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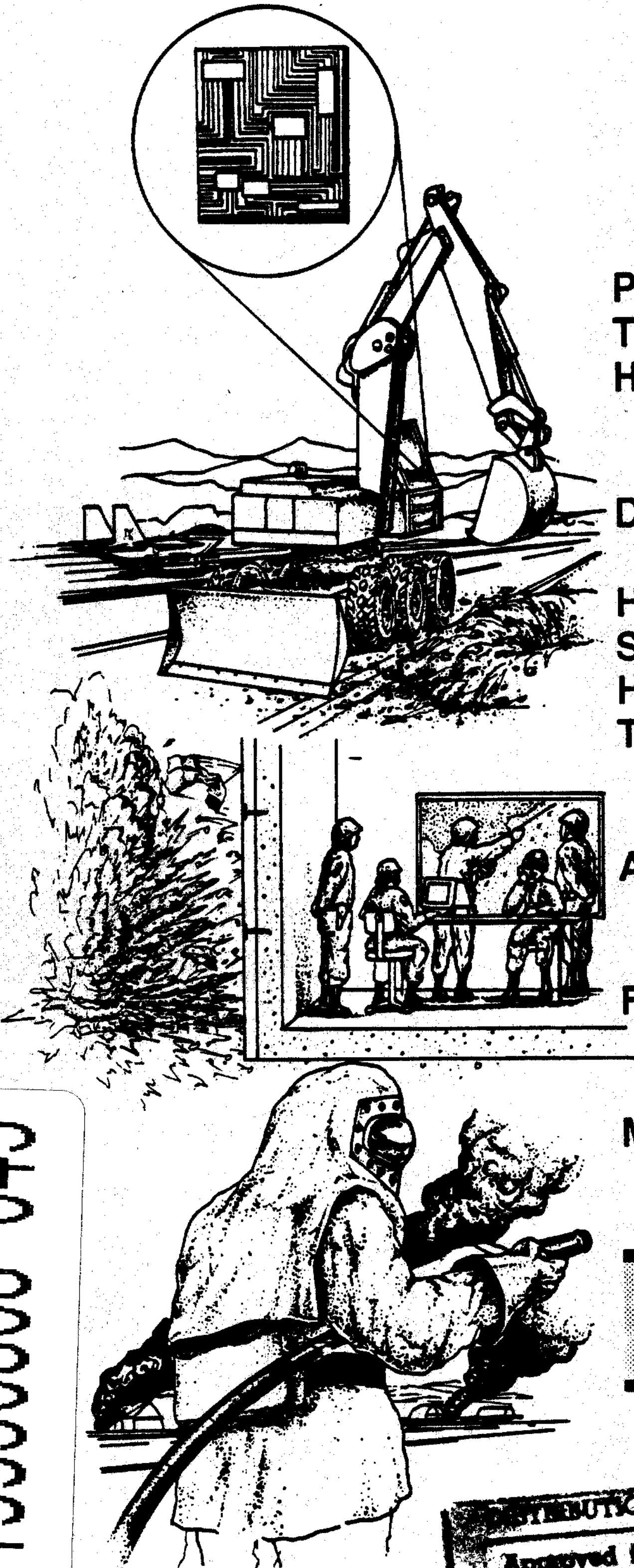

PULSED DC AND ANODE DEPOLARIZATION IN WATER ELECTROLYSIS FOR HYDROGEN GENERATION

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13. ABSTRACT *(Maximum 200 words)*

This research effort investigated the effects of anode depolarization and pulsed DC on the performance of the water electrolytic process for hydrogen generation. An experimental approach was implemented using the Fm01-LC electrolytic cell manufactured by ICI Chemical & Polymers Company. The Fm01-LC had a stainless steel cathode and platinum-coated titanium anode. Using a 10 percent by weight sulfuric acid as an electrolyte, the experimental results show that significant improvement in the performance of the water electrolysis is feasible. The anode depolarization process has the potential of improving the water electrolysis performance up to three times that of the conventional water electrolysis. On the other hand, Using pulsed DC caused current polarity reversal during the off period of the pulse. Placing a diode in the circuit prevented the polarity reversal but allowed the electrolytic cell to maintain a DC voltage level of 2.3 volts. The results of pulsed DC are in conflict with those reported in the literature. A basic research program is proposed to investigate the effects of pulsed DC, anode depolarization with the use of the state-of-the-art 3-D ultramicroelectrodes.

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EXECUTIVE SUMMARY

A. OBJECTIVES

The objective of this reseach is to document the performance of the electrolysis process for hydrogen generation when pulsed DC and anode depolarization are used. The resulting data were to be used in designing an efficient electrolytic cell that meets the Air Force needs.

B. BACKGROUND

Hydrogen can play an important role in future energy systems because of the diversity of its applications, the variety of ways in which it can be stored, its environmental advantages, and the possibility of producing hydrogen using solar, nuclear, wind, hydropower, and other renewable energy sources. The environmental impact of hydrogen as a source of energy is very favorable. Signs of the world moving to the hydrogen economy are evident. The Euro-Quebec Hydro-Hydrogen agreement will produce 20 million cubic feet of pure electrolytic hydrogen per day for use as transportation fuel at Hamburg, Germany, and to fuel a hydrogen-powered version of the European-made Airbus aircraft.

The U.S. Department of Defense interest in hydrogen applications is growing fast. The Army Research Office (ARO) obtained a 500-watt fuel cell design that weighs less than 10 pounds for individual soldier power. Currently, ARO is exploring the feasibility of using fuel cells for power generation on the battlefield. The requirement is a small, light, and inexpensive hydrogen supply device which could convert a readily available material to hydrogen of sufficient purity to operate the fuel cells. If such a device can be engineered with efficiencies much higher than those of existing methods, hydrogen would play a viable economic role in future Air Force applications. These applications could include heat pumps; power generation; and fuel for cooking, vehicles, and aircraft.

Water electrolysis is a simple process where electrical energy is converted to chemical energy in the form of hydrogen. However, the very use of electrical energy is the major disadvantage of the water electrolysis. Electrical energy is relatively expensive, and efforts are underway to maximize the efficiency of the water electrolysis process so that hydrogen can be produced at levels competitive with the production of petroleum fuel.

C. SCOPE

This research effort investigated the performance of water electrolysis using anode depolarization and pulsed DC power. The research consisted of four major tasks: 1) develop a laboratory experiment; 2) examine the anode depolarization effects; 3) examine the pulsed DC power operation; and 4) examine the combined effects of pulsed DC and anode depolarization. Due to the lack of 6.1 funds, only the first task was completed while the second and third tasks were partially accomplished.

D. RESULTS

The experimental results show that significant improvement in the performance of the water electrolysis is feasible. Using sulfur dioxide as anode depolarizer dissolved in a 10 percent by weight sulfuric acid anolyte has the potential of improving the process performance up to three times that of the conventional water electrolysis. In the case of pulsed DC, the results are in conflict with those reported in the literature, and further work is needed to settle the issue of using pulsed DC in water electrolysis.

E. RECOMMENDATIONS

This research offers many potential payoffs that would benefit the Air Force and other branches of the United States Government. Given a clearer understanding of the electrolytic process behavior at ionic level, advances are possible in the areas of electrode material and design, depolarizers, and electrolytes. Therefore, a basic research program is recommended and a new design based on the state-of-the-art ultramicroelectrode technology, is proposed. The use of these three-dimensional electrodes will increase the contact time with the depolarizer material which translate to larger hydrogen production. The hydrogen yield density is expected to be 1 to 2 order of magnitude greater than the conventional two-dimensional electrodes. The overall goal of the proposed research is to explicitly account for the characteristics of the double-layer and the nature of the oxidation process at the anode in describing the electrolytic process behavior under varied loading conditions.

PREFACE

This report was prepared by the Air Force Civil Engineering Support Agency (AFCESA), Research, Development, and Acquisition Division, Air Base Operability and Repair (RACO) and Applied Research Associates (ARA). ARA efforts were performed under SETA Contract Number F08635-C-88-0067.

The author wishes to express his gratitude to Mr Edgar Alexander for his interest in this project and continuous encouragement and support during the course of this effort. The author wishes to thank Dr Larry C. Muszynski for his help during the course of this effort and Mr Daniel J. Weston for his contributions in setting up the experiment and the design of the electrical setup.

This report summarizes work done between June 1991 and November 1992. Mr Edgar Alexander was the AFCESA Project Officer.

This report has been reviewed by the Public Affairs Office and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Concluded)

SECTION I

INTRODUCTION

A. OBJECTIVES

The principal objective of this research is to examine the effects of pulsed DC power and anode depolarization on the performance of the water electrolysis process. The resulting data then to be used in the design of an efficient electrolytic machine that meets Air Force needs.

B. BACKGROUND

Hydrogen can play an important role in future energy systems because of the diversity of its applications, the variety of ways in which it can be stored, its environmental advantages, and the possibility of producing hydrogen using solar, nuclear, wind, hydropower, and other renewable energy sources. The environmental impact of hydrogen as a source of energy is very favorable. It burns cleanly and can be obtained from water with water vapor as its combustion product.

The present market for hydrogen is limited to food hydrogenation, ammonia, and metallurgical processes. In the future, when the so-called hydrogen economy starts to take place, energy will be a major hydrogen user market which will dwarf the present market. Hydrogen applications in energy areas range from consumption of hydrogen as a fuel (e.g. transportation fuel, home heating and cooking, etc.) to closed cycle applications as in the metal hydrides heat pump. Signs of the world moving to the hydrogen economy are evident. The Euro-Quebec Hydro-Hydrogen agreement [1] will produce 20 million cubic feet of pure electrolytic hydrogen per day for use as transportation fuel at Hamburg, Germany, and to fuel a hydrogen-powered version of the European-made Airbus aircraft.

Combined with other elements hydrogen can be found in abundance. For example, one mole of water consists of one mole of hydrogen combined with half a mole of oxygen. Several methods were devised to liberate hydrogen from hydrides. Water electrolysis is the commercially applied process to obtain hydrogen from water at 99.99 percent purity. Water electrolysis is a simple process where electrical energy is converted to chemical energy in the form of hydrogen. However, the very use of electrical energy is the major disadvantage of the water electrolysis. Electrical energy is relatively expensive and efforts are underway to maximize the efficiency of the water electrolysis process so that hydrogen can be produced at levels competitive with the production of petroleum fuel.

The U.S. Department of Defense interest in hydrogen applications is growing fast. The Army Research Office (ARO) obtained a 500-watt fuel cell design that weighs less than 10 pounds for individual soldier power. Currently, ARO is exploring the feasibility of using fuel cells for power generation on the battlefield. The requirement is a small, light, and inexpensive hydrogen supply device which could convert a readily available material to hydrogen of sufficient purity to operate the fuel cells. If such a device can be engineered with efficiencies much higher than those of existing methods, hydrogen would play a viable economic role in future Air Force applications. These applications could include heat pumps; power generation; and fuel for cooking, vehicles, and aircraft.

C. SCOPE

This effort experimentally studied the performance of water electrolysis for hydrogen generation under two concepts: (1) the depolarization of the anode using sulfur dioxide to reduce/eliminate the anodic losses; and (2) the use of pulsed DC electric power instead of the nonpulsed DC currently used.

The effort involved the development of a laboratory experiment which consisted of a series of tests using the Fm01-LC electrolytic cell, manufactured by ICI Chemicals & Polymers. The tests were divided into four series: (1) A nonpulsed DC power test set to determine the cell's baseline performance; (2) Anode depolarization under nonpulsed DC power test set to determine the cell baseline performance efficiency using sulfur dioxide as anode depolarizer; (3) A pulsed DC power test set to determine the cell performance as a function of the pulsed energy parameters; and (4) Anode depolarization under pulsed DC power test set. Due to cuts in 6.1 findings, only the first three were partially accomplished.

SECTION II

WATER ELECTROLYSIS PROCESS

A. WATER ELECTROLYSIS THERMODYNAMICS

In the conventional electrolysis of water, hydrogen is generated by electrolyzing an acidic or alkaline aqueous solution. The overall reaction takes place as follows :

$$H_2O + \textit{Electrical Energy} \rightarrow H_2 + \frac{1}{2} O_2 \tag{1}$$

where the electrical energy is converted to chemical energy as hydrogen. The reaction at the electrodes can be as follows:

a. *Cathode (Hydrogen Electrode)*

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^- \tag{2}$$

b. *Anode (Oxygen Electrode)*

$$2\ OH^- \rightarrow \frac{1}{2} O_2 + H_2O + 2e^- \tag{3}$$

In this process water is consumed and only two electrons are involved in the dissociation of one molecule of water. There are no side reactions in water electrolysis that could yield undesirable products, so the process is clean and requires no extra separation or purification of products.

The first law of thermodynamics for an open system states that :

$$Q - W_s = \Delta H \tag{4}$$

where Q is the heat added to the system, W_s is the useful work done by the system and ΔH is the change in system enthalpy. Since the work done is the electrical energy applied to the electrolyzer, W_s is given as :

$$W_S = -n F E \tag{5}$$

where:

n is the number of electrons transferred;
F is the Faraday constant; = *23,074 cal/volt.gm equiv;* and
E is the electric potential applied to the cell in volts.

manipulating Equations (4 and 5) gives

$$E = \frac{\Delta H - Q}{n\,F} \tag{6}$$

For isothermal reversible process (no losses), Q is given as

$$Q_{rev} = T\,\Delta S \tag{7}$$

where T is temperature and ΔS is the change in system entropy. Substituting Equation (7) into Equation (6) results in the definition of the cell reversible potential below which neither hydrogen nor oxygen can be generated.

$$E_{rev} = \frac{\Delta H - T\Delta S}{n\,F} \tag{8}$$

$(\Delta H\text{-}T\Delta S)$ is the change in the system Gibbs free energy ΔG. At standard conditions (25 °C and 1 atm) ΔH equals 68,320 cal/gmole and ΔG equals 56,690 cal/gmole. Therefore, the cell reversible potential equals to

$$E_{rev} = \frac{\Delta G}{n\,F} = \frac{56{,}690}{2\ (23{,}074)} = 1.23 \quad volts \tag{9}$$

Because of the inefficiencies in the electrolysis process, the potential required to drive an electrolysis cell at a practical hydrogen generation rate (i.e. current, I, which is proportionate to hydrogen generation) is higher than the cell reversible potential. In Equation (6), n *and* F are constants, and for the same conditions of pressure, temperature, and electrolyte concentration, ΔH is constant and Q will change as E changes. As the process becomes irreversible and inefficient, Q decreases and eventually becomes negative where electric energy is wasted as heat. At the point where no heat need to be added to the cell *($Q=0$)* and all energy needed is supplied by electrical energy, the corresponding cell potential is called the thermoneutral voltage. This potential is given by :

$$E_{thermo} = \frac{\Delta H}{n\,F} = 1.48 \quad volts \tag{10}$$

However, current cell design requires operating voltages higher than the thermoneutral voltage. At these operating voltages, part of the electrical energy is lost as heat which raises the cell temperature and requires cell cooling.

The operating potential of an electrolyzer is given by:

$$E = E_{rev} + Losses \tag{11}$$

where the electrolysis process losses are :

$$Losses = E_{anode} + E_{cathode} + E_{mt} + IR \tag{12}$$

where

E_{anode} is anode activation overpotential
$E_{cathode}$ is cathode activation overpotential
E_{mt} is mass transfer overpotential
IR is ohmic overpotential (I is current and R is cell resistance which include electrolyte, electrode, and terminals)

The efficiency of a conventional electrolysis cell is given by:

$$\eta = \frac{\Delta H}{\Delta G + losses} = \frac{E_{thermo}}{E} \tag{13}$$

Therefore, under ideal conditions (no losses or reversible process), the production of hydrogen will take place with an efficiency of 120 percent, and at thermoneutral conditions the cell efficiency is 100 percent.

Current electrolyzers are running at 75 percent efficiency. The exergy analysis of the water electrolysis process shows the majority of the losses are caused by the cell internal design and not external emission. To reach higher electrolysis efficiency, current research efforts are devoted to optimizing cell design to reduce internal losses.

B. DOUBLE-LAYER THEORY - ELECTRIFIED INTERFACE

In the interior laminas of an electrolyte, the net charge is zero. This is because the solvent dipoles are in random orientation and equal distribution of positive and negative charges exists. For the ion discharge to take place, the electrical charge on the electrode has to be matched by an opposite charge in the electrolyte across the electrode-electrolyte interface where a potential difference arises. Therefore, upon applying an electrical field, the electrical forces operating at the electrode-electrolyte interface give rise to another arrangement of solvent dipoles and charged species. A net orientation of solvent dipoles and a net or access charge on a lamina parallel to the electrode are established. The existence of two oppositely charged layers gave rise to the term *double-layer.* The term *double-layer* is used to describe the arrangement of charges and orientated dipoles constituting the interphase region at the boundary of the electrolyte. Figure 1 shows the electrified interface in the double-layer concept. The charge and discharge of the double-layer could play a role in improving the performance of water electrolysis.

C. IMPROVEMENT IN WATER ELECTROLYSIS

The thermodynamic analysis of water electrolysis indicates that the electrical energy required for a practical dissociation rate can be reduced if the number of electrons involved in the reaction (Equation 6) is maximized and the losses that increase the cell potential (Equation 11) are minimized. The activation overpotential is one of these losses and represents the energy required to overcome the surface potential barrier which retards the ionic discharge processes to the electrodes. The activation overpotential is largely at the anode [2] and represents most of the losses in the electrolyzer cell. In order to enhance the ionic discharge, and thus the hydrogen evolution rate, we must diminish the energy barrier at the anode. However, diminishing the anode overpotential by using catalysts [3] while keeping oxygen evolution is expensive and will not reduce the cell potential below the reversible potential of 1.23 volts.

