417	9	0.2	15	220	0.5	7.75
418	10	0.2	15	225	0.5	8.00
419	2	0.2	15	170	0.5	6.00
420	3	0.2	15	190	0.5	6.50
421	4	0.2	15	205	0.5	7.00
422	5	0.2	15	210	0.5	7.25
423	6	0.2	15	210	0.5	7.25
424	7	0.2	15	210	0.5	7.50
425	8	0.2	15	215	0.5	7.50
426	9	0.2	15	215	0.5	7.50

TABLE IX (continued)

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Voltage (millivolts)	Enhanced Voltage (millivolts)	Initial Current (milliamperes)	Enhanced Current (milliamperes)
427	10	0.2	15	215	0.5	7.50
428	3	0.2	15	180	0.5	6.25
429	3	0.1	15	115	0.5	4.00
430	2	0.1	15	105	0.5	4.00
431	3	0.1	15	110	0.5	4.00
432	4	0.1	15	115	0.5	4.00
433	5	0.1	15	120	0.5	4.00
434	6	0.1	15	120	0.5	4.25
435	7	0.1	15	120	0.5	4.25
436	8	0.1	15	120	0.5	4.25
437	9	0.1	15	125	0.5	4.25
438	10	0.1	15	125	0.5	4.50
439	2	0.1	15	100	0.5	4.00
440	3	0.1	15	110	0.5	4.00
441	4	0.1	15	115	0.5	4.00
442	5	0.1	15	115	0.5	4.25
443	6	0.1	15	120	0.5	4.25
444	7	0.1	15	120	0.5	4.25
445	8	0.1	15	125	0.5	4.25
446	9	0.1	15	125	0.5	4.50
447	10	0.1	15	125	0.5	4.50
448	3	0.1	15	105	0.5	4.00
449	10	0.3	15	270	0.5	9.50
450	9	0.3	15	265	0.5	9.25
451	8	0.3	15	260	0.5	9.00
452	7	0.3	15	255	0.5	9.00
453	6	0.3	15	250	0.5	8.75
454	2	0.3	15	215	0.5	6.50
500	2	0.3	15	200	0.5	7.00
455	0.5	0.3	15	147	0.5	5.75
456	3	0.3	15	210	0.5	7.25



TABLE IX (continued)

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Voltage (millivolts)	Enhanced Voltage (millivolts)	Initial Current (milliamperes)	Enhanced Current (milliamperes)
457	2	0.3	15	190	0.5	6.50
458	1	0.3	15	160	0.5	5.50
459	2	0.3	15	190	0.5	6.50
460	3	0.3	15	210	0.5	7.25
461	1	0.3	15	160	0.5	5.50
462	0.5	0.3	15	145	0.5	5.62
463	5	0.3	15	240	0.5	8.00
464	0.5	0.3	15	140	0.5	5.32
465	10	0.2	15	220	0.5	7.75
466	9	0.2	15	215	0.5	7.50
467	8	0.2	15	215	0.5	7.50
468	7	0.2	15	205	0.5	7.25
469	0.5	0.2	15	130	0.5	5.00
470	3	0.2	15	185	0.5	6.50
471	4	0.2	15	205	0.5	7.00
472	5	0.2	15	210	0.5	7.25
473	6	0.2	15	215	0.5	7.50
474	2	0.2	15	175	0.5	5.75
475	1	0.2	15	150	0.5	5.25
476	0.5	0.2	15	130	0.5	5.00
477	1	0.2	15	150	0.5	5.25
478	0.5	0.2	15	125	0.5	5.00
469	3	0.1	15	115	0.5	4.25
480	10	0.1	15	130	0.5	4.50
481	9	0.1	15	130	0.5	4.50
482	8	0.1	15	125	0.5	4.50
483	7	0.1	15	125	0.5	4.25
484	6	0.1	15	120	0.5	4.25
485	5	0.1	15	115	0.5	4.25
486	4	0.1	15	115	0.5	4.00
487	3	0.1	15	110	0.5	4.00

TABLE IX (continued)

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Voltage (millivolts)	Enhanced Voltage (millivolts)	Initial Current (milliamperes)	Enhanced Current (milliamperes)
488	2	0.1	15	105	0.5	3.75
489	1	0.1	15	95	0.5	3.50
490	5	0.1	15	115	0.5	4.25
491	0.5	0.1	15	80	0.5	3.00
492	5	0.1	15	115	0.5	4.25
493	0.5	0.1	15	85	0.5	3.00
494	1	0.1	15	95	0.5	3.25
495	0.5	0.1	15	80	0.5	3.00
496	1	0.1	15	95	0.5	3.25
497	3	0.1	15	115	0.5	4.25
498	10	0.2	15	225	0.5	8.00
499	9	0.2	15	225	0.5	7.75
501	8	0.2	15	220	0.5	7.75
502	7	0.2	15	215	0.5	7.50
503	6	0.2	15	210	0.5	7.50
504	5	0.2	15	205	0.5	7.00
505	4	0.2	15	200	0.5	6.75
506	3	0.2	15	190	0.5	6.50
507	2	0.2	15	175	0.5	6.00
508	1	0.2	15	160	0.5	5.25
509	0.5	0.2	15	147	0.5	5.50
510	1	0.2	15	155	0.5	5.25
511	5	0.2	15	210	0.5	7.00
512	0.5	0.2	15	142	0.5	5.50
513	0.5	0.2	15	142	0.5	5.50
514	3	0.2	15	190	0.5	6.50
515	3	0.1	15	115	0.5	4.00
516	2	0.1	15	110	0.5	3.75
517	1	0.1	15	95	0.5	3.25
518	5	0.1	15	120	0.5	4.25
519	4	0.1	15	115	0.5	4.00

TABLE IX (continued)

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Voltage (millivolts)	Enhanced Voltage (millivolts)	Initial Current (milliamperes)	Enhanced Current (milliamperes)
520	6	0.1	15	120	0.5	4.25
521	0.5	0.1	15	82	0.5	3.25
522	7	0.1	15	125	0.5	4.50
523	8	0.1	15	125	0.5	4.50
524	9	0.1	15	130	0.5	4.50
525	10	0.1	15	130	0.5	4.50
526	0.5	0.1	15	82	0.5	3.25
527	1	0.1	15	95	0.5	3.50
999	3	0.3	15	115	0.5	4.00
528	10	0.3	15	255	0.5	8.75
529	9	0.3	15	250	0.5	8.75
530	8	0.3	15	250	0.5	8.75
531	7	0.3	15	245	0.5	8.50
532	6	0.3	15	245	0.5	8.50
533	5	0.3	15	235	0.5	8.25
534	4	0.3	15	230	0.5	8.00
535	3	0.3	15	220	0.5	7.50
536	2	0.3	15	200	0.5	7.25
537	1	0.3	15	195	0.5	6.50
538	0.5	0.3	15	155	0.5	5.50
539	3	0.2	15	190	0.5	6.50
540	4	0.2	15	205	0.5	7.00
541	4	0.2	15	210	0.5	7.50
DATA OF JUNE 28, 1968						
542	6	0.2	15	220	0.5	7.50
543	7	0.2	15	225	0.5	7.75
544	8	0.2	15	225	0.5	7.75
545	9	0.2	15	230	0.5	8.00
546	10	0.2	15	235	0.5	8.00

TABLE IX (continued)

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Voltage (millivolts)	Enhanced Voltage (millivolts)	Initial Current (milliamperes)	Enhanced Current (milliamperes)
547	2	0.2	15	170	0.5	6.00
548	1	0.2	15	165	0.5	5.50
549	0.5	0.2	15	135	0.5	5.00
550	3	0.3	15	220	0.5	7.50
551	10	0.1	15	130	0.5	4.50
552	9	0.1	15	130	0.5	4.50
553	8	0.1	15	125	0.5	4.50
554	7	0.1	15	125	0.5	4.50
555	6	0.1	15	125	0.5	4.50
556	5	0.1	15	120	0.5	4.50
557	4	0.1	15	120	0.5	4.25
558	3	0.1	15	115	0.5	4.00
559	2	0.1	15	105	0.5	3.75
560	1	0.1	15	100	0.5	3.50
561	0.5	0.1	15	85	0.5	3.00
562	0.5	0.3	15	140	0.5	5.25
DATA OF JULY 1, 1968						
563	3	0.3	15	220	0.5	7.50
564	10	0.3	15	270	0.5	9.50
565	20	0.3	15	290	0.5	10.00
566	30	0.3	15	295	0.5	10.25
567	40	0.3	15	295	0.5	10.25
568	50	0.3	15	295	0.5	10.25
569	60	0.3	15	295	0.5	10.25
570	70	0.3	15	295	0.5	10.25
571	80	0.3	15	295	0.5	10.25
572	90	0.3	15	295	0.5	10.25
573	100	0.3	15	295	0.5	10.25
574	200	0.3	15	295	0.5	10.25

TABLE IX (continued)