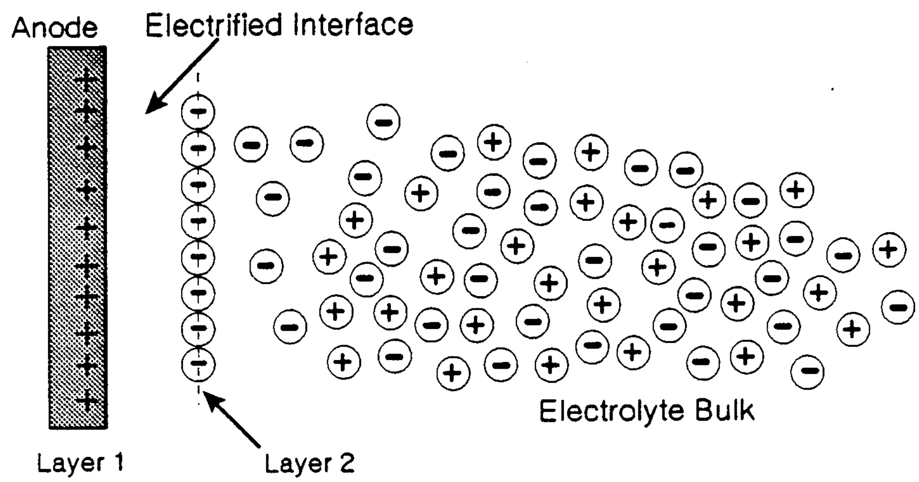

Figure 1 : Arrangement Of Charges And Orientated Dipoles In The Double-Layer Concept

If the oxygen evolution is replaced by another anodic reaction that takes place at lower potential than that of oxygen, then the cell potential (Equation 6) would be reduced. This process is called anode depolarization. Further, if the new anodic reaction involves more electrons, then the reversible potential, E_{rev}, and hence the cell potential, E, would be reduced dramatically.

Another likely approach to enhance ion discharge [4] would be a modification to the conventional electrolysis process and would involve assisting the electrochemical reaction by supplying either part or all of the energy required to overcome the surface potential barrier by using some energy form other than DC electric energy. In this area Brookhaven National Laboratory (BNL) [5] identified the utilization of heat and electricity in water vapor electrolysis, while Gutmann and Murphy [4] suggested the use of pulsed DC.

One major disadvantage in water electrolysis is the use of electricity as raw energy. If the electricity is produced by a thermal conversion of coal or oil, the Carnot limitation is applied, thereby limiting the process's overall efficiency. Renewable energy such as solar/photovoltaic, wind power, and hydroelectric power are attractive raw energy sources for water electrolysis. The use of solar energy in water electrolysis for hydrogen production has been studied in laboratory settings using a polycrystalline Si photovoltaic 100 W generator [6]. During the same period it has been demonstrated on a practical scale at an existing 350 kW photovoltaic site in Saudi Arabia [7]. This link between photovoltaic power and electrolysis eliminated the complex power conditioning interface required when AC electric energy is used and, in turn, eliminated the losses encountered in converting AC to DC.

1. Anode Depolarization

In the electrochemical decomposition of water, the overpotential in the splitting of water is largely at the anode. A lower anodic overpotential can be expected if some alternative anodic product other than oxygen can be produced. This can be achieved by introducing a depolarizer into the anolyte. The depolarizer must be sufficiently cheap while the anodic product must be nontoxic, easy to remove from anolyte, and marketable.

Work on anode depolarization for hydrogen production was reported as early as 1967 by Juda and Moulton [8]. In their search for cheap hydrogen to be used in the nitrogen fertilizer industry, they used sulfur dioxide (SO_2) as an anode depolarizer which had been used earlier as an anode depolarizer in the electrolysis of copper sulfate for electroplating. In their experiment, a 30 percent sulfuric acid was used as electrolyte and a 6 percent sulfurous acid was pumped through the porous carbon anode. They found that hydrogen could be produced cathodically while sulfur dioxide is oxidized anodically to sulfuric acid (H_2SO_4). The effect of SO_2 oxidation is reported to reduce the cell potential approximately 0.8 volts below that of nondepolarized cell. Conversely, the reaction would yield sulfur on the electrodes, so a cheap method would be needed to utilize the sulfur and recover it successfully [4]. Since the publication of Juda and Moulton's work [8], much work has been published on developments in the technology of sulfur dioxide depolarized electrolysis. For example, Lu et al [9] studied the effect of H_2SO_4 concentration on the operation of SO_2-depolarized electrolyzers. They reported that optimum acid concentration is about 30 percent by weight where the observed cell potential is 0.71 at 200 mA/cm^2. They observed that cell potential increased significantly with acid concentration.

Recent attempts to explore suitable depolarizer reactions have concentrated on the oxidation of fuel-like substances such as coal [11-16], methanol [17], and glucose [18]. All such reactions can be represented by the following general reaction:

$$F + x\,H_2O \rightarrow FO_x + 2x\,H^+ + 2x\,e^- \tag{14}$$

where F is the fuel-like molecule which becomes oxidized to FO_x with generation of hydrogen ions and electrons. The oxidation of the fuel-like molecule insures favorable thermodynamics in the form of a reversible potential more negative than oxygen evolution.

Renewable organic materials such as biomass (animal manures, sewage sludge, or food processing wastes) which contain too little caloric value to make them practical alternate sources of energy can be used as depolarizers. Dhooge and Henson [19] investigated the reaction rates and activation energies for the catalyzed electrolytic oxidation of wood chips, cattle manure, and municipal sewage sludge. They showed that the process is practical and can be used to produce hydrogen at potential of 1 volt with carbon dioxide and methane as anodic products.

Bockris, Dandapani, Cocke, and Ghoroghchian [10] reported that the use of lignite and anthracite as depolarizers has created a new field for coal slurry electrolysis. Using coal as anode depolarizer, Coughlin and Farooque [11-13] found the potential for CO_2 evolution about 1.0 volt. Current densities were very low around 0.01 to 0.02 mA/cm^2, not enough for commercial operations. Their work was carried out in coal slurries in sulfuric acid solution and the electrodes were platinum screens. They attributed the current obtained to the direct oxidation of coal particles at the anode surface. Okada et al [19] disputed some of Coughlin and Farooque's findings on the basis that acid washing of coal removed the reactive compounds. Dhooge and Park [20-22] indicated that much of the electrode depolarization reaction observed by Coughlin and Farooque was a result of the oxidation of ferrous ions that were leached out of the coal by the sulfuric acid. Further, production of hydrogen on large scale should avoid carbon compounds as depolarizers because their use injects an increasing amount of CO_2 into the atmosphere.

Other anode depolarizers suggested by Gutmann and Murphy [4] are NO, which can be obtained from stack gases, and sea water. In the case of sea water, the expected anodic product is chlorine. The industrial production of chlorine by brine electrolysis is a large industry and involves sophisticated technologies. Adaptation of these technologies could yield efficient electrolyzers for hydrogen production. One advantage of the anode depolarization process is that instead of oxygen evolution at the anode there will be some valuable by-products that can be sold and further reduce hydrogen production costs.

2. Pulsed DC Power

Using a mechanically interrupted DC power supply, Bockris et. al. [14,15] reported two phenomena in 1952. Immediately upon application of voltage to an electrochemical system, a high but short-lived current spike is observed. When the applied voltage is disconnected, significant current continues to flow for a short time. They explained the first phenomenon as a double-layer capacitance-charging transient, followed by the electrochemical discharge of the first ionic layer, giving rise to the current, then replenished by the ionic mass transport from the bulk of the electrolyte. The second phenomenon is due to ions in the double-layer facing the electrode being discharged in the absence of the externally applied field.

In 1984, Ghoroghchian and Bockris [23] designed a homopolar generator to drive an electrolyzer on pulsed DC voltage. They concluded that the rate of hydrogen production would be nearly twice as much as the rate for DC. Their conclusion was in agreement with the earlier works of Tseung and Vassie [24] and Jasem and Tseung [25]. In these earlier works [24,25] they attributed the increase in hydrogen and oxygen evolutions to an improvement in electrolyzer mass transfer. Ibl [26] also has shown that the application of short high-voltage pulses yields the highest possible electrolysis current. He concluded that pulsing affects the surface state of the electrodes. During conventional electrolysis, film of the gas bubbles forms on the electrode, raising its resistance overpotential. Pulsed voltage will eliminate the resistance overpotential of the gas bubbles. Viswanathan et. al. [29] showed that the thickness of the pulsating double-layer (they termed it as diffusion layer) is a function of the characteristics of pulsed DC. Further, pulsing action on electrochemical systems could give rise to the ionic vibration potentials. A more drastic effect is to be expected if pulsed power is applied at frequencies resonating with the dominant ionic discharge components. Thus, one of the methods for enhancing the ionic exchange is the pulsed electrolysis.

The use of pulsed DC for electrochemical reactions, especially in electroplating, is not new. In 1955 Robotron Corporation obtained a patent for "High Voltage Electroplating" using pulsed power [28]. In 1966 Popkov [29] further substantiated the advantage of using pulsed current. Avila and Brown [30] reviewed and confirmed the advantages of pulse plating on the quality of gold plating for integrated circuitry use, while Bockris and Kita [31] obtained a reduction in energy requirement by a factor of two. Pulsed electrolysis was also used in battery charging by Wagner and Williams [32] and Bedrossian and Cheh [33]. In pulsed DC related work, Savage and Thorntron [34] established that pulsed DC has advantages over continuous DC as reaction promoter in gas phase synthesis. They attributed the enhancement to the higher mean electron energies.

SECTION III

EXPERIMENTAL WORK

A. EXPERIMENT SETUP

To quantify the effects of pulsed energy and anode depolarization on the performance of the water electrolysis process, an experimental effort was initiated. The effort involved developing a laboratory experiment. The laboratory effort consisted of a series of tests using the Fm01-LC electrolytic cell, manufactured by ICI Chemicals & Polymers, and rated at 38 gram of H_2/KAmp.Hour.

The laboratory setup is shown in Figures 2, 3 and 4. It consists of an electrolyzer setup, electrolyte make-up water system, pH control, nonpulsed DC and pulsed DC power supply sources. The electrolyzer setup includes an electrolytic cell (Figure 3) model Fm01-LC, rated at 38 gram of H2/KAmp.Hour, and manufactured by ICI Chemicals & Polymers Company. The anolyte and catholyte compartments are separated by a Du Pont 324-Naflon® membrane. The anolyte and the catholyte are pumped through the corresponding compartment so that the anolyte and catholyte are separate except for ionic exchange through the membrane. The electrolyzer has a stainless steel cathode and a platinum-coated titanium anode which were placed 3 millimeters apart. Each electrode has a projected area of 64 square centimeters. Throughout the experiment a 10 percent by weight sulfuric acid solution was used as the electrolyte.

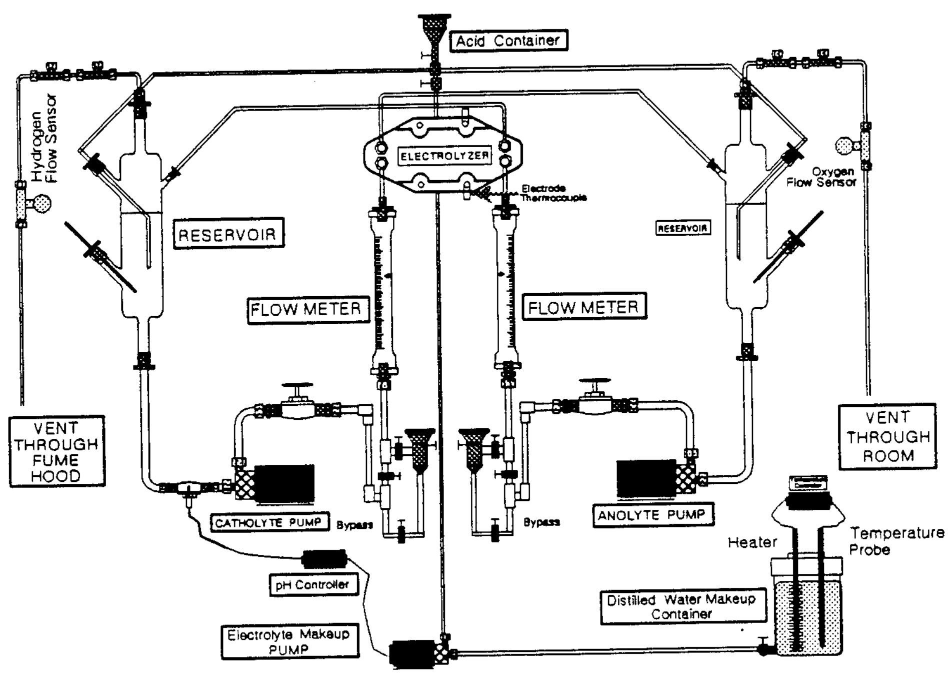

Figure 2 : Water Electrolysis Experiment Setup

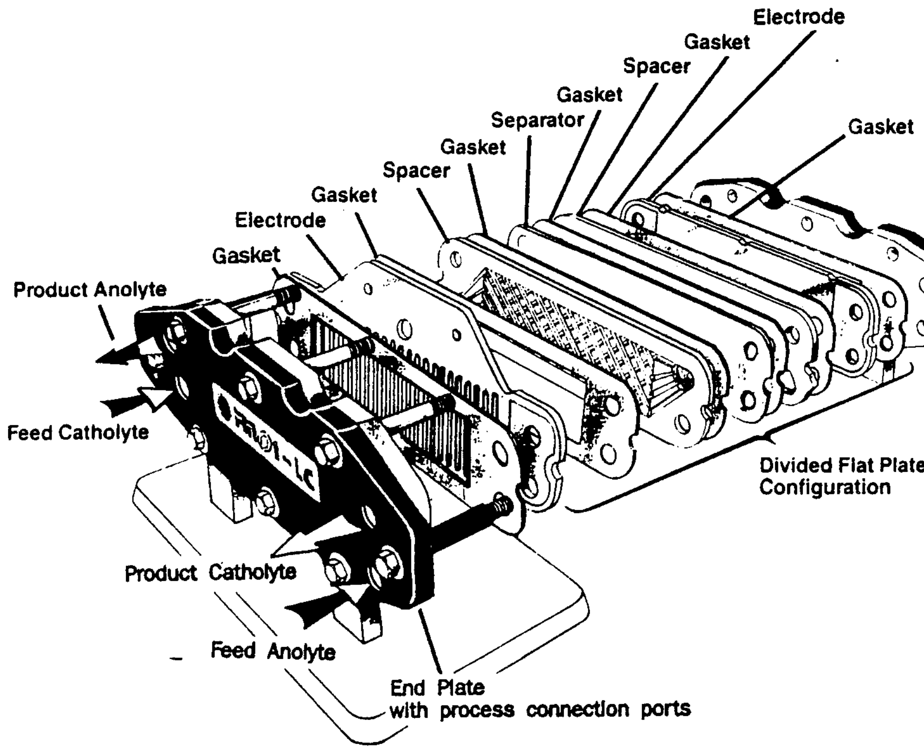

Figure 3 : Electrolyzer Exploded View

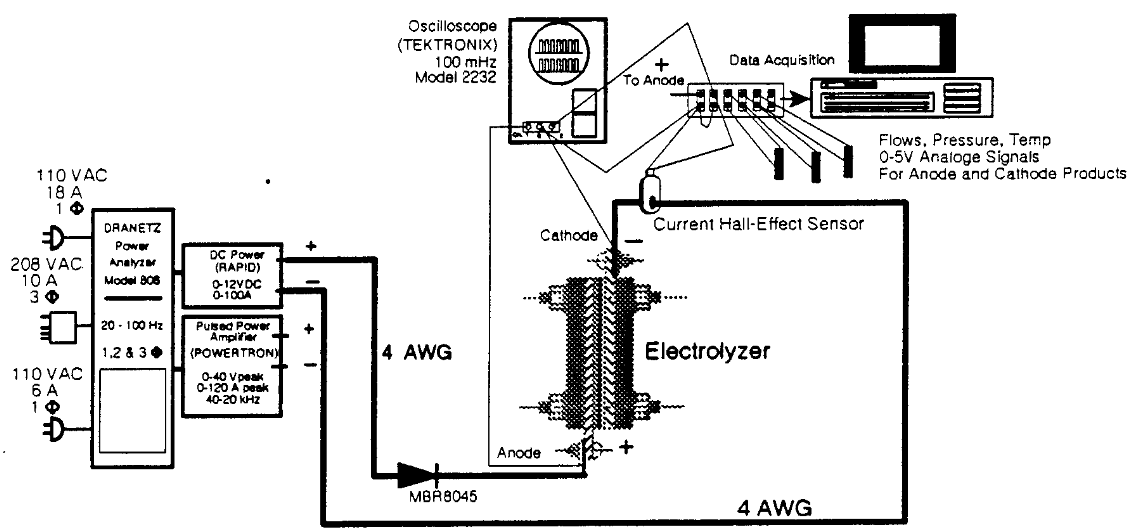

Figure 4 : Experiment Electrical and Instrument Diagram

The key electronic equipment (Figure 4) used in this experiment included the following: Industrial Equipment Co. power amplifier POWERTRAN model 2000 SHF-1-XA, (The POWERTRAN was modified to remove the output transformer to allow it to operate from DC to 70 kHz). The POWERTRAN 2000 SHF-1-XA is capable of 0 to ± 40 volts, 0 to ± 120 Amps with a maximum continuous power output of 2000 watts AND AN AMPLIFICATION FACTOR OF 25; a B&K Precision model 3011B function generator capable of generating square, triangle, and sine waves at frequencies up to 2 MHz with duty cycles ranges from 1 to 99 percent, with output amplitude up to 5 volts; a Rapid Power Technologies Inc., DC power supply, model TRSAA100012, with output 0 to +12 vDC, 0 to 100 Amps and continuous power available of 1000 watts. The electrolyzer was connected to the power supply by two one-foot long #4 AWG bare copper wires.

The pressure, temperature, and flow (in ccm) of the generated hydrogen and oxygen were measured using Ashcroft pressure sensors, a J-type thermocouple, and a Teledyne Hastings-Raydist flowmeters, model HFM-200, of 0 to 500 sccm range. The electric current was measured using a F.W.Bell hall-effect current sensor, model IHA-100, capable of measuring DC and pulsed current up to 50 kHz. Both current and voltage were displayed using a TEKTRONIX 2232 100 MHz oscilloscope then plotted using a TEKTRONIX HC-100 plotter. The plots were digitized using Summa Sketch II Professional digitizer. The current was measured in volts, 50 millivolts being equal to 1 amp. Voltage measurements were taken at the cell and at power supply output. This allowed the measurement of line losses.

B. LABORATORY TEST SERIES

Four sets of tests were planned. The four test series consisted of: (1) A nonpulsed DC power test set to determine the cell's baseline performance; (2) A pulsed DC power test set to determine the cell performance as a function of the pulsed energy parameters; (3) Anode depolarization under nonpulsed DC power test set to determine the cell baseline performance efficiency using sulfur dioxide as anode depolarizer; and (4) Anode depolarization under pulsed DC power test set. Due to cuts in 6.1 findings, only the first three were partially accomplished. The work accomplished is given in the following paragraphs.

1. Baseline Test, Nonpulsed DC Power.

This test series established the performance baseline for the laboratory setup. First, the deactivation of the cell was studied by recording the change in current at fixed voltage as a function of time. As shown in Figure 5, the cell reached steady-state conditions 5 minutes after potential was applied on the cell. Using this cell property throughout the experiment, data was collected at least 10 minutes after each test started. The cell's hydrogen yield as a function of cell potential and current was measured (Figures 6 and 7) to determine the cell's baseline performance. The cell's baseline performance was used for comparison with cell performance under pulsed DC and anode depolarization.

2. Pulsed DC Power.

For comparison purposes, the hydrogen yield was kept at 100 cubic centimeter per minute (ccm) for all pulsed DC runs. This selection was based on the baseline nonpulsed DC current density results. At 100 ccm of hydrogen (Figure 7), the measured current density was around 320 mA/cm^2 which is in the current densities range of 100-500 mA/cm^2 for economical hydrogen production. The test runs were carried out using square pulse for seven frequencies and four duty cycles. The duty cycle is the ratio of the pulse on-time to the pulse period. The seven frequencies are 10 Hz, 500 Hz, 1 kHz, 5 kHz, 10 kHz, 25 kHz, and 40 kHz. The duty cycles are 10 percent, 25 percent, 50 percent, and 80 percent. The test was divided into four test runs, one for each duty cycle. Each test run started by measuring the nonpulsed DC current and voltage for a 100 ccm of hydrogen yield. Then, a duty cycle was selected and the test run pulse frequency was changed. The cell potential was then changed to maintain the 100 ccm hydrogen yield. Data collection started after a period of fifteen minutes to allow for steady state condition.

The applied potential was measured at the power amplifier output terminals and at the cell electrodes. The voltage drop across the one-foot long #4 AWG bare copper wire was also recorded for some cases. The rate of electrical energy consumption (power) can be calculated using the relationship:

$$P = \frac{1}{T} \int_0^T i(t)\, e(t)\, dt \tag{15}$$

where T is the pulse period, $i(t)$ is the current wave form, and $e(t)$ is the voltage wave form.

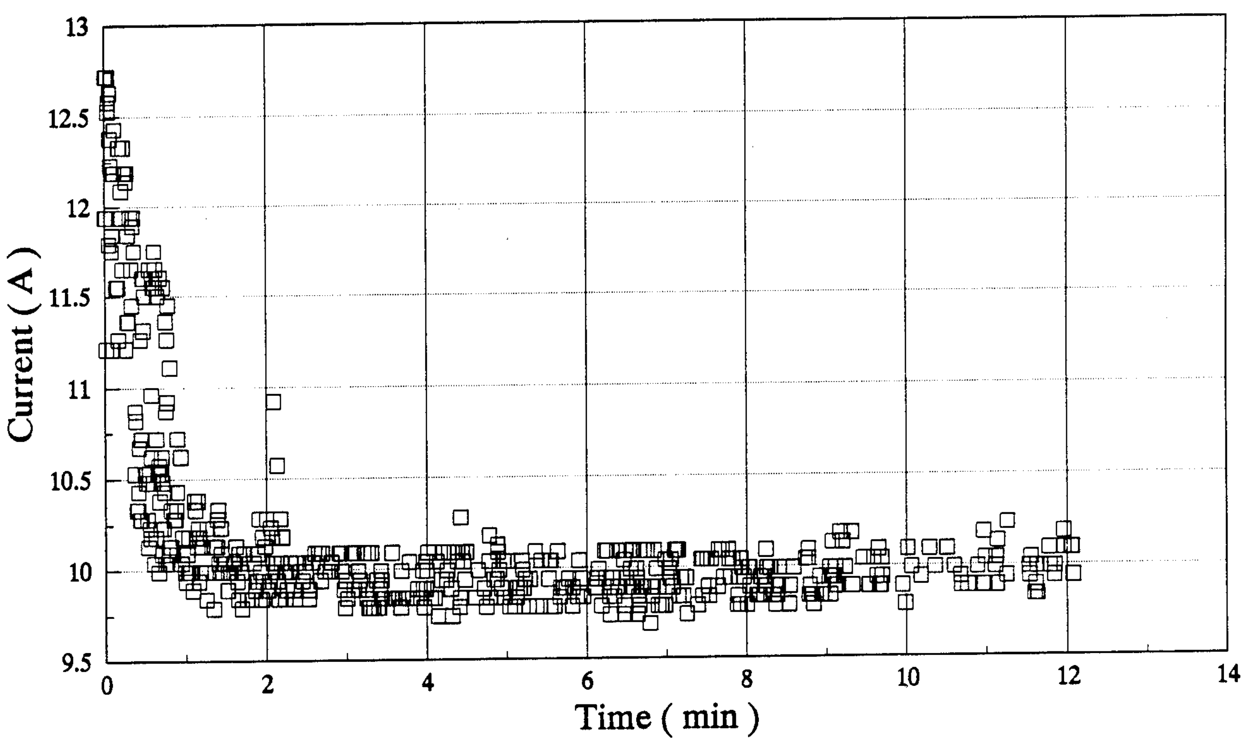

Figure 5 : Current Decay Characteristics of The ICI Electrolyzer with 10 Percent by Weight Sulfuric Acid Operating at 2.8 volts.

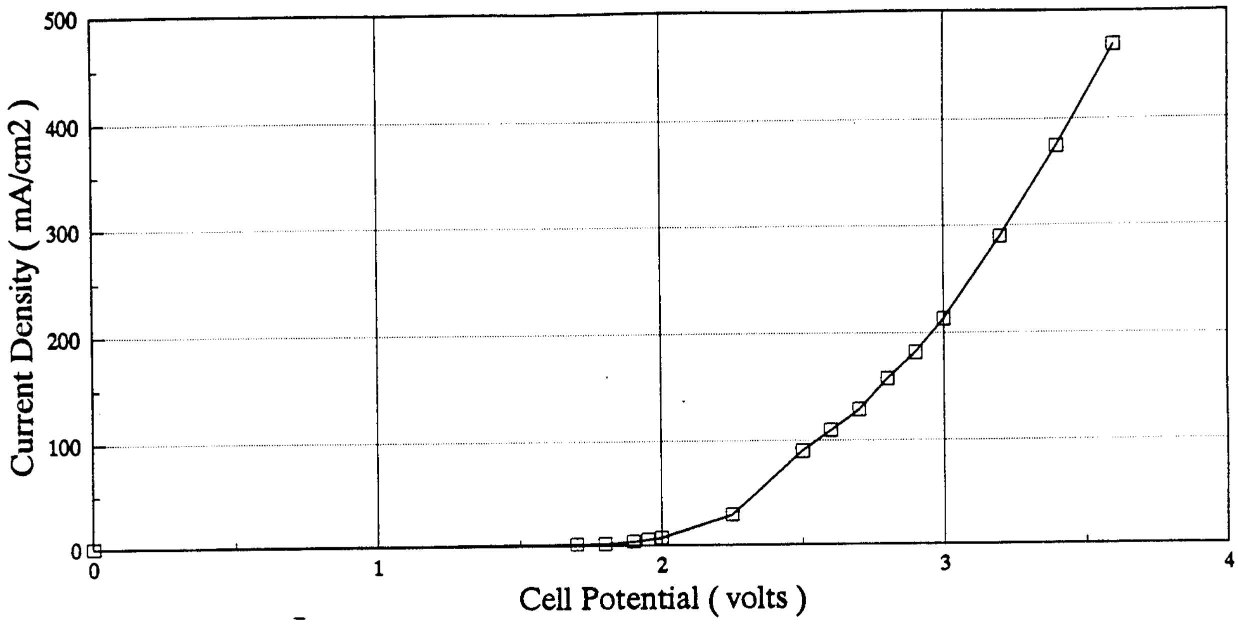

Figure 6 : Performance Characteristics of the ICI Electrolyzer Using 10 Percent by Weight Sulfuric Acid

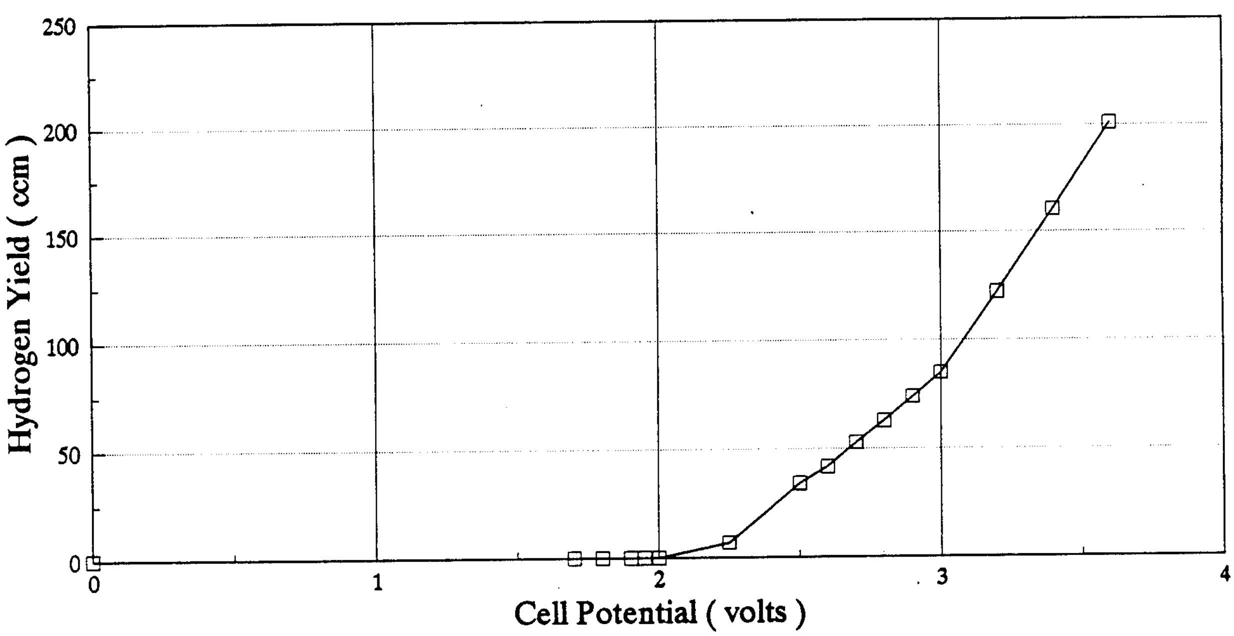

Figure 7 : Hydrogen Yield vs. Cell Potential for 10 Percent by Weight Sulfuric Acid.

3. *Baseline Anode Depolarization*

In this test series, sulfur dioxide was used to depolarize the cell anode. Used in its gaseous state, it was bubbled through the anolyte prior to and during the cell's nonpulsed DC operation. The test started by setting the DC power supply output to zero. Then, the potential was incremented by 0.05 of a volt until a 5 ccm of hydrogen yield was recorded. The applied potential was then incremented by 0.2 of a volt thereafter. For each voltage increment, the cell potential, current, and hydrogen flow were measured after steady state was reached.

SECTION IV

RESULTS AND DISCUSSION

A. PULSED DC POWER

During the preliminary test runs, conducted to examine the experiment setup, the current reversed polarity during the off-period of the pulse (Figure 8). The polarity reversal is attributed to a reversible reaction in the electrolyzer cell during the off-period. The effect of the current polarity reversal was seen in the catholyte when its color changed to a light blue. To examine and quantify the various metals in the catholyte, the atomic absorption spectrometry was used. The observations were made with a Perkin-Elmer 6500 flame atomic absorption spectrometer, using a laminar flame burner and equipped with hollow-cathode emission lamps for the different metals sought. Metals sought were based on the stainless steel alloy content of the cathode. The catholyte was found to give no absorbance signal for Molybdenum and Titanium, and only a weak absorbance for copper. Low absorbencies were obtained for Chromium and Zinc, but a large signal was given for Nickel and Iron. These analyses showed that the cathode had lost some of its content to the catholyte. This was confirmed by weighing the cathode which showed 2 grams loss. To separate the power amplifier from the cell during the off-time, a Motorola schottky diode, model MBR8045, was installed. The diode's maximum ratings are 45 volts and 80 Amps. Use of the diode stopped the current polarity reversal, but allowed the cell to maintain about a 2.3 volts instead of zero volt during the off-period.

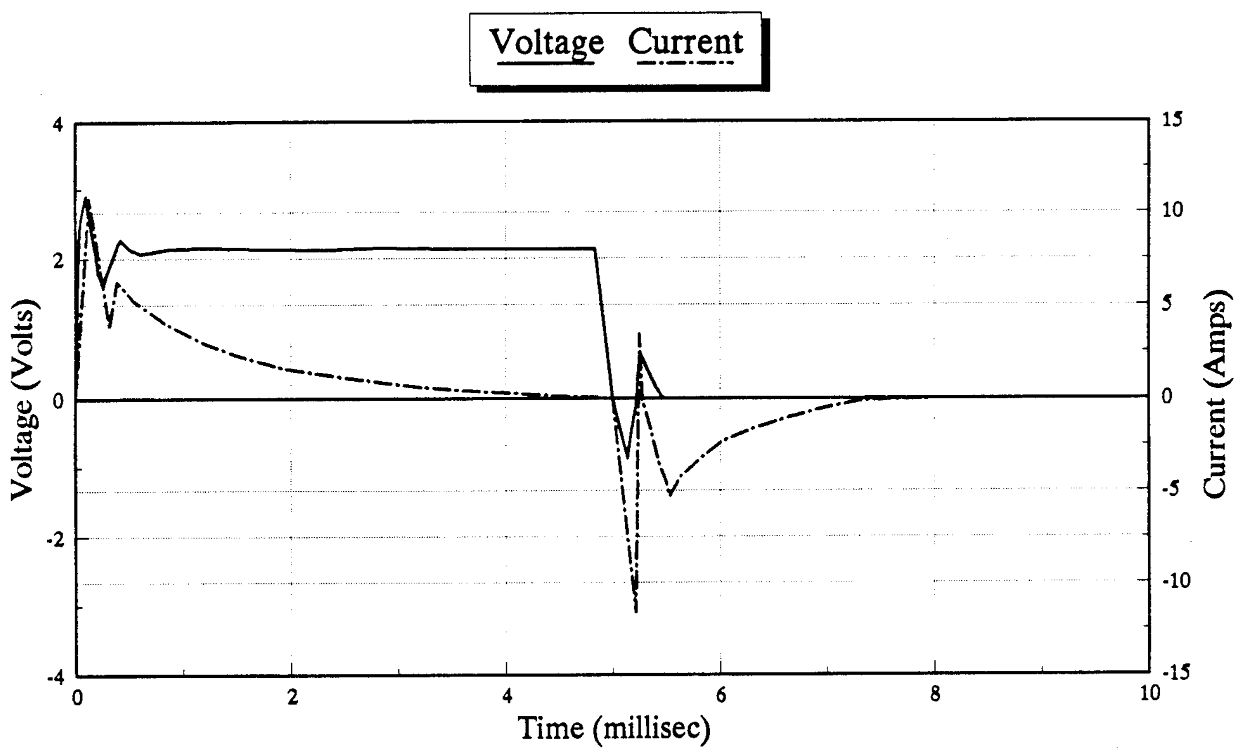

Figure 8 : Applied Current Polarity Reversal.

The digitized waveforms of the current, power amplifier output voltage (source V), and the cell voltage (cell V) are given in Figures 9-31. The digitized data is given in Appendix A. These figures represent the experiment setup responses in generating the 100 ccm of hydrogen and cover the test matrix. A careful examination of these figures reveals the current is lagging behind the voltage, an indication of an inductive circuit. However, the delay in the current is also due to the cell voltage. With the diode installed, the cell has maintained a DC level of about 2.3 volts. Until the power supply voltage overcame the cell potential and the losses in the circuit, no current flowed. As shown in Figure 24 (50 percent duty cycle and 25 kHz), the applied potential is higher than the electrolyzer's potential by about 25 to 40 percent, and the voltage rise and fall times are less than 4 micro-seconds with a high current rate of change which is attributed to the low impedance of the circuit. The high voltage drop is due to the large reactive losses mainly produced by the inductive reactance caused by the high current rate of change. This can be seen by examining the voltage drop of the negative lead connecting the cell to the power amplifier and the current waveforms (Figure 24). The relation between the lead voltage drop and the current is given as:

$$v_l = - L \frac{di}{dt} \qquad (16)$$

where L is the wire inductance. For a one-foot long #4 AWG copper wire, the inductance is in the range of micro farads; however, the time rate of change of the current is about 2 million amps per second causing, the high voltage drop.