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Voltage (millivolts)	Enhanced Voltage (millivolts)	Initial Current (milliamperes)	Enhanced Current (milliamperes)
575	300	0.3	15	295	0.5	10.25
576	400	0.3	15	295	0.5	10.25
577	500	0.3	15	295	0.5	10.25
578	1000	0.3	15	295	0.5	10.25
579	3	0.3	15	215	0.5	7.50
580	10	0.3	15	260	0.5	9.00
581	20	0.3	15	275	0.5	9.50
582	30	0.3	15	275	0.5	9.75
583	40	0.3	15	280	0.5	9.75
584	50	0.3	15	285	0.5	10.00
585	60	0.3	15	285	0.5	10.00
586	70	0.3	15	285	0.5	10.00
587	80	0.3	15	285	0.5	10.00
588	90	0.3	15	285	0.5	10.00
589	100	0.3	15	290	0.5	10.00
590	200	0.3	15	290	0.5	10.00
591	300	0.3	15	290	0.5	10.00
592	400	0.3	15	290	0.5	10.00
593	500	0.3	15	290	0.5	10.00
594	1000	0.3	15	290	0.5	10.00
595	3	0.2	15	195	0.5	6.75
596	10	0.2	15	235	0.5	7.75
597	20	0.2	15	255	0.5	9.00
598	30	0.2	15	255	0.5	8.75
599	40	0.2	15	255	0.5	9.00
600	50	0.2	15	255	0.5	9.00
601	60	0.2	15	255	0.5	9.00
602	70	0.2	15	255	0.5	9.00
603	80	0.2	15	255	0.5	9.00
604	90	0.2	15	255	0.5	9.00

TABLE IX (continued)

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Voltage (millivolts)	Enhanced Voltage (millivolts)	Initial Current (milliamperes)	Enhanced Current (milliamperes)
605	100	0.2	15	255	0.5	9.00
606	200	0.2	15	260	0.5	9.00
607	300	0.2	15	260	0.5	9.00
608	400	0.2	15	260	0.5	9.00
609	500	0.2	15	260	0.5	9.00
610	1000	0.2	15	260	0.5	9.00
611	10	0.2	15	235	0.5	7.75
612	20	0.2	15	250	0.5	8.75
613	30	0.2	15	255	0.5	8.75
614	40	0.2	15	260	0.5	9.00
615	50	0.2	15	260	0.5	9.00
616	60	0.2	15	260	0.5	9.00
617	70	0.2	15	260	0.5	9.00
618	80	0.2	15	260	0.5	9.00
619	90	0.2	15	260	0.5	9.00
620	100	0.2	15	260	0.5	9.00
621	200	0.2	15	260	0.5	9.00
622	300	0.2	15	260	0.5	9.00
623	400	0.2	15	260	0.5	9.00
624	500	0.2	15	260	0.5	9.00
625	1000	0.2	15	265	0.5	9.25
626	20	0.1	15	150	0.5	5.25
627	30	0.1	15	150	0.5	5.25
628	40	0.1	15	145	0.5	5.00
629	50	0.1	15	145	0.5	5.25
630	60	0.1	15	150	0.5	5.25
631	70	0.1	15	150	0.5	5.25
632	80	0.1	15	150	0.5	5.25
633	90	0.1	15	150	0.5	5.25
634	100	0.1	15	150	0.5	5.25
635	200	0.1	15	155	0.5	5.50

TABLE IX (continued)

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Voltage (millivolts)	Enhanced Voltage (millivolts)	Initial Current (milliamperes)	Enhanced Current (milliamperes)
636	300	0.1	15	160	0.5	5.50
637	400	0.1	15	160	0.5	5.50
638	500	0.1	15	160	0.5	5.50
639	1000	0.1	15	160	0.5	5.50
640	20	0.1	15	145	0.5	5.00
641	30	0.1	15	150	0.5	5.00
642	40	0.1	15	150	0.5	5.25
643	50	0.1	15	150	0.5	5.25
644	60	0.1	15	150	0.5	5.25
645	70	0.1	15	150	0.5	5.25
646	80	0.1	15	155	0.5	5.25
647	90	0.1	15	155	0.5	5.25
648	100	0.1	15	155	0.5	5.50
649	200	0.1	15	155	0.5	5.50
650	300	0.1	15	160	0.5	5.50
651	400	0.1	15	160	0.5	5.50
652	500	0.1	15	160	0.5	5.50
653	1000	0.1	15	160	0.5	5.50
654	3	0.1	15	120	0.5	4.25

TABLE X

VOLTAGE AND CURRENT ENHANCEMENT BY APPLICATION OF ALTERNATING CURRENT ELECTRIC FIELD TO GRID ELECTRODES OF SYSTEM B DURING FUEL CELL OPERATION

DATA OF JULY 16, 1968

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Voltage (millivolts)	Enhanced Voltage (millivolts)	Initial Current (milliamperes)	Enhanced Current (milliamperes)
1	1	0.3	17	25.5	0.1	0.17
2	2	0.3	17	26.0	0.1	0.18
3	3	0.3	17	26.5	0.1	0.18
4	5	0.3	17	25.5	0.1	0.17
5	10	0.3	17	24.5	0.1	0.16
6	50	0.3	17	24.5	0.1	0.16
7	100	0.3	17	24.5	0.1	0.16
8	1	0.2	17	24.0	0.1	0.16
9	2	0.2	17	24.5	0.1	0.17
10	3	0.2	17	24.5	0.1	0.16
11	5	0.2	17	24.5	0.1	0.16
12	10	0.2	17	24.5	0.1	0.16
13	50	0.2	17	24.5	0.1	0.16
14	100	0.2	17	24.5	0.1	0.16
15	1	0.2	17	24.0	0.1	0.17
16	2	0.2	17	25.0	0.1	0.18
17	3	0.2	17	26.0	0.1	0.17
18	5	0.2	17	25.0	0.1	0.17
19	10	0.2	17	25.0	0.1	0.17
20	50	0.2	17	25.0	0.1	0.17
21	100	0.2	17	25.0	0.1	0.17
22	1	0.2	17	25.0	0.1	0.17
23	2	0.2	17	24.5	0.1	0.17
24	3	0.2	17	24.5	0.1	0.17
25	5	0.2	17	24.5	0.1	0.17



TABLE X (continued)

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Voltage (millivolts)	Enhanced Voltage (millivolts)	Initial Current (milliamperes)	Enhanced Current (milliamperes)
26	10	0.2	17	25.0	0.1	0.17
27	50	0.2	17	25.0	0.1	0.17
28	100	0.2	17	25.0	0.1	0.17
29	1	0.1	17	24.5	0.1	0.16
30	2	0.1	17	24.5	0.1	0.16
31	3	0.1	17	24.5	0.1	0.16
32	5	0.1	17	24.5	0.1	0.16
33	10	0.1	17	24.5	0.1	0.16
34	50	0.1	17	24.5	0.1	0.16
35	100	0.1	17	24.5	0.1	0.16
36	1	0.1	17	24.0	0.1	0.15
37	2	0.1	17	24.0	0.1	0.16
38	3	0.1	17	24.0	0.1	0.16
39	5	0.1	17	24.0	0.1	0.16
40	10	0.1	17	24.5	0.1	0.16
41	50	0.1	17	24.5	0.1	0.16
42	100	0.1	17	24.5	0.1	0.16
43	1	0.3	17	20.0	0.1	0.11
44	2	0.3	17	20.0	0.1	0.12
45	3	0.3	17	22.0	0.1	0.12
46	5	0.3	17	21.0	0.1	0.12
47	10	0.3	17	18.0	0.1	0.11
48	50	0.3	17	11.0	0.1	0.06
49	100	0.3	17	11.0	0.1	0.06
50	1	0.3	17	18.0	0.1	0.10
51	2	0.3	17	19.0	0.1	0.10
52	3	0.3	17	19.0	0.1	0.11
53	5	0.3	17	19.0	0.1	0.11
54	10	0.3	17	19.0	0.1	0.10
55	50	0.3	17	18.0	0.1	0.10
56	100	0.3	17	18.0	0.1	0.10

TABLE X (continued)

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Voltage (microvolts)	Enhanced Voltage (microvolts)	Initial Current (milliamperes)	Enhanced Current (milliamperes)
57	1	0.3	26	71.0	13	35.5
58	2	0.3	26	72.0	13	36.0
59	3	0.3	26	73.0	13	36.0
60	4	0.3	26	70.0	13	34.5
61	5	0.3	26	69.0	13	34.0
62	10	0.3	26	65.0	13	32.5
63	50	0.3	26	55.0	13	27.0
64	100	0.3	26	49.0	13	25.0
65	1	0.2	26	41.0	13	21.5
66	2	0.2	26	42.0	13	22.0
67	3	0.2	26	43.0	13	22.0
68	4	0.2	26	41.0	13	20.0
69	5	0.2	26	40.0	13	20.0
70	10	0.2	26	38.0	13	19.0
71	50	0.2	26	36.0	13	18.0
72	100	0.2	26	34.0	13	17.0
73	1	0.1	26	27.0	13	14.0
74	2	0.1	26	28.0	13	14.0
75	3	0.1	26	28.0	13	14.0
76	4	0.1	26	27.0	13	14.0
77	5	0.1	26	27.0	13	13.5
78	10	0.1	26	27.0	13	13.5
79	50	0.1	26	26.0	13	13.0
80	100	0.1	26	26.0	13	13.0
81	1	0.3	26	71.0	13	35.5
82	2	0.3	26	72.0	13	35.5
83	3	0.3	26	72.0	13	36.0
84	4	0.3	26	69.0	13	34.0
85	5	0.3	26	67.0	13	33.5
86	10	0.3	26	63.0	13	31.5