Figures 9-31 also reveal the interesting shape of the source voltage waveform. Although the function generator produced a clean voltage square wave, the resulting source voltage waveform was far from being a clean one. For example, in Figure 24 the source voltage waveform has a step and a ringing at its trailing side instead of turning off at the 20th microsecond from pulse initiation. The shape of the source voltage waveform during the off-time period of the pulse is the result of the induced voltage in the #4 AWG wires and the cell maintained voltage of 2.3 volts. The induced voltage in the #4 AWG wires connecting the cell to the power amplifier is induced by the discharge of current generated by the collapse of magnetic flux around these wires.

Using Equation (15), the electrical power delivered to the setup circuit and electrolyzer were calculated. For the setup circuit, the source voltage and current waveforms were used, while for the electrolyzer the cell potential and current were used to calculate the power consumption. The results are summarized in Figure 32 for the setup circuit and in Figure 33 for the electrolyzer. From Figures 32, 33 and 34 the nonpulsed DC (100 percent duty cycle) requires the least electrical power. The effects of pulse frequency and duty cycle on the electrical power needed are noticeable. The demand for electrical power increases with the decrease of duty cycle and pulse frequency. At 10 percent duty cycle the electrolyzer power demand for 10 Hz is slightly more than twice that of nonpulsed DC, while for 25 kHz it is only 27 percent higher. It is clear that during this effort one of the two phenomena reported by Bockris et al [14,15] was not seen, namely, the high but short-lived current spike. Furthermore, the conclusion that nonpulsed DC requires the least electrical power conflicts with those of Ghoroghchian and Bockris [23] and Tseung and Vassie [24]. The difference between these results should be investigated in details so that the use of pulsed DC issue can be settled.

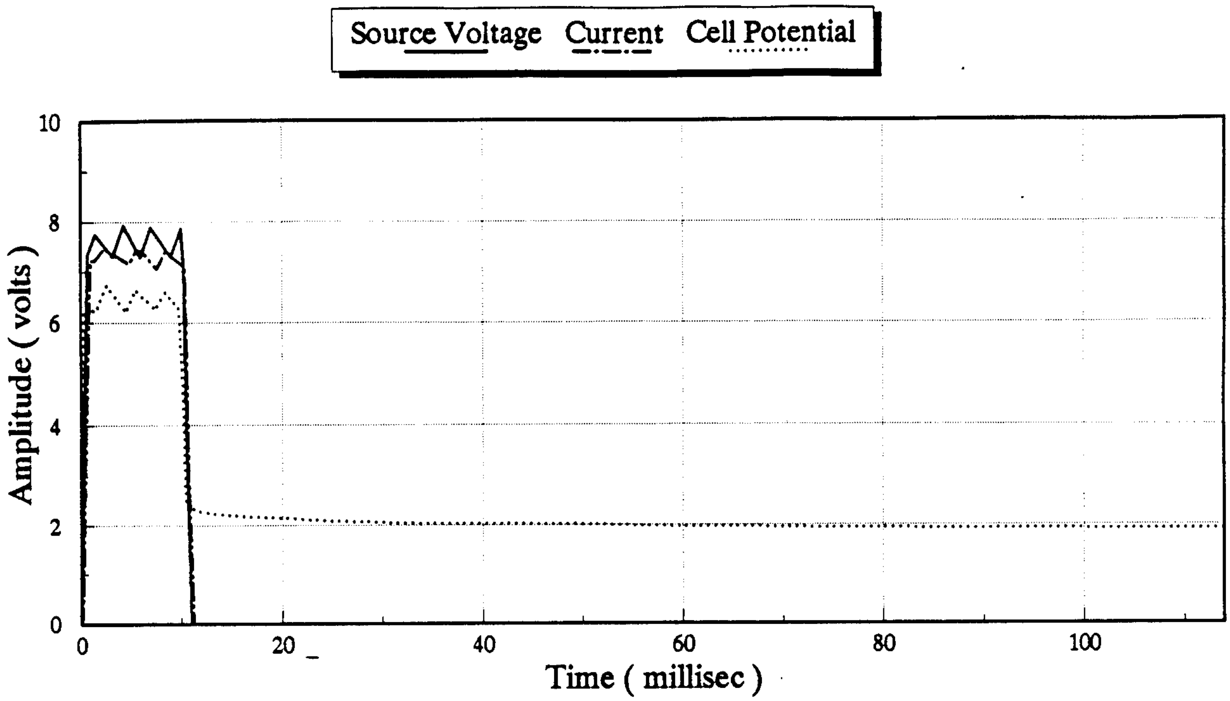

Figure 9 : Experiment Setup Response For 10 Percent Duty Cycle and 10 Hz Pulse at 100 ccm Hydrogen Yield.

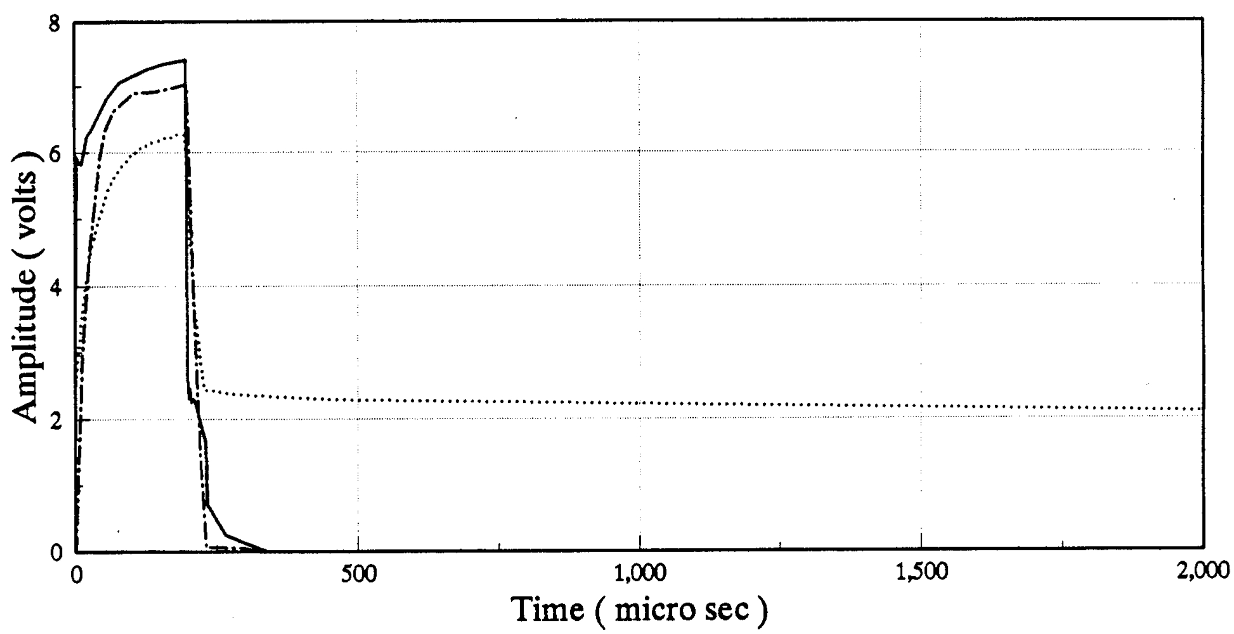

Figure 10 : Experiment Setup Response For 10 Percent Duty Cycle and 500 Hz Pulse at 100 ccm Hydrogen Yield.

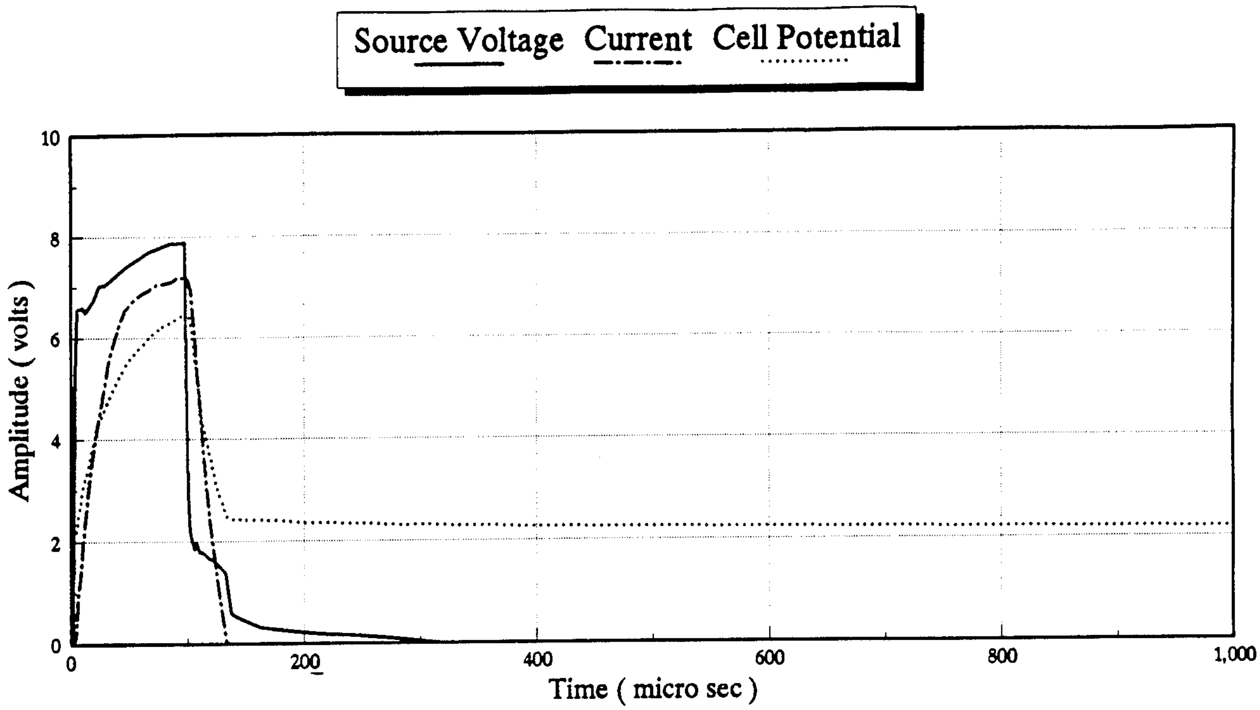

Figure 11 : Experiment Setup Response For 10 Percent Duty Cycle and 1 kHz Pulse at 100 ccm Hydrogen Yield.

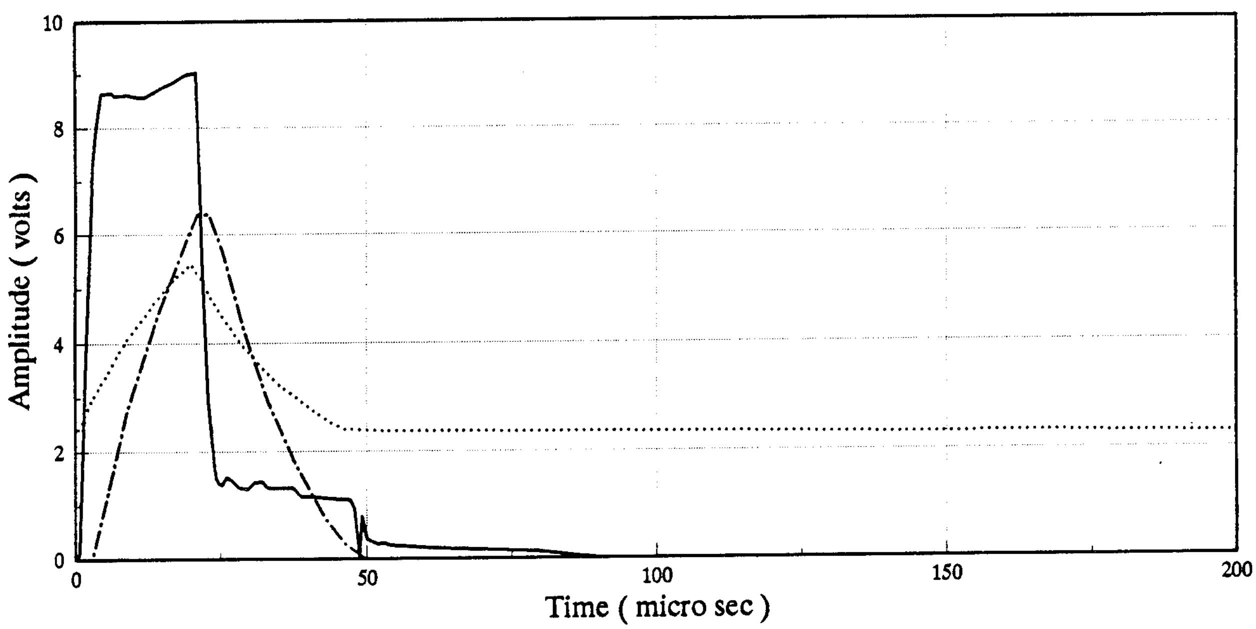

Figure 12 : Experiment Setup Response For 10 Percent Duty Cycle and 5 kHz Pulse at 100 ccm Hydrogen Yield.

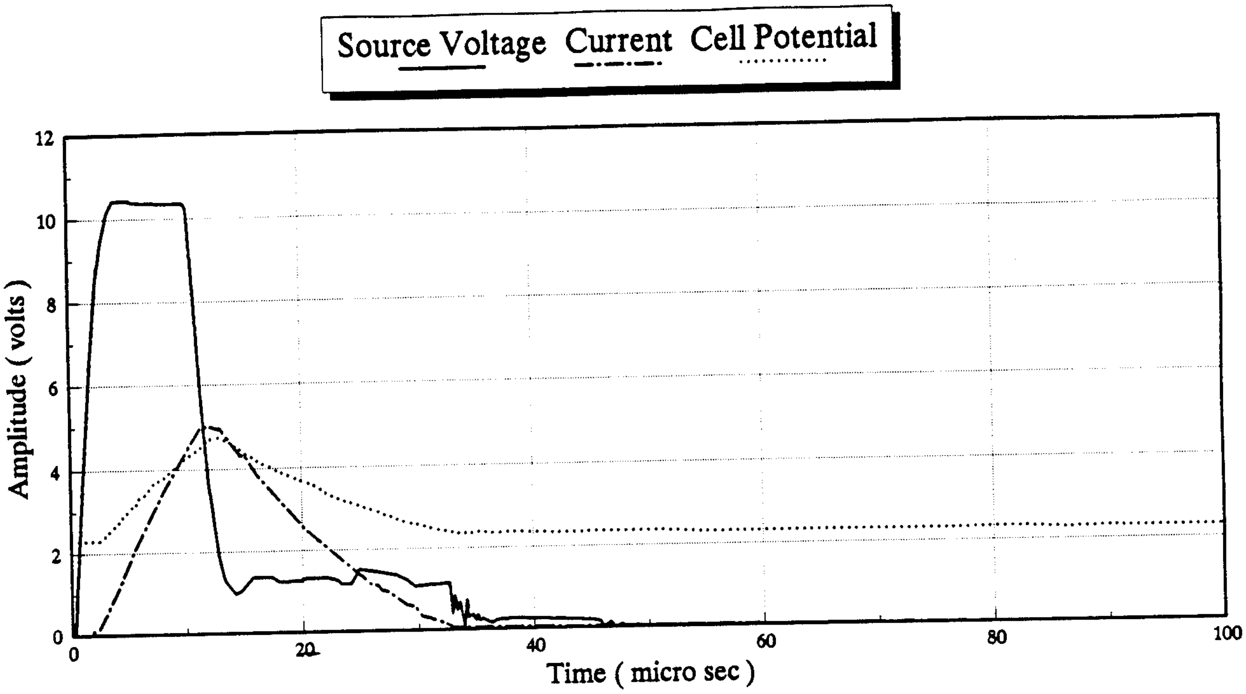

Figure 13 : Experiment Setup Response For 10 Percent Duty Cycle and 10 kHz Pulse at 100 ccm Hydrogen Yield.

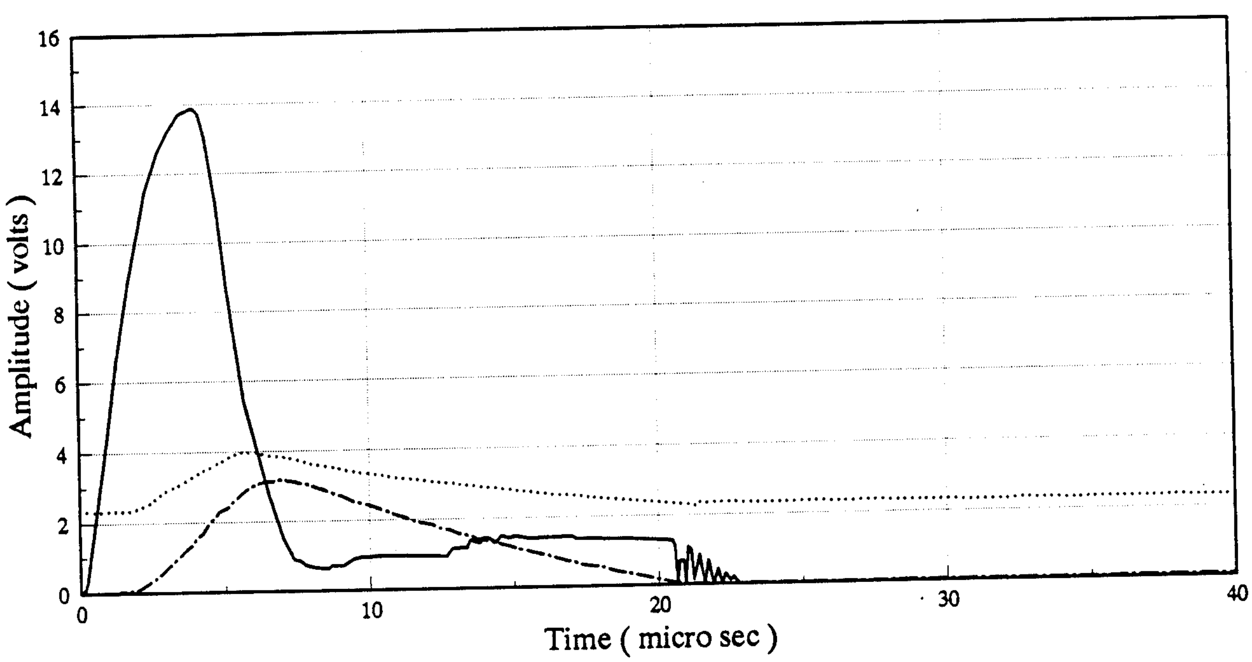

Figure 14 : Experiment Setup Response For 10 Percent Duty Cycle and 25 kHz Pulse at 100 ccm Hydrogen Yield.