DATA OF JULY 17, 1968

TABLE X (continued)

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Voltage (microvolts)	Enhanced Voltage (microvolts)	Initial Current (milliamperes)	Enhanced Current (milliamperes)
87	50	0.3	26	53.0	13	26.0
88	100	0.3	26	47.0	13	23.5
89	1	0.2	26	38.0	13	19.0
90	2	0.2	26	38.0	13	19.5
91	3	0.2	26	38.0	13	19.5
92	4	0.2	26	38.0	13	19.0
93	5	0.2	26	37.0	13	18.5
94	10	0.2	26	35.0	13	18.0
95	50	0.2	26	32.0	13	16.0
96	100	0.2	26	31.0	13	15.5
97	1	0.1	26	26.0	13	13.0
98	2	0.1	26	26.0	13	13.0
99	3	0.1	26	27.0	13	14.0
100	4	0.1	26	26.0	13	13.5
101	5	0.1	26	26.0	13	13.5
102	10	0.1	26	26.0	13	13.0
103	50	0.1	26	26.0	13	13.0
104	100	0.1	26	25.0	13	12.5
105	1	0.3	26	71.5	13	35.5
106	2	0.3	26	72.0	13	35.5
107	3	0.3	26	72.0	13	36.0
108	4	0.3	26	68.0	13	34.0
109	5	0.3	26	66.0	13	33.0
110	10	0.3	26	62.0	13	31.0
111	50	0.3	26	53.0	13	26.0
112	100	0.3	26	47.0	13	23.5
113	1	0.2	26	41.0	13	21.0
114	2	0.2	26	41.0	13	20.5
115	3	0.2	26	41.0	13	21.0
116	4	0.2	26	40.0	13	20.0
117	5	0.2	26	39.0	13	19.5

TABLE X (continued)

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Voltage (microvolts)	Enhanced Voltage (microvolts)	Initial Current (milliamperes)	Enhanced Current (milliamperes)
118	10	0.2	26	38.0	13	19.0
119	50	0.2	26	35.0	13	18.0
120	100	0.2	26	35.0	13	17.5
121	1	0.1	26	29.0	13	14.5
122	2	0.1	26	29.0	13	14.5
123	3	0.1	26	29.0	13	15.0
124	4	0.1	26	29.0	13	14.5
125	5	0.1	26	29.0	13	14.5
126	10	0.1	26	29.0	13	14.5
127	50	0.1	26	28.0	13	14.0
128	100	0.1	26	28.0	13	14.0
129	1	0.3	26	72.0	13	35.5
130	2	0.3	26	72.0	13	36.0
131	3	0.3	26	72.0	13	36.0
132	4	0.3	26	68.0	13	34.0
133	5	0.3	26	67.0	13	33.5
134	10	0.3	26	63.0	13	31.0
135	50	0.3	26	53.0	13	26.5
136	100	0.3	26	49.0	13	24.0
137	1	0.2	26	46.0	13	22.0
138	2	0.2	26	46.0	13	22.0
139	3	0.2	26	44.0	13	22.0
140	4	0.2	26	43.0	13	21.5
141	5	0.2	26	42.0	13	21.0
142	10	0.2	26	39.0	13	19.5
143	50	0.2	26	36.0	13	18.0
144	100	0.2	26	34.0	13	17.5
145	1	0.1	26	27.0	13	13.5
146	2	0.1	26	27.0	13	14.0
147	3	0.1	26	28.0	13	14.0
148	4	0.1	26	28.0	13	14.0
149	5	0.1	26	28.0	13	14.0

TABLE X (continued)

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Voltage (microvolts)	Enhanced Voltage (microvolts)	Initial Current (milliamperes)	Enhanced Current (milliamperes)
150	10	0.1	26	27.0	13	13.5
151	50	0.1	26	27.0	13	13.5
152	100	0.1	26	27.0	13	13.5

## APPENDIX D

DATA OF POWER ENHANCEMENT BY APPLICATION OF ALTERNATING CURRENT  
ELECTRIC FIELD TO GRID ELECTRODES DURING FUEL CELL OPERATION

Table XI contains the power enhancement data for System A and Table XII contains the power enhancement data for System B. The fuel cell system was operated until it reached a quasi steady state condition. An alternating current electric field was applied to the grid electrodes of the system and any variation from the quasi steady state power output was calculated as a percentage enhancement or abatement. The voltage and the frequency of the applied field were varied in order to study the effects of each on the fuel cell system power output.

TABLE XI  
 POWER ENHANCEMENT BY APPLICATION OF ALTERNATING CURRENT ELECTRIC FIELD  
 TO GRID ELECTRODES OF SYSTEM A DURING FUEL CELL OPERATION

DATA OF JUNE 27, 1968

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Power (microwatts)	Enhanced Power (microwatts)	Enhancement (percent)
371	5	0.3	7.5	1840	24,000
372	6	0.3	7.5	2040	27,000
373	7	0.3	7.5	2130	28,000
374	8	0.3	7.5	2340	31,000
375	9	0.3	7.5	2340	31,000
376	10	0.3	7.5	2610	33,000
377	6	0.3	7.5	2130	28,000
378	5	0.3	7.5	1920	26,000
379	4	0.3	7.5	1880	25,000
380	3	0.3	7.5	1610	21,000
381	2	0.3	7.5	1400	19,000
382	7	0.3	7.5	2190	29,000
383	8	0.3	7.5	2340	31,000
384	2	0.3	7.5	1650	22,000
385	1	0.3	7.5	1350	18,000
386	0.8	0.3	7.5	1200	16,000
387	3	0.3	7.5	1610	21,000
388	4	0.3	7.5	1740	23,000
389	5	0.3	7.5	1840	24,000
390	6	0.3	7.5	1840	24,000
391	7	0.3	7.5	1880	25,000
392	8	0.3	7.5	1940	26,000
393	9	0.3	7.5	1940	26,000
394	10	0.3	7.5	1940	26,000
395	5	0.3	7.5	1705	23,000

TABLE XI (continued)

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Power (microwatts)	Enhanced Power (microwatts)	Enhancement (percent)
396	6	0.3	7.5	1705	23,000
397	7	0.3	7.5	1800	27,000
398	4	0.3	7.5	1520	20,000
399	3	0.3	7.5	1450	19,000
400	2	0.3	7.5	1400	19,000
401	3	0.3	7.5	1595	21,000
402	4	0.3	7.5	1840	19,000
403	5	0.3	7.5	1980	26,000
404	6	0.3	7.5	2020	27,000
405	7	0.3	7.5	2190	29,000
406	8	0.3	7.5	2340	31,000
407	9	0.3	7.5	2340	31,000
408	10	0.3	7.5	2450	31,000
409	3	0.2	7.5	1235	16,000
410	2	0.2	7.5	1020	14,000
411	3	0.2	7.5	1200	16,000
412	4	0.2	7.5	1400	19,000
413	5	0.2	7.5	1435	19,000
414	6	0.2	7.5	1610	21,000
415	7	0.2	7.5	1610	21,000
416	8	0.2	7.5	1650	22,000
417	9	0.2	7.5	1705	23,000
418	10	0.2	7.5	1800	24,000
419	2	0.2	7.5	1020	14,000
420	3	0.2	7.5	1235	16,000
421	4	0.2	7.5	1435	19,000
422	5	0.2	7.5	1520	20,000
423	6	0.2	7.5	1520	20,000
424	7	0.2	7.5	1575	21,000
425	8	0.2	7.5	1610	21,000
426	9	0.2	7.5	1610	21,000
427	10	0.2	7.5	1610	21,000



TABLE XI (continued)

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Power (microwatts)	Enhanced Power (microwatts)	Enhancement (percent)
428	3	0.2	7.5	1125	15,000
429	3	0.1	7.5	460	6,000
430	4	0.1	7.5	420	5,500
431	3	0.1	7.5	440	5,800
432	4	0.1	7.5	460	6,000
433	5	0.1	7.5	480	6,300
434	6	0.1	7.5	510	6,700
435	7	0.1	7.5	510	6,700
436	8	0.1	7.5	510	6,700
437	9	0.1	7.5	531	7,000
438	10	0.1	7.5	563	7,400
439	2	0.1	7.5	400	5,200
440	3	0.1	7.5	440	5,800
441	4	0.1	7.5	460	6,000
442	5	0.1	7.5	489	6,400
443	6	0.1	7.5	510	6,700
444	7	0.1	7.5	510	6,700
445	8	0.1	7.5	531	7,000
446	9	0.1	7.5	563	7,400
447	10	0.1	7.5	563	7,400
448	3	0.1	7.5	420	5,500
449	10	0.3	7.5	2570	34,000
450	9	0.3	7.5	2390	32,000
451	8	0.3	7.5	2340	31,000
452	7	0.3	7.5	2300	30,000
453	6	0.3	7.5	2100	29,000
454	2	0.3	7.5	1395	18,000
455	0.5	0.3	7.5	820	11,000
500	2	0.3	7.5	1400	19,000
456	3	0.3	7.5	1520	20,000
457	2	0.3	7.5	1235	16,000