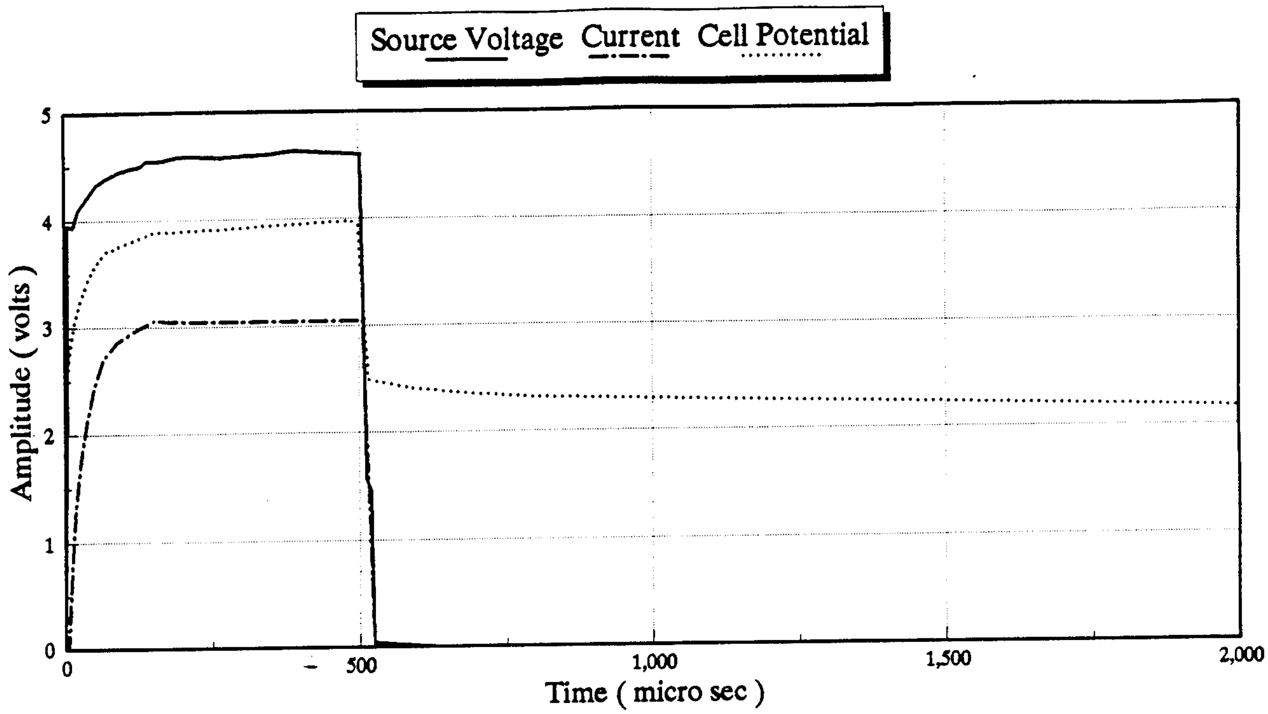

Figure 15 : Experiment Setup Response For 25 Percent Duty Cycle and 500 Hz Pulse at 100 ccm Hydrogen Yield.

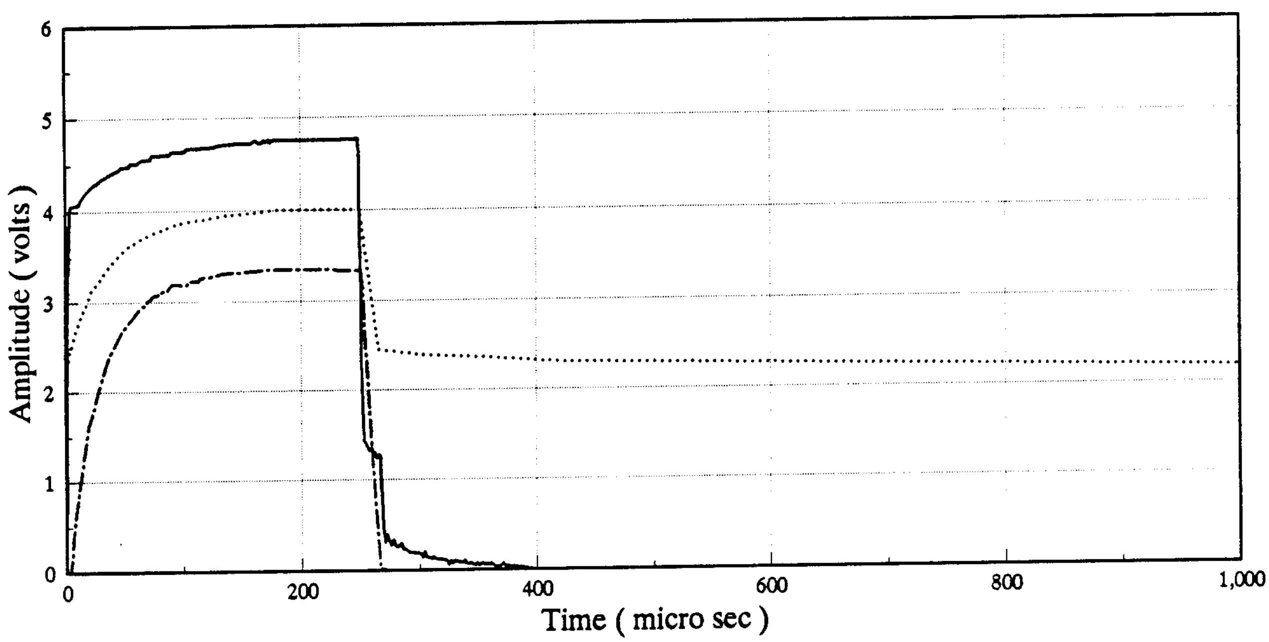

Figure 16 : Experiment Setup Response For 25 Percent Duty Cycle and 1 kHz Pulse at 100 ccm Hydrogen Yield.

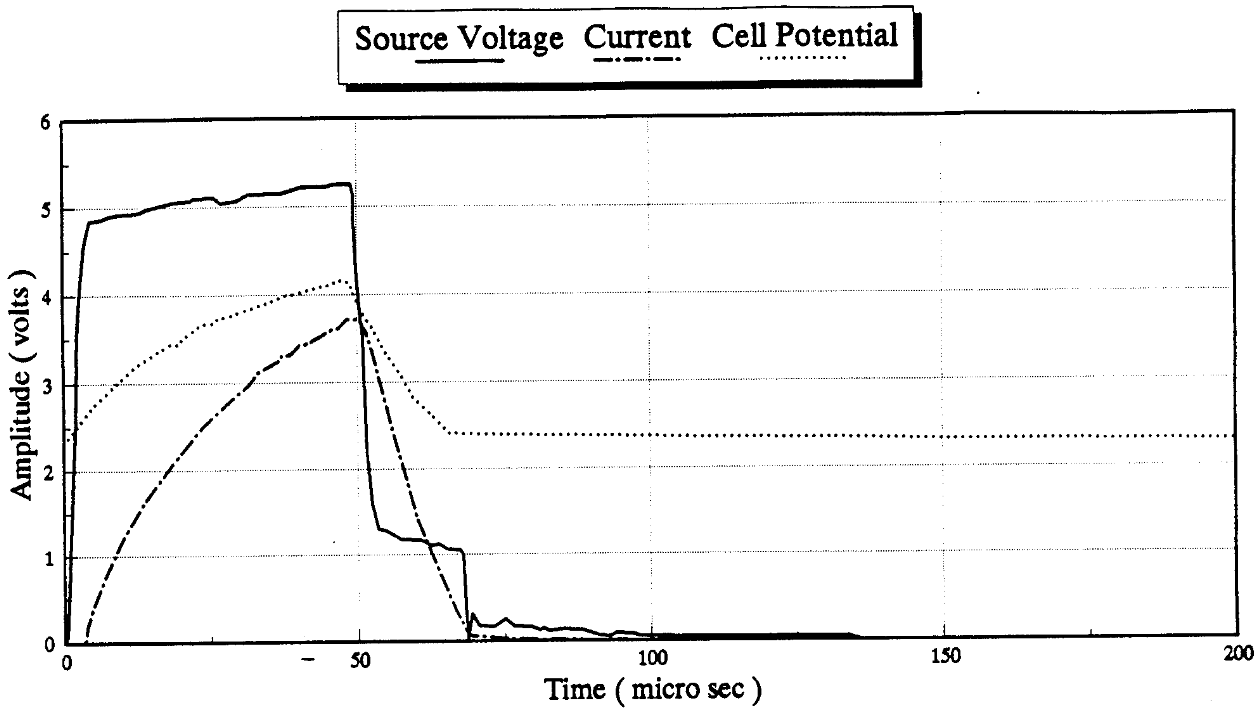

Figure 17 : Experiment Setup Response For 25 Percent Duty Cycle and 5 kHz Pulse at 100 ccm Hydrogen Yield.

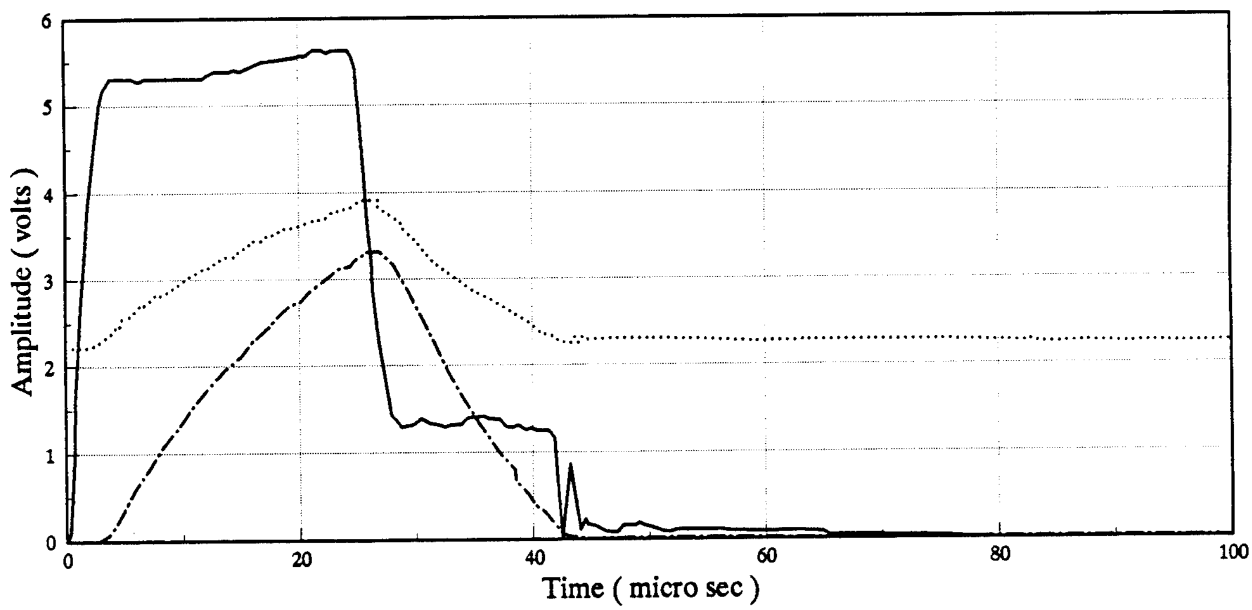

Figure 18 : Experiment Setup Response For 25 Percent Duty Cycle and 10 kHz Pulse at 100 ccm Hydrogen Yield.

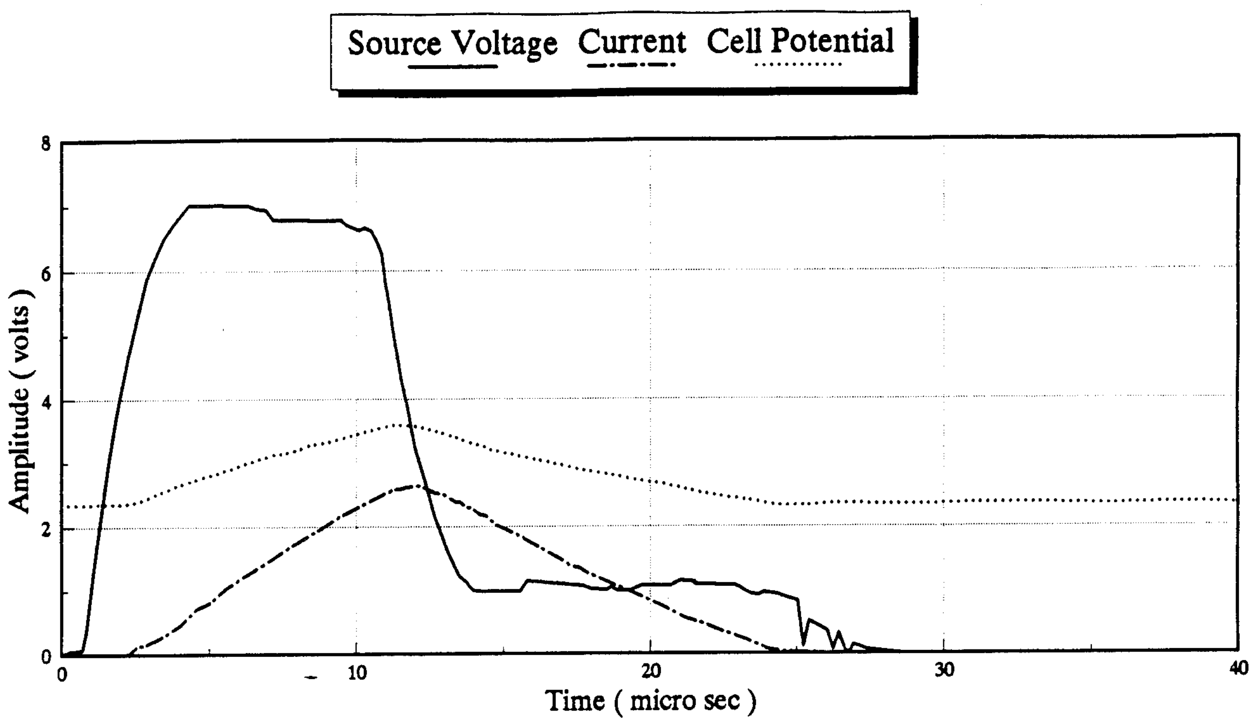

Figure 19 : Experiment Setup Response For 25 Percent Duty Cycle and 25 kHz Pulse at 100 ccm Hydrogen Yield.

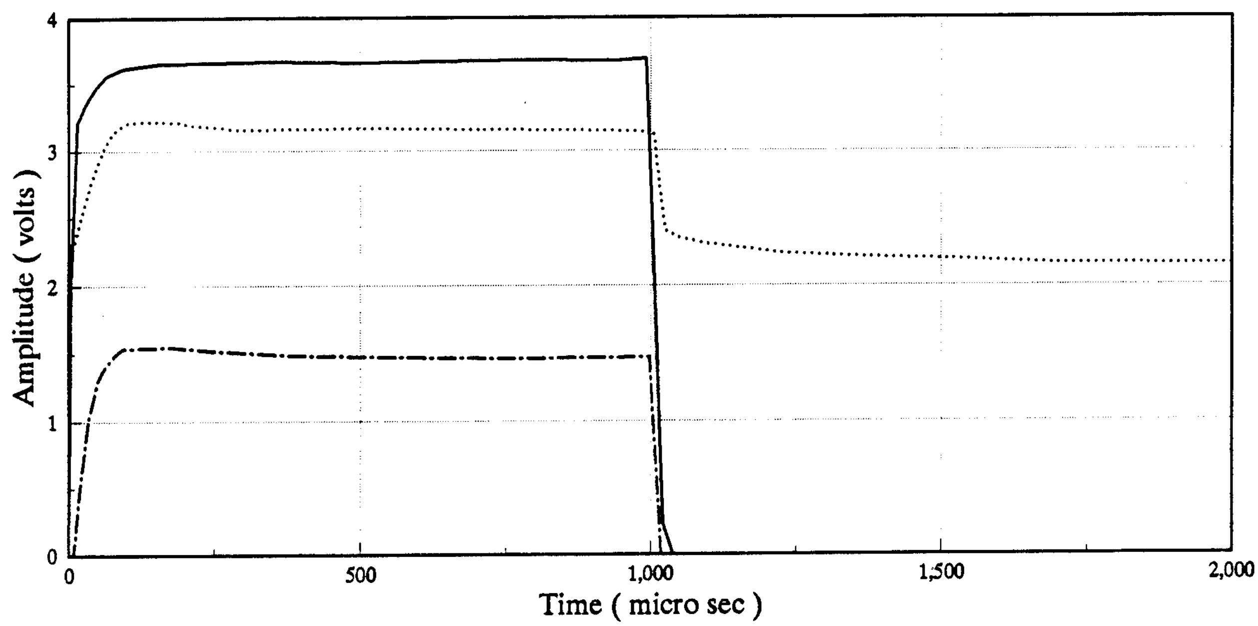

Figure 20 : Experiment Setup Response For 50 Percent Duty Cycle and 500 Hz Pulse at 100 ccm Hydrogen Yield.