TABLE XI (continued)

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Power (microwatts)	Enhanced Power (microwatts)	Enhancement (percent)
458	1	0.3	7.5	880	12,000
459	2	0.3	7.5	1235	16,000
460	3	0.3	7.5	1520	20,000
461	1	0.3	7.5	880	12,000
462	0.5	0.3	7.5	816	11,000
463	5	0.3	7.5	1920	26,000
464	0.5	0.3	7.5	746	9,800
465	10	0.2	7.5	1705	23,000
466	9	0.2	7.5	1610	21,000
467	8	0.2	7.5	1610	21,000
468	7	0.2	7.5	1485	20,000
469	0.5	0.2	7.5	650	8,600
470	3	0.2	7.5	1205	16,000
471	4	0.2	7.5	1435	19,000
472	5	0.2	7.5	1520	20,000
473	6	0.2	7.5	1610	21,000
474	2	0.2	7.5	1005	13,000
475	1	0.2	7.5	788	10,000
476	0.5	0.2	7.5	665	8,800
477	1	0.2	7.5	788	10,000
478	0.5	0.2	7.5	625	8,200
479	3	0.1	7.5	489	6,400
480	10	0.1	7.5	585	7,600
481	9	0.1	7.5	585	7,600
482	8	0.1	7.5	563	7,400
483	7	0.1	7.5	531	7,000
484	6	0.1	7.5	510	6,700
485	5	0.1	7.5	489	6,400
486	4	0.1	7.5	460	6,000
487	3	0.1	7.5	440	5,800
488	2	0.1	7.5	394	5,200

TABLE XI (continued)

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Power (microwatts)	Enhanced Power (microwatts)	Enhancement (percent)
489	1	0.1	7.5	332	4,300
490	5	0.1	7.5	489	6,400
491	0.5	0.1	7.5	240	3,100
492	5	0.1	7.5	489	6,400
493	0.5	0.1	7.5	255	3,300
494	1	0.1	7.5	309	4,000
495	0.5	0.1	7.5	240	3,100
496	1	0.1	7.5	309	4,000
497	3	0.1	7.5	489	6,400
498	10	0.2	7.5	1800	24,000
499	9	0.2	7.5	1740	24,000
501	8	0.2	7.5	1705	23,000
502	7	0.2	7.5	1610	21,000
503	6	0.2	7.5	1575	21,000
504	5	0.2	7.5	1435	19,000
505	4	0.2	7.5	1350	18,000
506	3	0.2	7.5	1235	16,000
507	2	0.2	7.5	1050	14,000
508	1	0.2	7.5	840	11,000
509	0.5	0.2	7.5	808	11,000
510	1	0.2	7.5	815	11,000
511	5	0.2	7.5	1470	20,000
512	0.5	0.2	7.5	785	10,000
513	0.5	0.2	7.5	785	10,000
514	3	0.2	7.5	1235	16,000
515	3	0.1	7.5	460	6,000
516	2	0.1	7.5	412	5,400
517	1	0.1	7.5	309	4,000
518	5	0.1	7.5	510	6,700
519	4	0.1	7.5	460	6,000
520	6	0.1	7.5	510	6,700
521	0.5	0.1	7.5	268	3,500

TABLE XI (continued)

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Power (microwatts)	Enhanced Power (microwatts)	Enhancement (percent)
522	7	0.1	7.5	563	7,400
523	8	0.1	7.5	563	7,400
524	9	0.1	7.5	585	7,600
525	10	0.1	7.5	585	7,600
526	0.5	0.1	7.5	268	3,500
527	1	0.1	7.5	332	4,300
999	3	0.1	7.5	460	6,000
528	10	0.3	7.5	2230	30,000
529	9	0.3	7.5	2190	29,000
530	8	0.3	7.5	2190	29,000
531	7	0.3	7.5	2020	27,000
532	6	0.3	7.5	2020	27,000
533	5	0.3	7.5	1940	26,000
534	4	0.3	7.5	1840	24,000
535	3	0.3	7.5	1650	22,000
536	2	0.3	7.5	1450	19,000
537	1	0.3	7.5	1268	17,000
538	0.5	0.3	7.5	853	11,000
539	3	0.2	7.5	1235	16,000
540	4	0.2	7.5	1435	19,000
541	5	0.2	7.5	1575	21,000
542	6	0.2	7.5	1650	22,000
543	7	0.2	7.5	1745	23,000
544	8	0.2	7.5	1745	23,000
545	9	0.2	7.5	1840	24,000
546	10	0.2	7.5	1880	25,000
547	2	0.2	7.5	1020	14,000
548	1	0.2	7.5	908	12,000
549	0.5	0.2	7.5	675	8,900
550	3	0.1	7.5	1650	22,000
551	10	0.1	7.5	585	7,600

TABLE XI (continued)

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Power (microwatts)	Enhanced Power (microwatts)	Enhancement (percent)
552	9	0.1	7.5	585	7,600
553	8	0.1	7.5	563	7,400
554	7	0.1	7.5	563	7,400
555	6	0.1	7.5	563	7,400
556	5	0.1	7.5	510	6,700
557	4	0.1	7.5	510	6,700
558	3	0.1	7.5	460	6,000
559	2	0.1	7.5	394	5,200
560	1	0.1	7.5	350	4,600
561	0.5	0.1	7.5	255	3,300
562	0.5	0.3	7.5	735	9,700

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563	3	0.3	7.5	1650	22,000
564	10	0.3	7.5	2570	34,000
565	20	0.3	7.5	2900	39,000
566	30	0.3	7.5	3030	42,000
567	40	0.3	7.5	3030	42,000
568	50	0.3	7.5	3030	42,000
569	60	0.3	7.5	3030	42,000
570	70	0.3	7.5	3030	42,000
571	80	0.3	7.5	3030	42,000
572	90	0.3	7.5	3030	42,000
573	100	0.3	7.5	3030	42,000
574	200	0.3	7.5	3030	42,000
575	300	0.3	7.5	3030	42,000
576	400	0.3	7.5	3030	42,000
577	500	0.3	7.5	3030	42,000
578	1000	0.3	7.5	3030	42,000
579	3	0.3	7.5	1610	21,000

TABLE XI (continued)

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Power (microwatts)	Enhanced Power (microwatts)	Enhancement (percent)
580	10	0.3	7.5	2340	31,000
581	20	0.3	7.5	2610	35,000
582	30	0.3	7.5	2680	36,000
583	40	0.3	7.5	2730	36,000
584	50	0.3	7.5	2850	38,000
585	60	0.3	7.5	2850	38,000
586	70	0.3	7.5	2850	38,000
587	80	0.3	7.5	2850	38,000
588	90	0.3	7.5	2850	38,000
589	100	0.3	7.5	2900	39,000
590	200	0.3	7.5	2900	39,000
591	300	0.3	7.5	2900	39,000
592	400	0.3	7.5	2900	39,000
593	500	0.3	7.5	2900	39,000
594	1000	0.3	7.5	2900	39,000
595	3	0.2	7.5	1315	17,000
596	10	0.2	7.5	1820	24,000
597	20	0.2	7.5	2290	30,000
598	30	0.2	7.5	2230	30,000
599	40	0.2	7.5	2290	30,000
600	50	0.2	7.5	2290	30,000
601	60	0.2	7.5	2290	30,000
602	70	0.2	7.5	2290	30,000
603	80	0.2	7.5	2290	30,000
604	90	0.2	7.5	2290	30,000
605	100	0.2	7.5	2290	30,000
606	200	0.2	7.5	2340	31,000
607	300	0.2	7.5	2340	31,000
608	400	0.2	7.5	2340	31,000
609	500	0.2	7.5	2340	31,000
610	1000	0.2	7.5	2400	32,000

TABLE XI (continued)

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Power (microwatts)	Enhanced Power (microwatts)	Enhancement (percent)
611	10	0.2	7.5	1820	24,000
612	20	0.2	7.5	2190	29,000
613	30	0.2	7.5	2230	30,000
614	40	0.2	7.5	2340	31,000
615	50	0.2	7.5	2340	31,000
616	60	0.2	7.5	2340	31,000
617	70	0.2	7.5	2340	31,000
618	80	0.2	7.5	2340	31,000
619	90	0.2	7.5	2340	31,000
620	100	0.2	7.5	2340	31,000
621	200	0.2	7.5	2340	31,000
622	300	0.2	7.5	2340	31,000
623	400	0.2	7.5	2340	31,000
624	500	0.2	7.5	2340	31,000
625	1000	0.2	7.5	2450	32,000
626	20	0.1	7.5	788	10,000
627	30	0.1	7.5	788	10,000
628	40	0.1	7.5	725	9,600
629	50	0.1	7.5	761	10,000
630	60	0.1	7.5	788	10,000
631	70	0.1	7.5	788	10,000
632	80	0.1	7.5	788	10,000
633	90	0.1	7.5	788	10,000
634	100	0.1	7.5	788	10,000
635	200	0.1	7.5	853	11,000
636	300	0.1	7.5	880	12,000
637	400	0.1	7.5	880	12,000
638	500	0.1	7.5	880	12,000
639	1000	0.1	7.5	880	12,000
640	20	0.1	7.5	725	9,600
641	30	0.1	7.5	750	9,900

TABLE XI (continued)

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Power (microwatts)	Enhanced Power (microwatts)	Enhancement (percent)
642	40	0.1	7.5	788	10,000
643	50	0.1	7.5	788	10,000
644	60	0.1	7.5	788	10,000
645	70	0.1	7.5	788	10,000
646	80	0.1	7.5	814	11,000
647	90	0.1	7.5	814	11,000
648	100	0.1	7.5	853	11,000
649	200	0.1	7.5	853	11,000
650	300	0.1	7.5	880	12,000
651	400	0.1	7.5	880	12,000
652	500	0.1	7.5	880	12,000
653	1000	0.1	7.5	880	12,000
654	3	0.1	7.5	510	6,800



TABLE XII  
 POWER ENHANCEMENT BY APPLICATION OF ALTERNATING CURRENT ELECTRIC FIELD  
 TO GRID ELECTRODES OF SYSTEM B DURING FUEL CELL OPERATION

DATA OF JULY 16, 1968

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Power (microwatts)	Enhanced Power (microwatts)	Enhancement (percent)
1	1	0.3	1.7	4.33	150
2	2	0.3	1.7	4.68	180
3	3	0.3	1.7	4.77	190
4	5	0.3	1.7	4.33	150
5	10	0.3	1.7	3.92	130
6	50	0.3	1.7	3.92	130
7	100	0.3	1.7	3.92	130
8	1	0.2	1.7	3.84	120
9	2	0.2	1.7	3.92	130
10	3	0.2	1.7	4.05	140
11	5	0.2	1.7	3.92	130
12	10	0.2	1.7	3.92	130
13	50	0.2	1.7	3.92	130
14	100	0.2	1.7	3.92	130
15	1	0.2	1.7	3.84	120
16	2	0.2	1.7	4.25	150
17	3	0.2	1.7	4.68	180
18	5	0.2	1.7	4.25	150
19	10	0.2	1.7	4.25	150
20	50	0.2	1.7	4.25	150
21	100	0.2	1.7	4.25	150
22	1	0.2	1.7	3.84	130
23	2	0.2	1.7	3.92	130
24	3	0.2	1.7	4.42	160
25	5	0.2	1.7	4.16	150
26	10	0.2	1.7	4.25	150

TABLE XIII (continued)

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Power (microwatts)	Enhanced Power (microwatts)	Enhancement (percent)
27	50	0.2	1.7	4.25	150
28	100	0.2	1.7	4.25	150
29	1	0.1	1.7	3.92	130
30	2	0.1	1.7	3.92	130
DATA OF JULY 16, 1968					
31	2	0.1	1.7	3.92	130
32	3	0.1	1.7	3.92	130
33	5	0.1	1.7	3.92	130
34	10	0.1	1.7	3.92	130
35	50	0.1	1.7	3.92	130
36	100	0.1	1.7	3.60	110
37	1	0.1	1.7	3.84	120
38	2	0.1	1.7	3.84	120
39	3	0.1	1.7	3.84	120
40	5	0.1	1.7	3.92	130
41	10	0.1	1.7	3.92	130
42	50	0.1	1.7	3.92	130
43	100	0.1	1.7	2.20	29
44	1	0.3	1.7	2.40	41
45	2	0.3	1.7	2.64	55
46	3	0.3	1.7	2.52	48
47	5	0.3	1.7	1.98	16
48	10	0.3	1.7	0.66	-61
49	50	0.3	1.7	0.66	-61
50	100	0.3	1.7	1.80	5.9
51	1	0.3	1.7	1.90	12
52	2	0.3	1.7	2.09	23
53	3	0.3	1.7	2.09	23
54	5	0.3	1.7	1.90	12

TABLE XII (continued)

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Power (microwatts)	Enhanced Power (microwatts)	Enhancement (percent)
55	10	0.3	1.7	1.80	5.9
56	50	0.3	1.7	1.80	5.9
DATA OF JULY 17, 1968					
57	1	0.3	0.34	2.52	640
58	2	0.3	0.34	2.59	660
59	3	0.3	0.34	2.63	670
60	4	0.3	0.34	2.41	610
61	5	0.3	0.34	2.35	590
62	10	0.3	0.34	2.11	520
63	50	0.3	0.34	1.48	340
64	100	0.3	0.34	1.22	230
65	1	0.2	0.34	0.88	160
66	2	0.2	0.34	0.92	170
67	3	0.2	0.34	0.95	180
68	4	0.2	0.34	0.82	140
69	5	0.2	0.34	0.80	140
70	10	0.2	0.34	0.72	110
71	50	0.2	0.34	0.65	90
72	100	0.2	0.34	0.58	70
73	1	0.1	0.34	0.38	11
74	2	0.1	0.34	0.39	15
75	3	0.1	0.34	0.39	15
76	4	0.1	0.34	0.38	11
77	5	0.1	0.34	0.36	7.4
78	10	0.1	0.34	0.36	7.4
79	50	0.1	0.34	0.34	0.0
80	100	0.1	0.34	0.34	0.0
81	1	0.3	0.34	2.52	640
82	2	0.3	0.34	2.56	650

TABLE XII (continued)

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Power (microwatts)	Enhanced Power (microwatts)	Enhancement (percent)
83	3	0.3	0.34	2.59	660
84	4	0.3	0.34	2.34	590
85	5	0.3	0.34	2.24	560
86	10	0.3	0.34	1.98	480
87	50	0.3	0.34	1.38	310
88	100	0.3	0.34	1.10	120
89	1	0.2	0.34	0.72	110
90	2	0.2	0.34	0.74	120
91	3	0.2	0.34	0.74	120
92	4	0.2	0.34	0.72	110
93	5	0.2	0.34	0.68	100
94	10	0.2	0.34	0.63	85
95	50	0.2	0.34	0.51	51
96	100	0.2	0.34	0.50	46
97	1	0.1	0.34	0.34	0.0
98	2	0.1	0.34	0.34	0.0
99	3	0.1	0.34	0.38	11.0
100	4	0.1	0.34	0.35	3.2
101	5	0.1	0.34	0.35	3.2
102	10	0.1	0.34	0.34	0.0
103	50	0.1	0.34	0.34	0.0
104	100	0.1	0.34	0.31	-7.9
105	1	0.3	0.34	2.54	650
106	2	0.3	0.34	2.56	650
107	3	0.3	0.34	2.59	660
108	4	0.3	0.34	2.31	580
109	5	0.3	0.34	2.18	540
110	10	0.3	0.34	1.92	460
111	50	0.3	0.34	1.38	310
112	100	0.3	0.34	1.11	230
113	1	0.2	0.34	0.86	150

TABLE XII (continued)

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Power (microwatts)	Enhanced Power (microwatts)	Enhancement (percent)
114	2	0.2	0.34	0.86	150
115	3	0.2	0.34	0.86	150
116	4	0.2	0.34	0.80	140
117	5	0.2	0.34	0.76	120
118	10	0.2	0.34	0.72	110
119	50	0.2	0.34	0.63	85
120	100	0.2	0.34	0.61	80
121	1	0.1	0.34	0.42	24
122	2	0.1	0.34	0.42	24
123	3	0.1	0.34	0.44	28
124	4	0.1	0.34	0.42	24
125	5	0.1	0.34	0.42	24
126	10	0.1	0.34	0.42	24
127	50	0.1	0.34	0.39	15
128	100	0.1	0.34	0.39	15
129	1	0.3	0.34	2.56	650
130	2	0.3	0.34	2.59	660
131	3	0.3	0.34	2.59	660
132	4	0.3	0.34	2.31	580
133	5	0.3	0.34	2.24	560
134	10	0.3	0.34	1.95	470
135	50	0.3	0.34	1.41	320
136	100	0.3	0.34	1.18	250
137	1	0.2	0.34	1.01	200
138	2	0.2	0.34	1.01	200
139	3	0.2	0.34	0.97	180
140	4	0.2	0.34	0.92	170
141	5	0.2	0.34	0.88	160
142	10	0.2	0.34	0.76	120
143	50	0.2	0.34	0.65	90

TABLE XII (continued)

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Initial Power (microwatts)	Enhanced Power (microwatts)	Enhancement (percent)
144	100	0.2	0.34	0.60	75
145	1	0.1	0.34	0.36	7.4
146	2	0.1	0.34	0.39	15
147	3	0.1	0.34	0.39	15
148	4	0.1	0.34	0.39	15
149	5	0.1	0.34	0.39	15
150	10	0.1	0.34	0.36	7.4
151	50	0.1	0.34	0.36	7.4
152	100	0.1	0.34	0.36	7.4

## APPENDIX E

DATA OF DECAY TIME AFTER APPLICATION OF ALTERNATING CURRENT  
ELECTRIC FIELD TO GRID ELECTRODES FOR THIRTY SECONDS

Table XIII contains data of the decay time of System A after removal of the applied field. During the measurement of the fuel cell power enhancement by the application of the applied alternating field, it was noticed that a large portion of the enhancement lingered for a definite period of time after the removal of the applied field. This decay time was measured as a function of the frequency and voltage of the applied field and is presented in Table XIII.