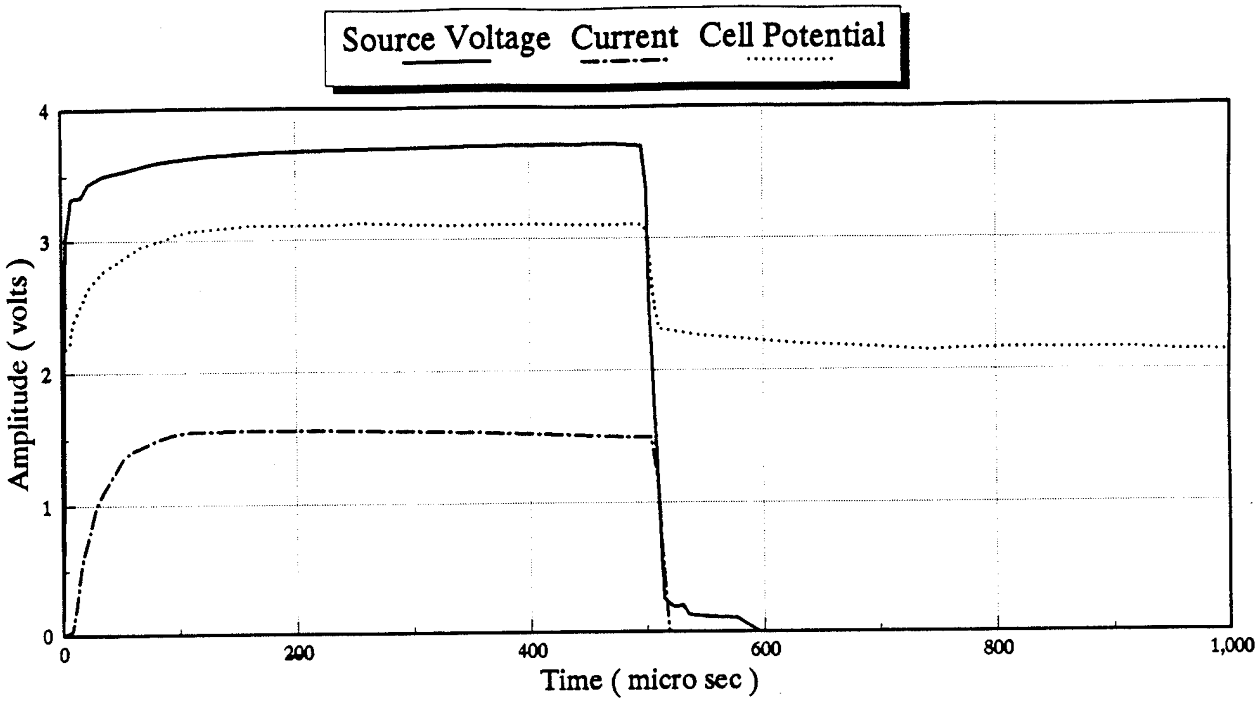

Figure 21 : Experiment Setup Response For 50 Percent Duty Cycle and 1 kHz Pulse at 100 ccm Hydrogen Yield.

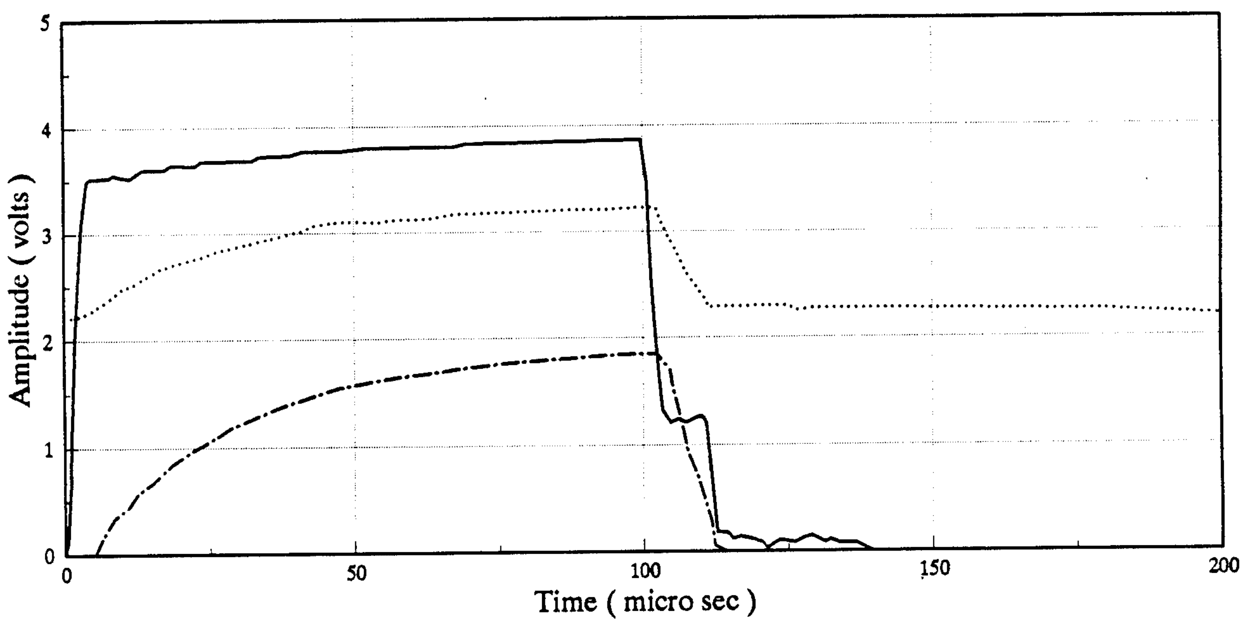

Figure 22 : Experiment Setup Response For 50 Percent Duty Cycle and 5 kHz Pulse at 100 ccm Hydrogen Yield.

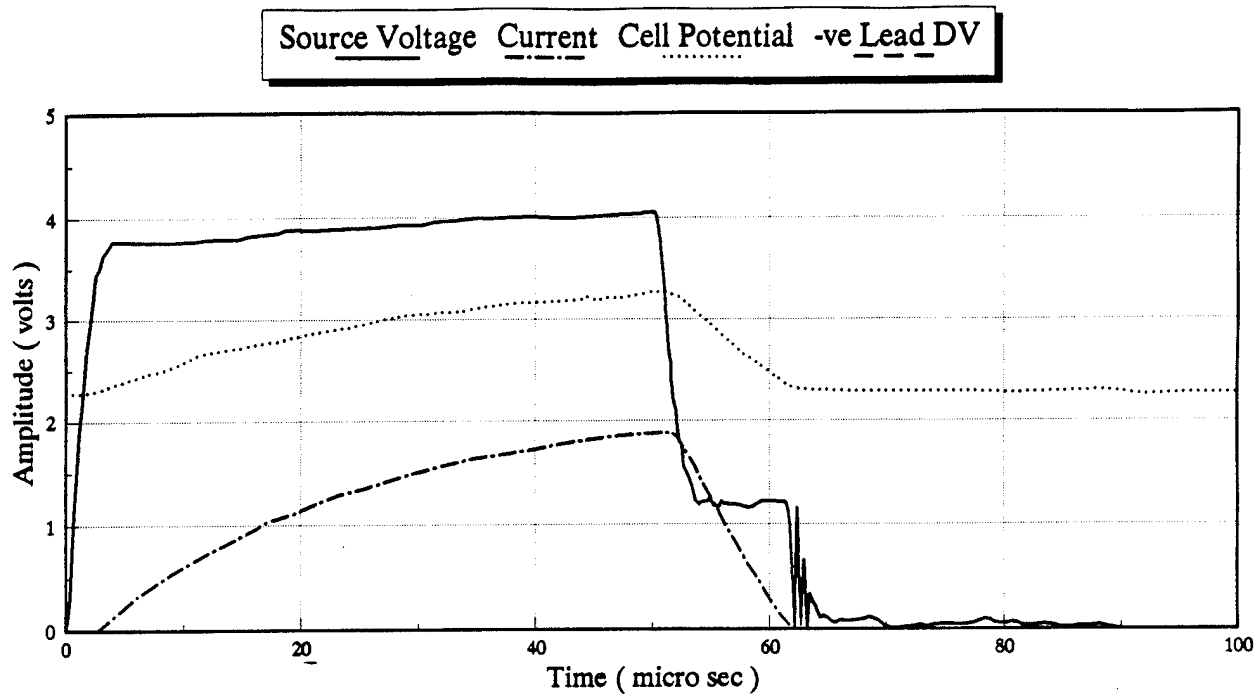

Figure 23 : Experiment Setup Response For 50 Percent Duty Cycle and 10 kHz Pulse at 100 ccm Hydrogen Yield.

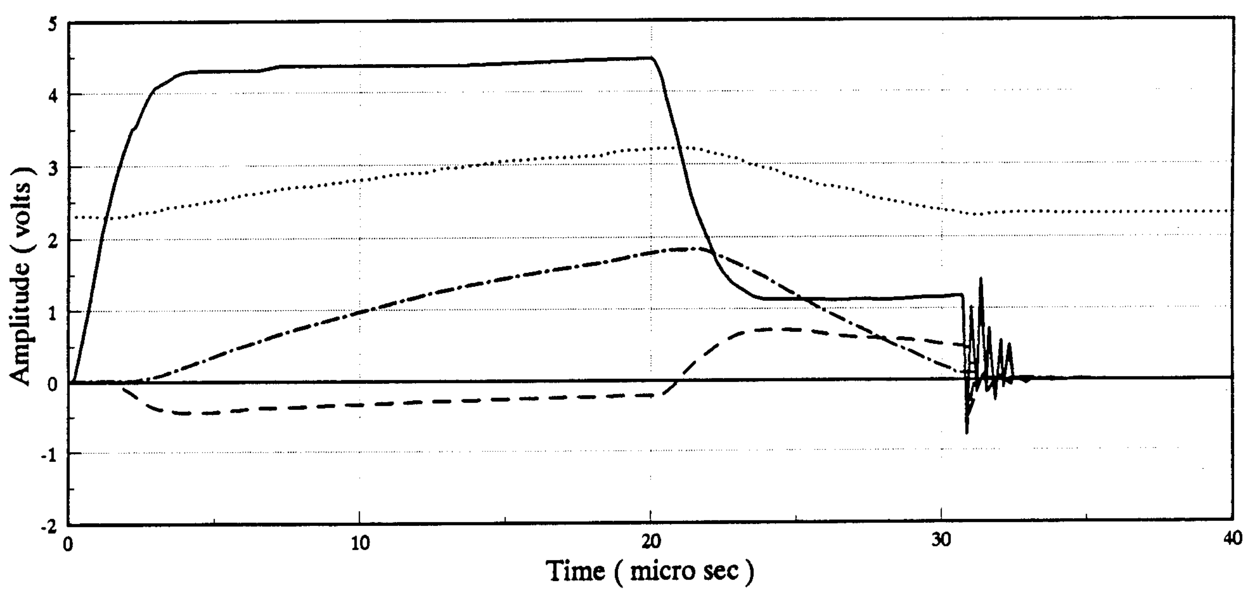

Figure 24 : Experiment Setup Response For 50 Percent Duty Cycle and 25 kHz Pulse at 100 ccm Hydrogen Yield.

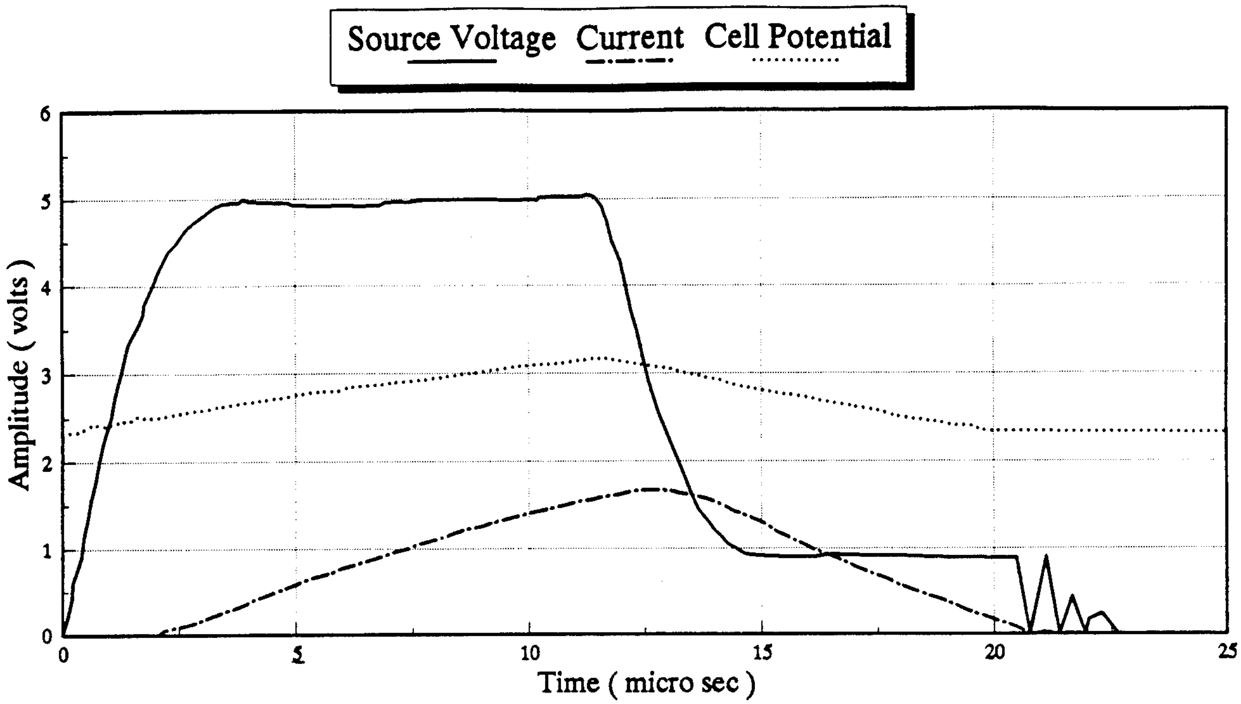

Figure 25 : Experiment Setup Response For 50 Percent Duty Cycle and 40 kHz Pulse at 100 ccm Hydrogen Yield.

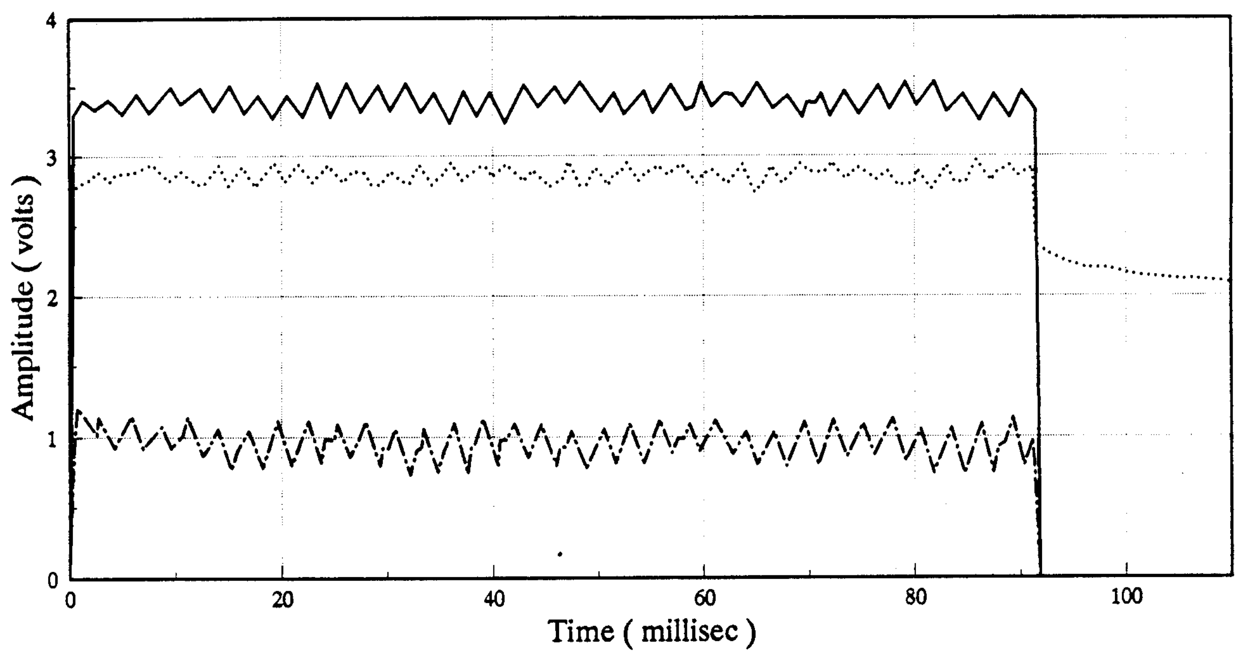

Figure 26 : Experiment Setup Response For 80 Percent Duty Cycle and 10 Hz Pulse at 100 ccm Hydrogen Yield.