TABLE XIII

## DECAY TIME AFTER APPLICATION OF ALTERNATING CURRENT ELECTRIC

## FIELD TO GRID ELECTRODES FOR THIRTY SECONDS

DATA OF JUNE 28, 1968

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Decay Time (seconds)
1	1	0.2	40
2	3	0.2	50
3	5	0.2	90
4	7	0.2	125
5	9	0.2	125
6	1	0.2	42
7	3	0.2	65
8	5	0.2	85
9	7	0.2	115
10	9	0.2	130

DATA OF JULY 1, 1968

11	3	0.2	150
12	1	0.2	140
13	5	0.2	165
14	7	0.2	180
15	9	0.2	190
16	20	0.2	190
17	40	0.2	190
18	100	0.2	190
19	1	0.1	45
20	3	0.1	60
21	5	0.1	75
22	7	0.1	90
23	9	0.1	105
24	20	0.1	110
25	40	0.1	110
26	100	0.1	113
27	1	0.3	50
28	3	0.3	65
29	5	0.3	70
30	7	0.3	80
31	9	0.3	92
32	20	0.3	90
33	40	0.3	90
34	100	0.3	90

DATA OF JULY 2, 1968

35	1	0.2	120
36	3	0.2	135
37	5	0.2	165



TABLE XIII (continued)

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Decay Time (seconds)
38	7	0.2	190
39	9	0.2	200
40	20	0.2	210
41	40	0.2	210
42	100	0.2	215
43	500	0.2	215
44	1	0.1	65
45	3	0.1	70
46	5	0.1	70
47	7	0.1	70
48	9	0.1	70
49	20	0.1	70
50	40	0.1	71
51	100	0.1	71
52	500	0.1	71
53	1	0.3	120
54	3	0.3	140
55	5	0.3	165
56	7	0.3	180
57	9	0.3	200
58	20	0.3	195
59	40	0.3	210
60	100	0.3	225
61	500	0.3	225
62	1	0.3	110
63	3	0.3	140
64	5	0.3	135
65	7	0.3	145
66	9	0.3	135
67	20	0.3	155
68	40	0.3	155
69	100	0.3	160
70	500	0.3	155
71	1	0.1	45
72	3	0.1	55
73	5	0.1	60
74	7	0.1	65
75	9	0.1	70
76	20	0.1	74
77	40	0.1	75
78	100	0.1	75
79	500	0.1	75
80	3	0.3	125
DATA OF JULY 3, 1968			
81	1	0.3	120
82	3	0.3	145
83	5	0.3	170

TABLE XIII (continued)

Trial	Frequency (cy/sec)	A. C. Voltage (volts)	Decay Time (seconds)
84	7	0.3	180
85	9	0.3	180
86	20	0.3	200
87	40	0.3	200
88	100	0.3	200
89	500	0.3	200
90	1	0.3	120
91	3	0.3	125
92	5	0.3	150
93	7	0.3	180
94	9	0.3	190
95	20	0.3	200
96	40	0.3	230
97	100	0.3	200
98	500	0.3	210
99	1	0.3	115
100	3	0.3	135
101	5	0.3	170
102	7	0.3	190
103	9	0.3	210
104	20	0.3	210
105	40	0.3	215
106	100	0.3	230
107	500	0.3	230

## APPENDIX F

## INPUT POWER MEASUREMENT DATA

Figure 22 indicates the electrical connections used in measuring the power input to the fuel cell system due to the applied alternating current field. It was necessary to measure this power input in order to determine if the enhanced power output of the fuel cell system was greater than the power input from the applied field. The maximum power input to System A was calculated to be 3,000 microwatts and the maximum power input to System B was calculated to be 9,000 microwatts.

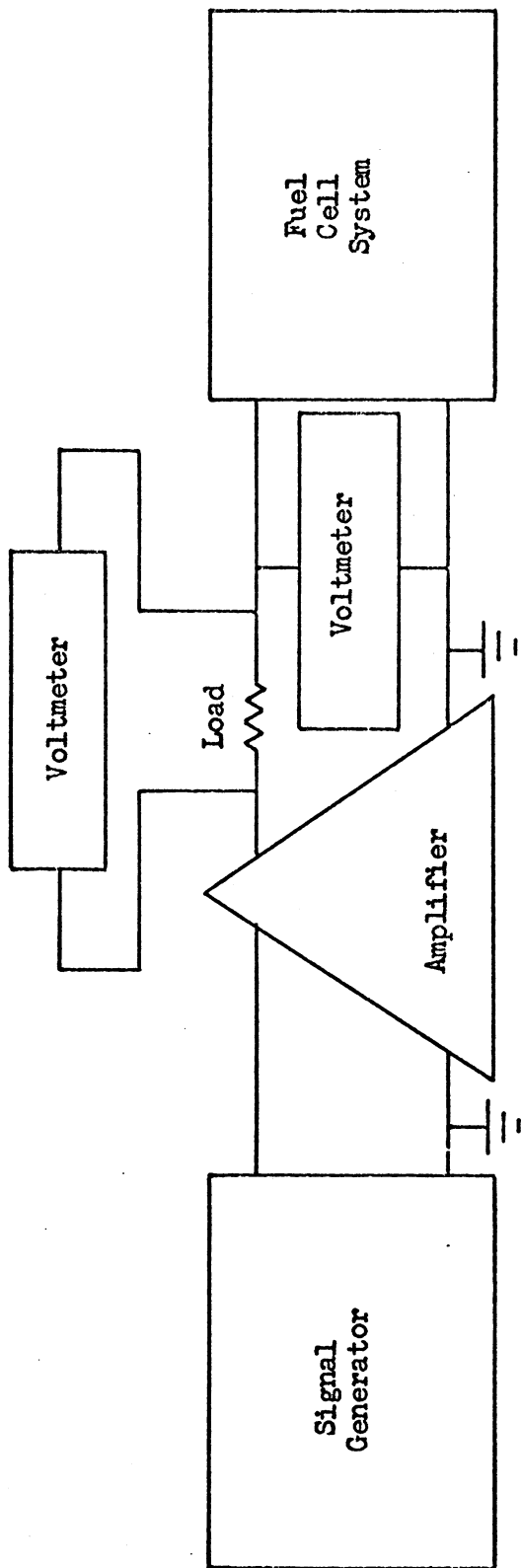


Figure 22. Schematic of Input Power Measurement System.

The voltage measured across the two-ohm load resistance of System A was 0.02 volt. Therefore, the current supplied to the fuel cell system was calculated to be 0.01 amperes. The voltage measured between the grid electrodes and ground was 0.3 volt.

A maximum power factor of one was assumed in order to estimate the upper bound of the power input to the system. The maximum power input to System A was calculated as:

$$\text{Power} = VI \text{ (Power Factor)}$$

$$\text{Power} = (0.3) (0.01) (1.0)$$

$$\text{Power} = 3,000 \text{ microwatts}$$

The same method was used to calculate the power input to System B. The voltage across the two-ohm load resistance was 0.06 volt. The calculated current was 0.03 amperes. The voltage measured between the grid electrodes and ground was 0.3 volt. The maximum power input to System B was calculated as:

$$\text{Power} = VI \text{ (Power Factor)}$$

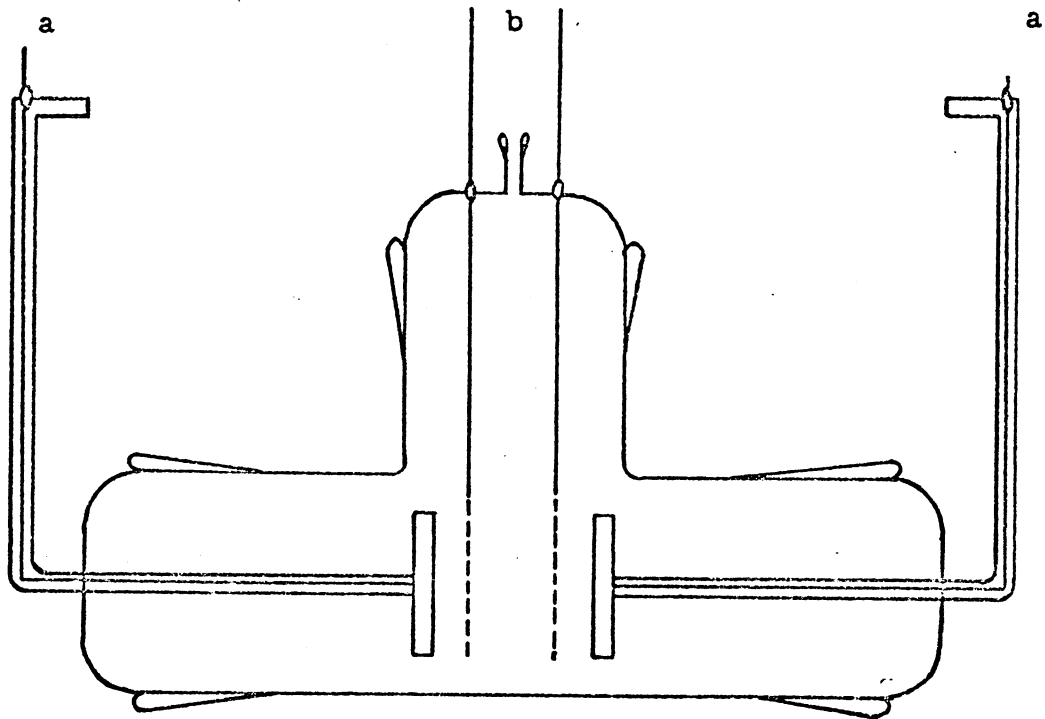
$$\text{Power} = (0.3) (0.03) (1.0)$$

$$\text{Power} = 9,000 \text{ microwatts}$$

## APPENDIX G

## SHIMAMOTO'S ENHANCEMENT DATA

Typical enhancement values obtained by Shimamoto (37) are contained in this appendix. The enhancement of the fuel cell power output was achieved by the application of an alternating current field to the grid electrodes of the fuel cell. The maximum power enhancement achieved was 5,000 percent with an applied field of 2.0 volts, at a frequency of three cycles per second. Figure 23 shows the fuel cell assembly used to obtain the values contained in Table XIV and shown in Figure 24.



- a. Fuel Cell Terminals
- b. Grid Electrode Terminals

Figure 23. Fuel Cell Housing with Terminals for Electric Fields.

TABLE XIV

ENHANCEMENT BY APPLYING 2.0 VOLTS TO  
THE GRID ELECTRODES

Test	Frequency (cy/sec)	Voltage (millivolts)	Enhancement (percent)
2176	3	44.0	5000
2177	2	26.5	2900
2178	4	26.5	2900

ENHANCEMENT BY APPLYING 1.8 VOLTS TO  
THE GRID ELECTRODES

Test	Frequency (cy/sec)	Voltage (millivolts)	Enhancement (percent)
2170	10	0.8	-10
2171	5	0.9	0
2172	3	44.0	5000
2173	1	20.3	2200
2174	2	26.5	2900
2175	4	26.5	2900



TABLE XIV (continued)  
 ENHANCEMENT BY APPLYING 1.6 VOLTS TO  
 THE GRID ELECTRODES

Test	Frequency (cy/sec)	Voltage (millivolts)	Enhancement (percent)
2180	2	19.7	1420
2181	1	11.0	452
2182	3	35.2	2190
2183	4	3.1	120
2184	5	1.3	-6
2185	10	1.2	-12

ENHANCEMENT BY APPLYING 0.8 VOLTS TO  
 THE GRID ELECTRODES

Test	Frequency (cy/sec)	Voltage (millivolts)	Enhancement (percent)
2102	5	3.1	None
2103	3	3.1	None
2104	10	3.1	None
2105	20	3.1	None

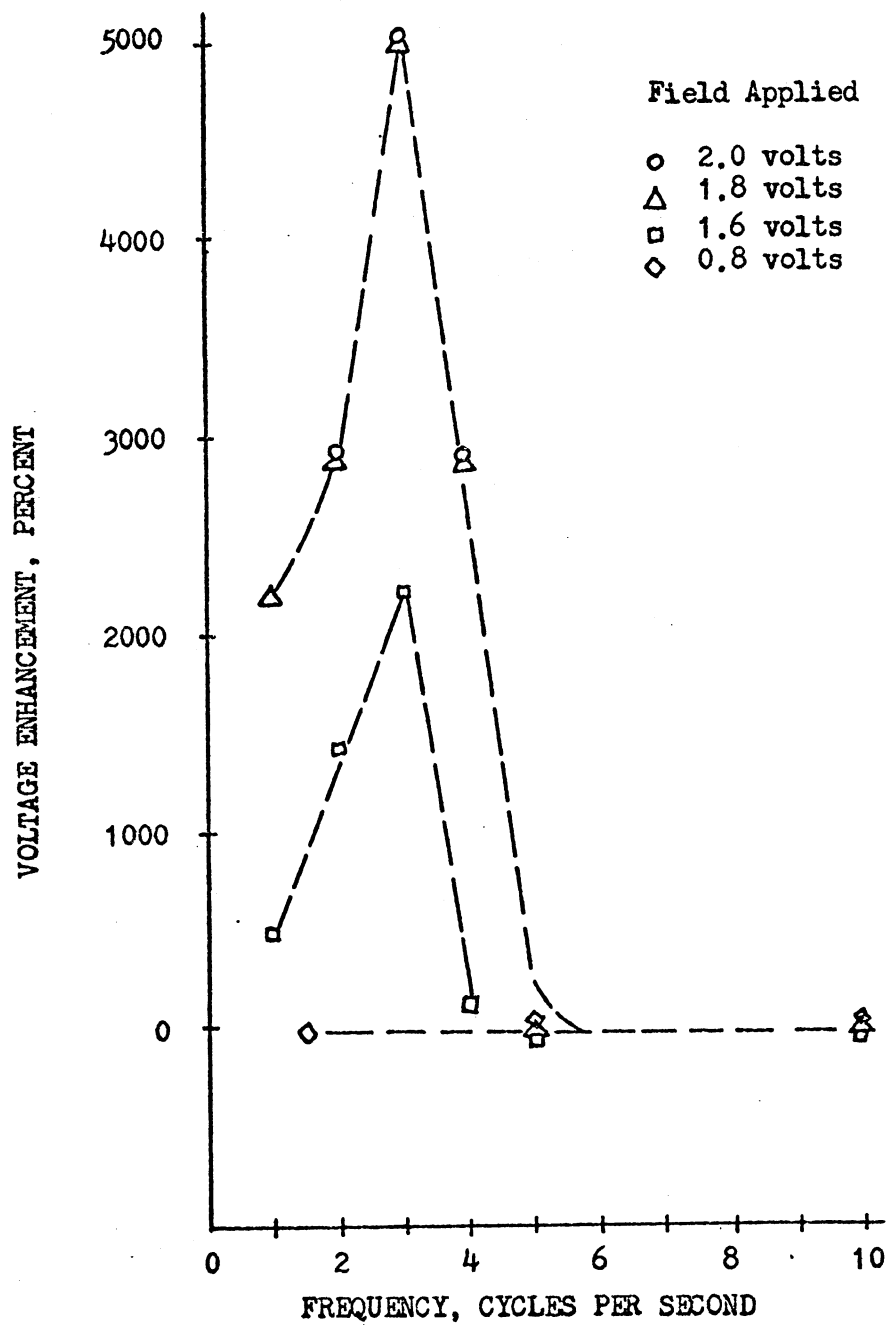


Figure 24. Enhancement with Grid Electrodes.

APPENDIX H  
SEMICONDUCTOR ELECTRODE DATA

This appendix contains the values that were obtained when the fuel cell system was operated with extrinsic silicon semiconductive material as electrodes. The first configuration used n-type material as the hydrogen electrode and p-type material as the oxygen electrode. The second configuration used n-type material as the oxygen electrode and p-type material as the hydrogen electrode. The open circuit voltage of the first configuration was greater than the open circuit voltage of the second configuration. Table XV contains the values of the open circuit voltages when silicon was used as the electrodes of the system.

TABLE XV

## OPEN CIRCUIT VOLTAGES USING SILICON ELECTRODES

DATA FOR N-TYPE HYDROGEN ELECTRODE AND P-TYPE OXYGEN ELECTRODE

Time (minutes)	Voltage (millivolts)
0	3.0
5	1.5
10	1.0
15	1.5
20	1.5
25	1.0
30	1.0
35	1.0
40	1.5
45	1.5
50	1.5
55	2.0
60	2.0
65	2.0
70	2.0
75	2.0
80	2.0
85	2.5
90	2.5
95	3.0
100	4.5
105	6.0
110	9.5
115	9.5
120	8.5
125	7.5
130	8.0
135	7.5
140	7.0
145	7.0
150	7.0
155	7.0
160	7.0
165	7.0
170	6.5
175	7.0
180	7.0
185	7.0
190	6.5
195	6.5
200	7.0
205	7.0

TABLE XV (continued)