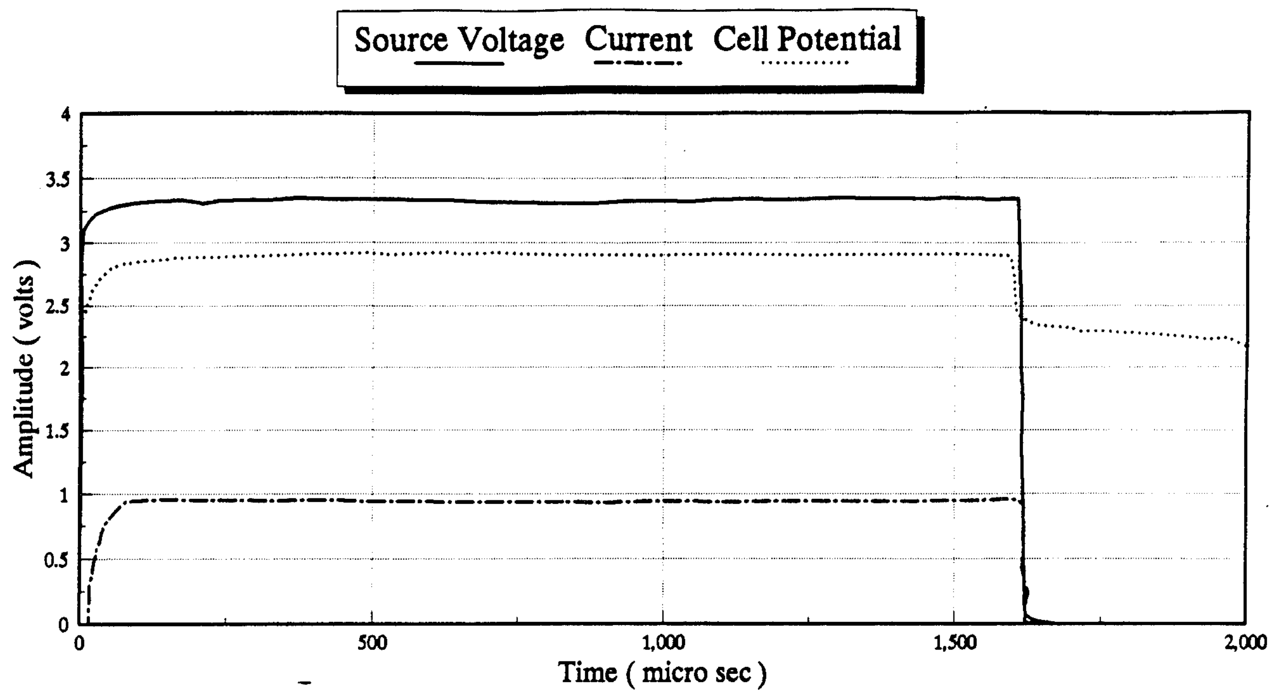

Figure 27 : Experiment Setup Response For 80 Percent Duty Cycle and 500 Hz Pulse at 100 ccm Hydrogen Yield.

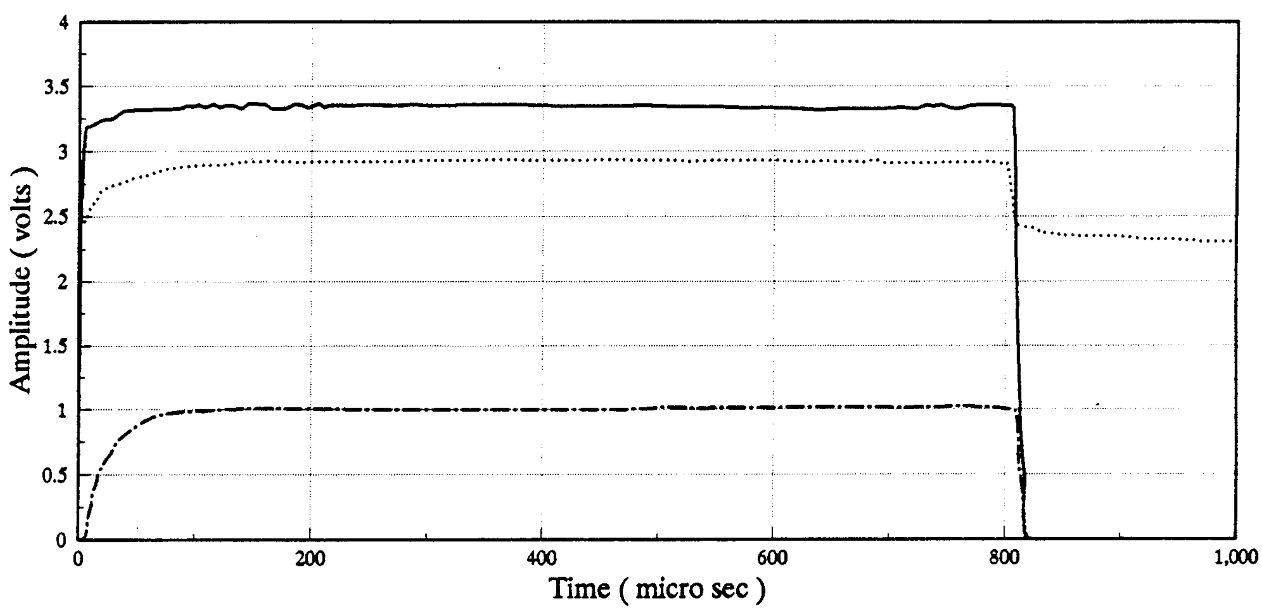

Figure 28 : Experiment Setup Response For 80 Percent Duty Cycle and 1 kHz Pulse at 100 ccm Hydrogen Yield.

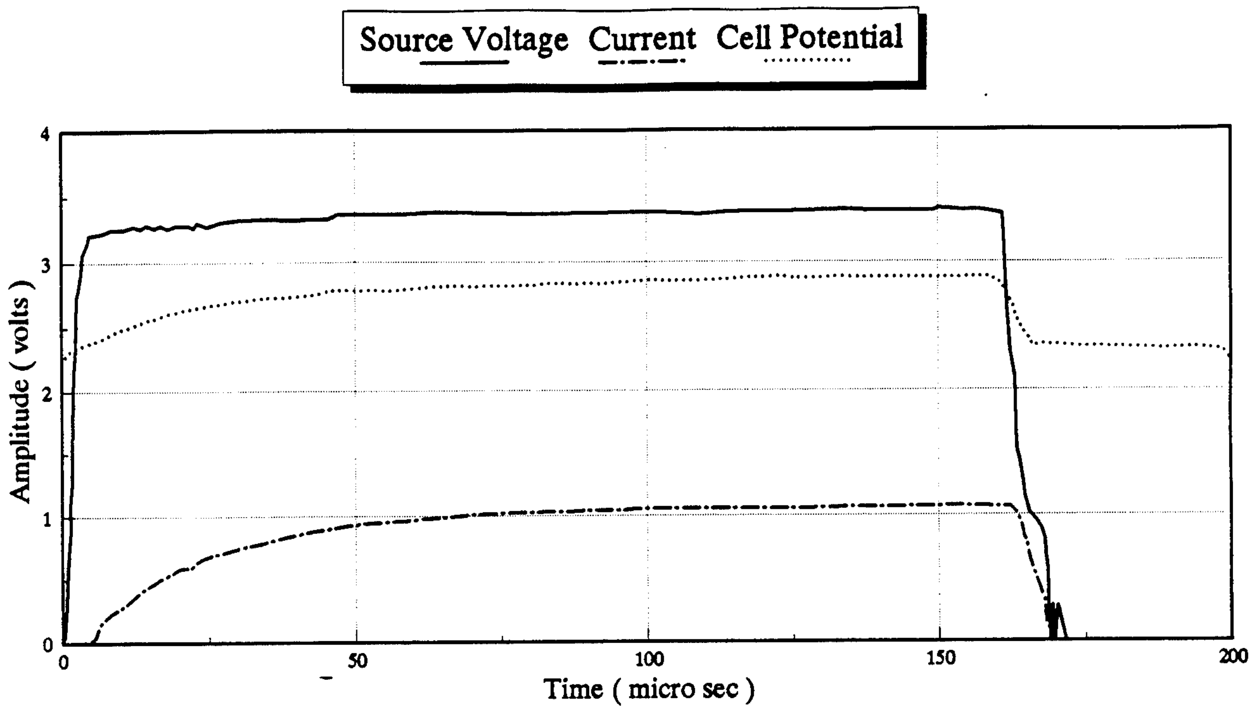

Figure 29 : Experiment Setup Response For 80 Percent Duty Cycle and 5 kHz Pulse at 100 ccm Hydrogen Yield.

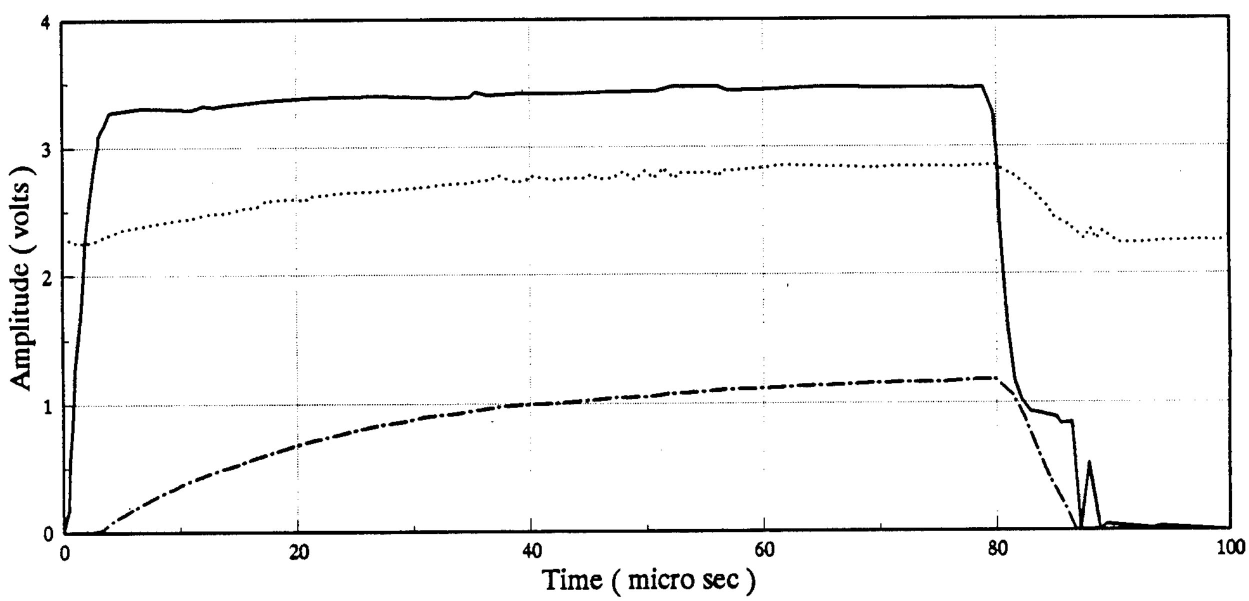

Figure 30 : Experiment Setup Response For 80 Percent Duty Cycle and 10 kHz Pulse at 100 ccm Hydrogen Yield.

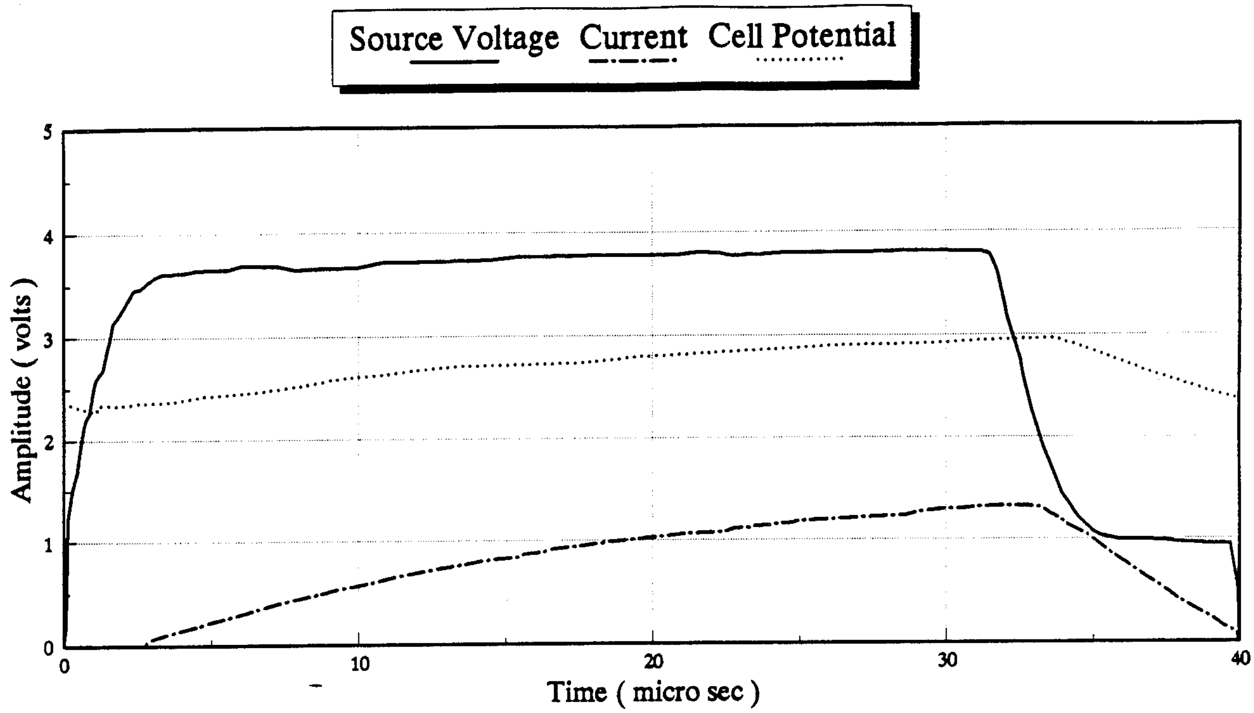

Figure 31 : Experiment Setup Response For 80 Percent Duty Cycle and 25 kHz Pulse at 100 ccm Hydrogen Yield.

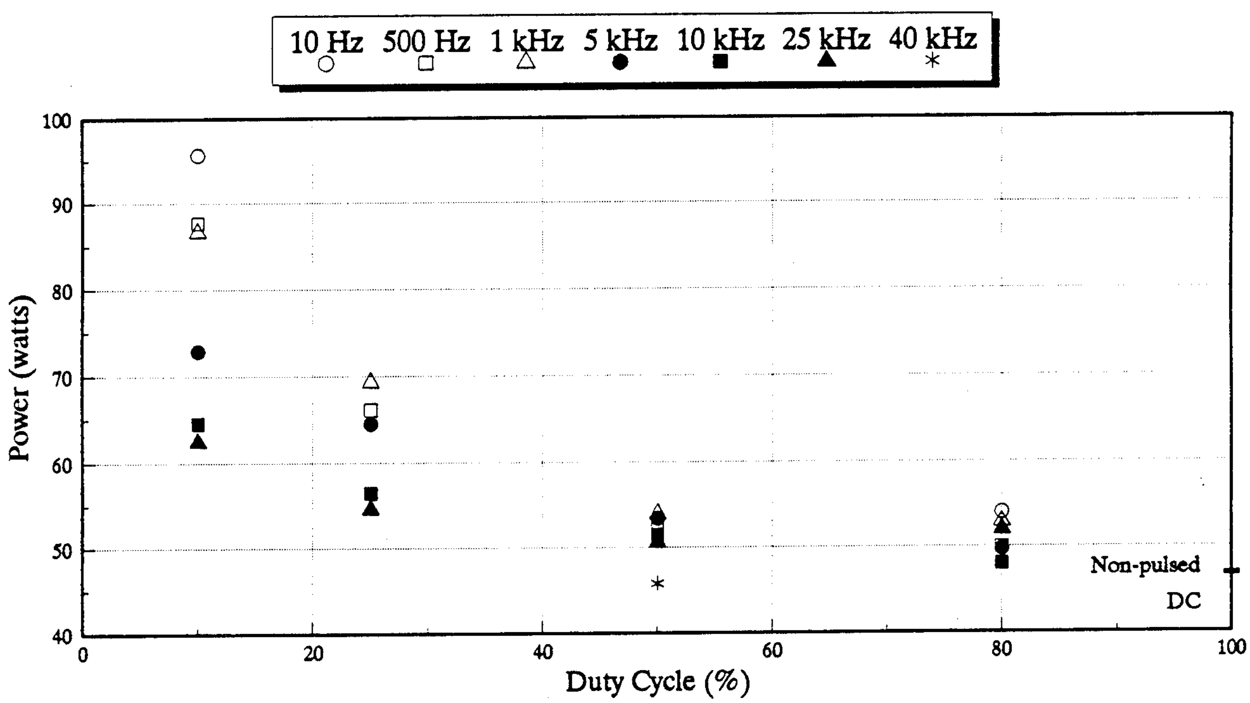

Figure 32 : Experiment Setup Circuit Power Demands.