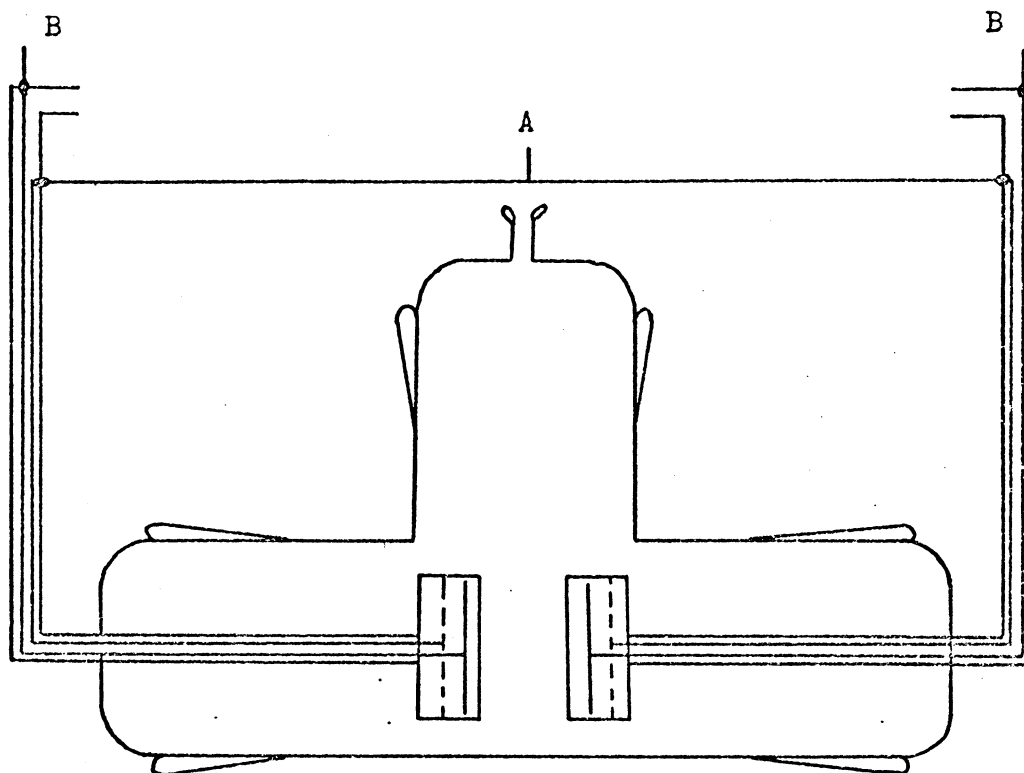
DATA FOR P-TYPE HYDROGEN ELECTRODE AND N-TYPE OXYGEN ELECTRODE

Time (minutes)	Voltage (millivolts)
0	1.0
5	1.0
10	2.0
15	1.5
20	1.0
25	1.0
30	1.0
35	2.5
40	3.0
45	3.5
50	3.5
55	3.5
60	3.5
65	3.5
70	3.5
75	3.5
80	3.5
85	4.0
90	4.0
95	4.0
100	4.0
105	4.5
110	4.5
115	4.5
120	4.5
125	5.0
130	4.5
135	4.5
140	4.0
145	4.5
150	4.5
155	4.5
160	4.5
165	4.5

## APPENDIX I

## GRID ELECTRODES IN THE GAS PHASE

This appendix contains preliminary data concerning the effects of placing the grid electrodes in the gas phase. A copper wire cloth grid electrode was placed behind each platinum fuel cell electrode. Only one fuel cell was employed in this study and it was assembled as shown in Figure 25. An alternating current field of 0.3 volt was applied to the grid electrodes and a maximum power enhancement of 720 percent was achieved at a frequency of three cycles per second. The input power to the system was measured in the same manner as described in Appendix F, Figure 22. In this case, the power input was so small that it could not be accurately measured. Further work in this area could very well lead to a method of applying an alternating current electric field to the fuel cell system with no expenditure of energy. Table XVI, Table XVII and Figure 26 illustrate the power enhancement achieved when an alternating current field was applied to the fuel cell grid electrodes contained in the gas phase.



A. Grid Electrodes to Signal Generator

B. Fuel Cell Electrodes

Figure 25. Fuel Cell System with Electrodes in the Gas Phase.

TABLE XVI

CURRENT AND VOLTAGE ENHANCEMENT ACHIEVED BY THE APPLICATION OF 0.3 VOLTS  
TO THE GRID ELECTRODES CONTAINED IN THE GAS PHASE

DATA OF AUGUST 8, 1968

Frequency	Initial Current (milliamperes)	Enhanced Current (milliamperes)	Initial Voltage (millivolts)	Enhanced Voltage (millivolts)
1	0.55	1.30	30	80
2	0.55	1.45	30	80
3	0.55	1.60	30	85
4	0.55	1.25	30	70
5	0.55	1.15	30	65
10	0.55	1.15	30	65
50	0.55	1.15	30	65
100	0.55	1.15	30	65



TABLE XVII

POWER ENHANCEMENT ACHIEVED BY THE APPLICATION OF 0.3 VOLTS

TO THE GRID ELECTRODES CONTAINED IN THE GAS PHASE

Frequency	Initial Power (microwatts)	Enhanced Power (microwatts)	Power Enhancement (percent)
1	16.5	104	530
2	16.5	116	600
3	16.5	136	720
4	16.5	87.5	430
5	16.5	74.8	350
10	16.5	74.8	350
50	16.5	74.8	350
100	16.5	74.8	350

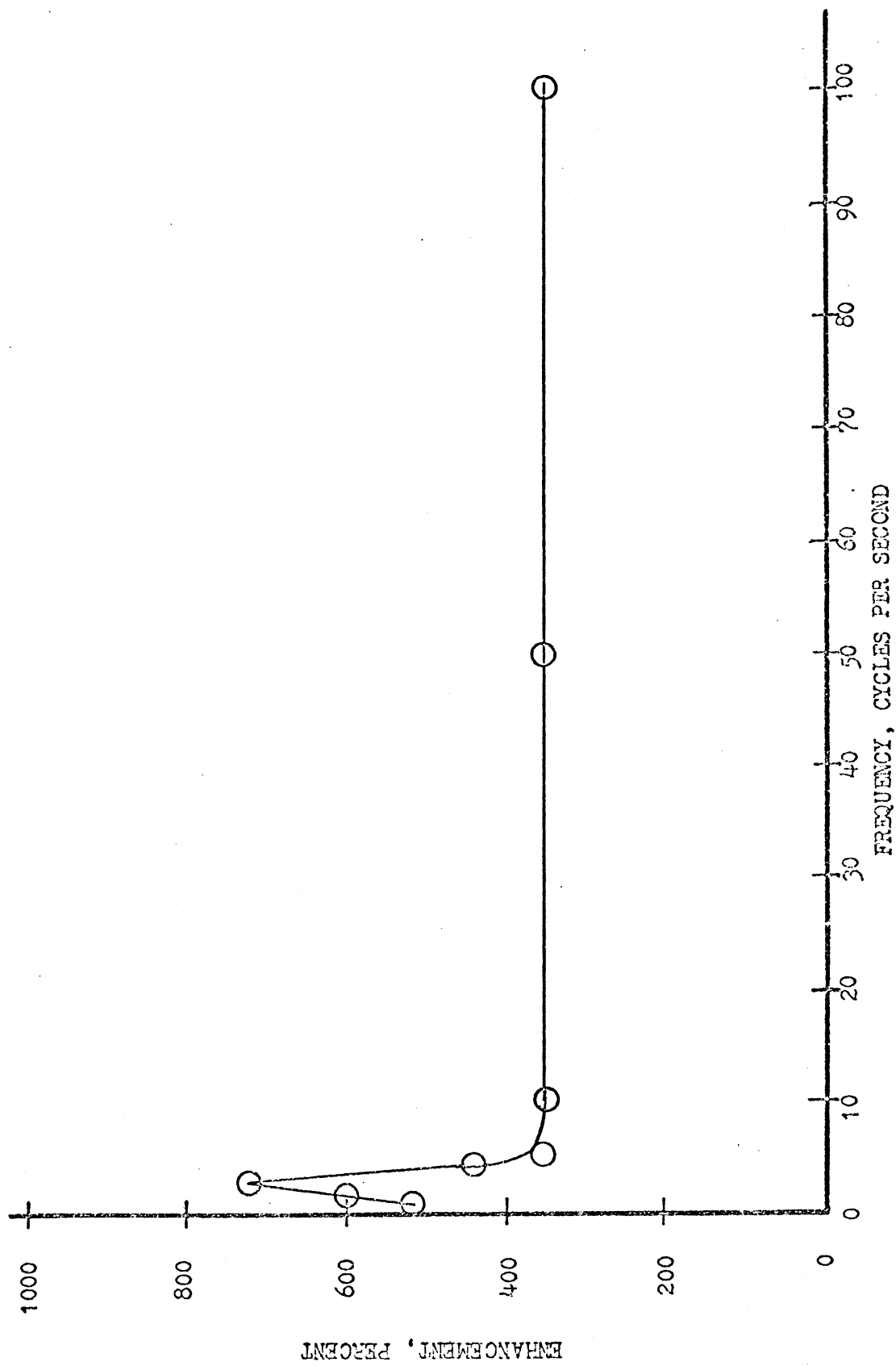


Figure 26. Enhancement Obtained by the Application of 0.3 Volts to Grid Electrodes in the Gas Phase.

## VITA

Gordon Henry Twedt was born in El Paso, Texas on January 28, 1945. He attended public school at Maddock, North Dakota and graduated from the Benson County Agricultural and Training School in Maddock, North Dakota in 1963. In September, 1963, the author entered the University of North Dakota in Grand Forks, North Dakota. He graduated with the degree Bachelor of Science in Chemical Engineering in June, 1967.

He was commissioned a Second Lieutenant in the United States Air Force in July, 1967.

During the fall of 1967, the author entered graduate school at the University of Missouri, supported by a National Science Foundation Fellowship.

The author is a member of Sigma Tau engineering honorary society and Delta Upsilon social fraternity.

He is married to the former Marie Louise Blanchard of Washburn, Wisconsin.

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