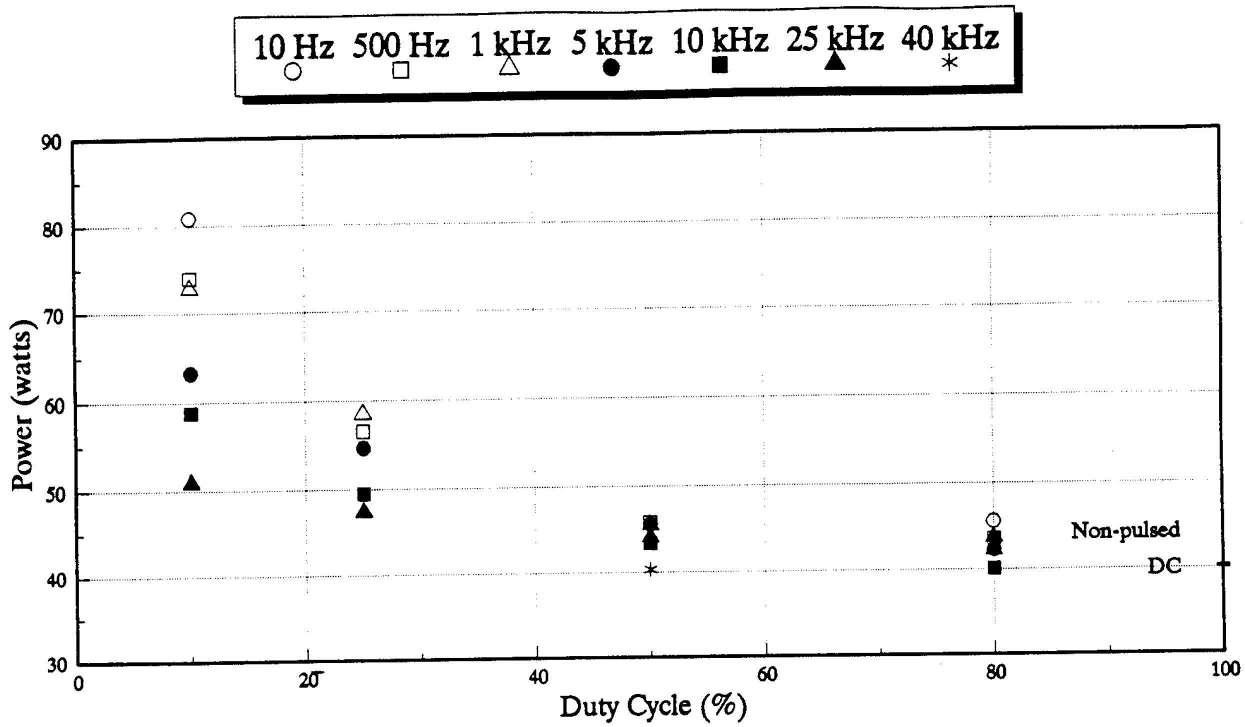

Figure 33 : Electrolyzer Power Demands (power vs. duty cycle)

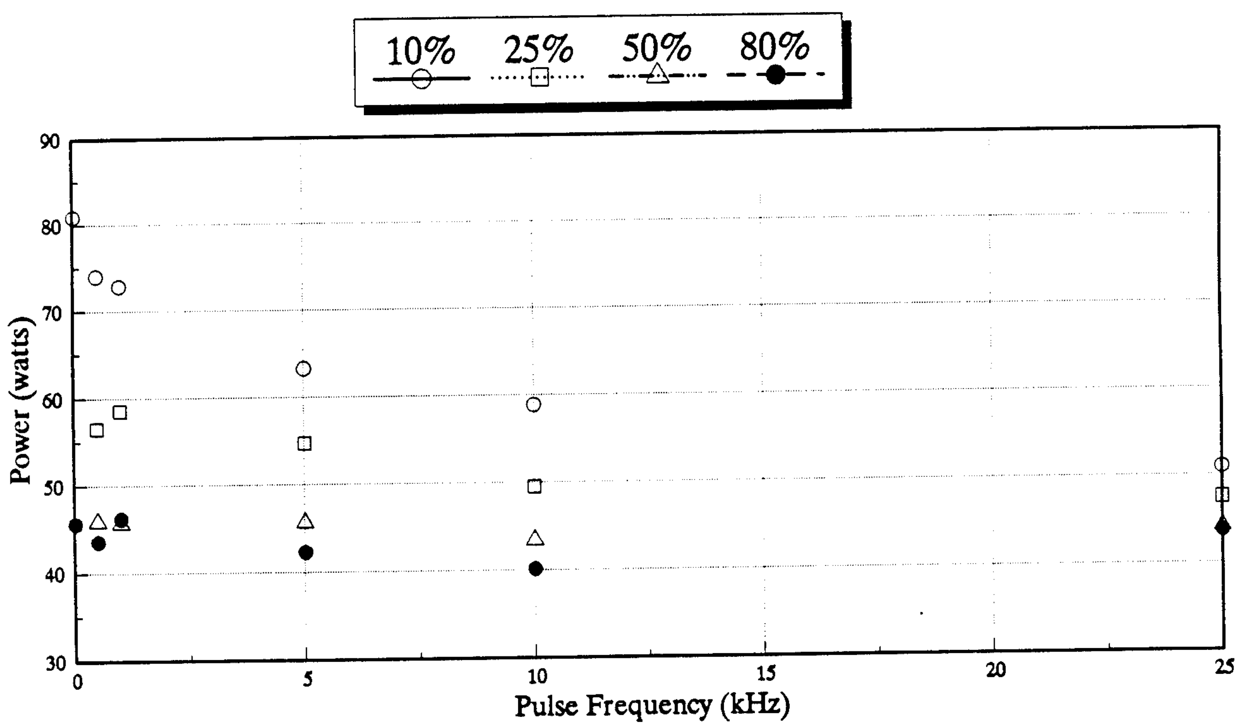

Figure 34 : Electrolyzer Power Demands (power vs. frequency)

B. BASELINE ANODE DEPOLARIZATION

The results of anode depolarization and the baseline nonpulsed DC test series are given in Figures 35 and 36 for comparison. Using anode depolarization with 10 percent by weight sulfuric acid at 30 °C with the anolyte fully saturated with SO_2, a current of 100 mAmps was recorded at cell potential of 0.635 volts instead of the 1.8 volts required for nondepolarized operation. The cell potential fell 1.3 volts below that of the nondepolarized cell potential at a current density of 30 mA/cm^2. At this current density, as seen in Figure 36, the depolarized-cell's hydrogen yield was three times that of the nondepolarized cell for the same 1.71 watts of electrical power delivered.

During test runs the catholyte gradually changed to an opaque bluish color. The test run was terminated when the current dropped suddenly. Examining the catholyte, revealed a rotten egg odor confirming the generation of hydrogen sulfide which dissolved in the catholyte, changing its color. The electrolyzer was dismantled, and sulfur powder was found on the cathode side of the membrane. This explained the sudden drop in current. The sulfur powder had covered all the membrane area preventing the ion exchange from taking place. The generation of hydrogen sulfide and the sulfur covering of the membrane had affected the slope of the anode depolarization curve given in Figure 36. At the beginning of the first change of slope, hydrogen yield had tripled when sulfur dioxide was used as a depolarizer. Overcoming these obstacles is technically feasible which makes anode depolarization a viable avenue to decrease hydrogen production costs.

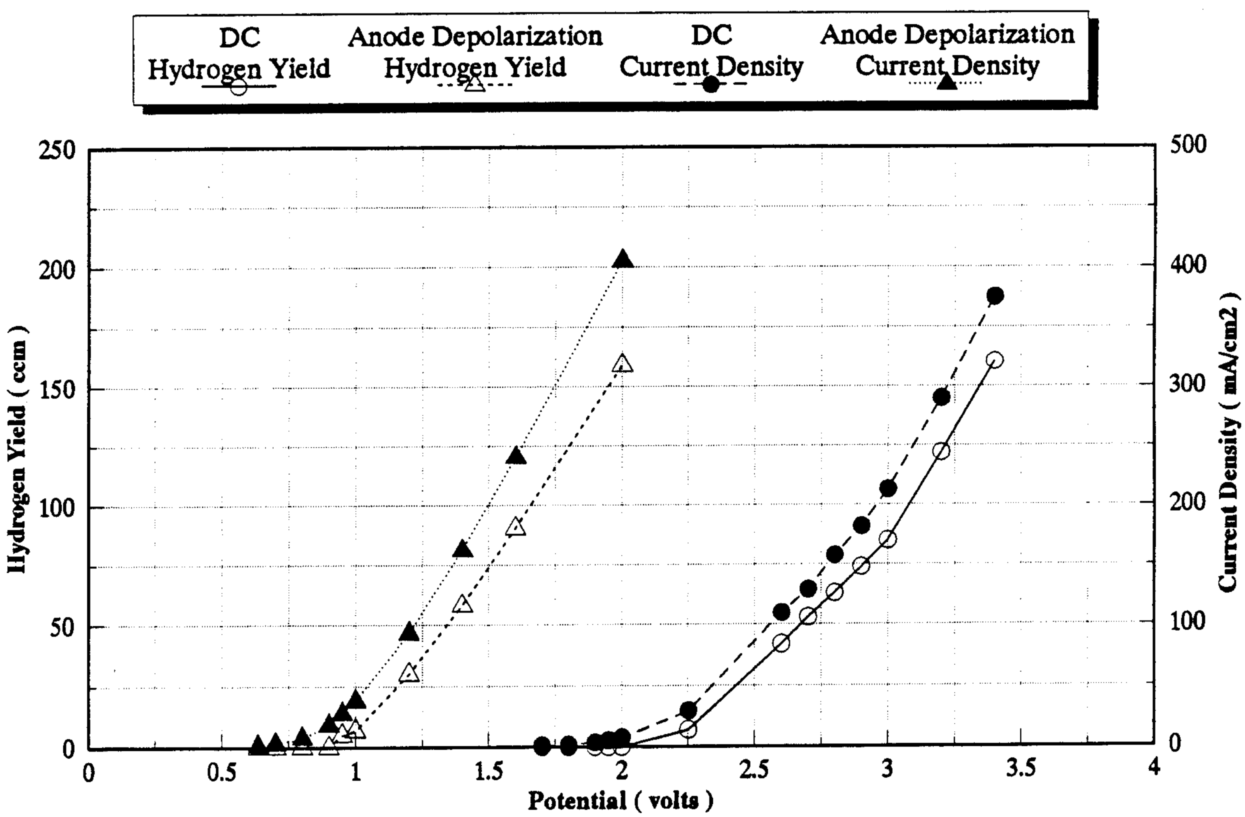

Figure 35 : Performance Characteristics of the ICI Electrolyzer With SO_2 Saturated Anolyte.

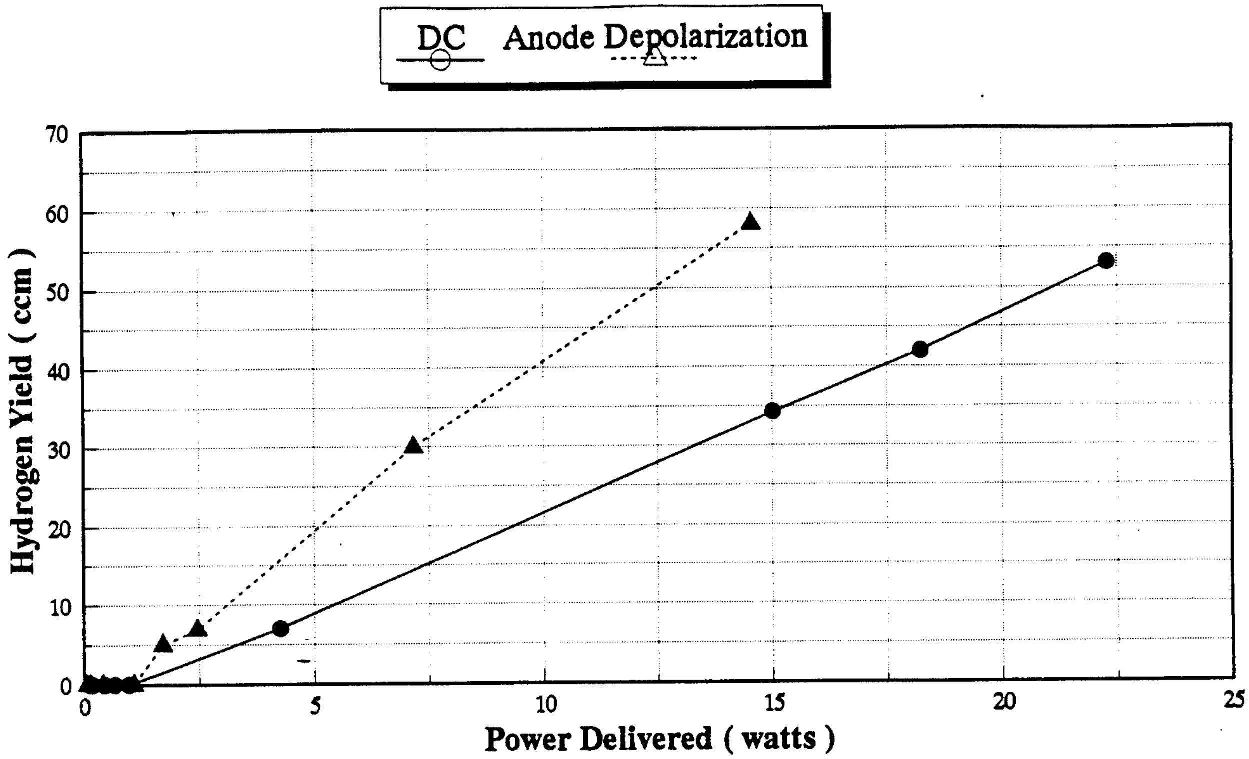

Figure 36 : Anode Depolarized Hydrogen Generation Rate vs. Power Demand.

SECTION VI

CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

This effort experimentally studied the effects of pulsed DC and anode depolarization on the performance of the water electrolysis process for hydrogen generation. The selection of the these two concepts was based on works published in the fifties, sixties, and seventies. Juda and Moulton [8] found that using 6 percent by weight sulfurous acid (sulfur dioxide dissolved in water) to depolarize the cell anode reduces the cell potential by 0.8 volts below that of nondepolarized cell potential. Bockris et al [14, 15, and 22] and Tseung and Vassie [23] concluded that pulsed DC may be used to improve the electrolysis process for hydrogen generation for up to twice the performance of the nonpulsed DC electrolysis.

The work accomplished during this effort showed the potential of the anode depolarization method in reducing the cost of electrolysis for hydrogen production. A three-to-one improvement in electrolysis performance is feasible.

In the case of pulsed DC, one of the phenomena recorded by Bockris in 1953 was not duplicated by this effort, namely the high but short-lived current spike. The second phenomenon, significant current continue to flow for a short time, was observed. Bockris explained the cause of this phenomenon as the discharge of the ions in the double-layer facing the electrode in the absence of the externally applied electric field. However, the current flow during the off-period of the pulse is largely due to the discharge of the current generated by the collapse of the magnetic flux around the leads connecting the cell to the power amplifier. Since the results of this effort contradict those of Backris et al [14, 15 and 22] and Tseung and Vassie [23] more effort is needed to settle the pulsed DC issue.

B. RECOMMENDATIONS

Due to the lack in 6.1 funds this effort was terminated before its conclusion. To achieve the objectives, a basic research program, which consists of an aggressive experimental and theoretical investigation of the water electrolysis behavior under pulsed DC and anode depolarization loadings, is proposed. A new cell design is also proposed. The new design is based on a dispersion of ultramicroelectrodes to maximize surface area per unit volume under high mass transport conditions. The overall philosophy is to explicitly account for the characteristics of the double-layer and the nature of the oxidation process in describing the electrolytic process behavior under varied loading conditions. Observations of charging, discharging, and the thickness of the double-layer and electrode oxidation process are proposed, backed up by theoretical modeling. The following describes the proposed research.

C. PROPOSED RESEARCH OBJECTIVES

The long-term objective of this research is the development of an efficient electrolytic cell using pulsed DC power and anode depolarization concepts. Because few, if any, researchers have ever studied the electrolyzer behavior using the dispersive ultramicroelectrodes under pulsed

DC combined with anode depolarization, considerable experimental effort is required before definitive answers can be found. Therefore, specific objectives of the proposed effort :

1. Develop quantitative descriptions of the double-layer behavior under pulsed DC.

2. Study the anodic oxidation process under both nonpulsed and pulsed DC.

D. WORK BREAKDOWN STRUCTURE

A combined experimental-theoretical investigation is planned. Emphasis is on developing the experimental capabilities and techniques required for studying double-layer behavior and anodic oxidation kinetics. Parallel development of theoretical descriptions of this behavior will be used to guide the experiments toward meaningful results. Three major task areas, consisting of (1) laboratory experiments, (2) theoretical modeling, and (3) data analysis, are described in the following paragraphs.

Task 1. Laboratory Experiment

The success of this effort depends on the understanding of the double-layer behavior and the oxidation process at the anode as well as the direct measurement of changes in these processes under various test conditions. All experimental work for this project falls under Task 1. A combination of linear sweep cyclic voltammetry, atomic absorption spectrometry, gas/liquid chromatography, and computerized histogrammetry is proposed. The cathodic and anodic products will be analyzed for selected cases using a gas chromatograph. These analyses will determine the hydrogen weight percentages in the cathodic product and the anodic product makeup. Consideration will be given to the measurement of overpotentials, hydrogen generation rate, cell potential and current, and double-layer charge and discharge processes. The oxidation process of the sulfur dioxide at the anode has been examined [35]; therefore, only the oxidation process of chlorides will be studied in the proposed effort. In addition to the subtasks detailed below, possible additions, improvements, and enhancements to the proposed experimental methods will be considered throughout the effort when appropriate.

Subtask 1a. Baseline Characterization.

Under this subtask the baseline performance of an electrolytic cell will be characterized for depolarized and nondepolarized operations. The baseline performances will be used to compare with the cell performance under pulsed DC operations. Existing laboratory facilities at AFCESA/RACO will be used for testing under this subtask, which include the following:

▸ ***Electrolyzer Cell Development.*** A successful hydrogen production process requires low power consumption, kWh/kg product. This can be achieved with a cell design that has a large surface area per unit volume and operates under a high mass transport condition. Both of these objectives will be achieved by using *Dispersion of Ultramicroelectrodes.* These three-dimensional electrodes and some of their applications have been reported by Ghoroghchian et al [37-40]. We will utilize dispersion of ultramicroelectrodes in the form of a monopolar fluidized bed, packed bed, and/or slurry systems. The development of spherical diffusion fields in the bulk of the solution surrounding these electrodes lead to high rates of mass transfer to the electrode surface. Equally the spherical potential fields leads to a decrease of charging times, so that transient measurements are simplified (the time constants are proportional to the radius of the electrodes). This system will be used for all the depolarization processes discussed above. The use of ultramicroelectrodes is a powerful new methodology for hydrogen production. The number of particles that can be put into the suspension may be as large as 10^9 Ultramicroelectrodes per cubic centimeter of solution. This will increase the contact time with the depolarizer materials such as SO_2 or biomass, which in turn translate to large hydrogen generation. The space time yield (amount of product produced per time of electrolysis and per cell volume) is expected to be 1-2 order of magnitude greater than 2-D systems.

Different electrode material, metallic powders, such as pt, Ru, Pb, PbO, metal supported materials as well as carbon, graphite and semiconductors will be used and their performance from a catalytic point of view will be studied. The preparation of ultramicroelectrode dispersion will be undertaken by various methods, depending on the conducting substrates and their physical form. Metal powders, carbon, and some supported metal powders are available from a variety of commercial sources. Other materials will be prepared in-house by grinding and crushing techniques followed by appropriate sieving and cleaning methods. Reactions will be studied as function of microelectrode size and concentration (due to difference in mass transfer rates as size is changed and thus possibility of changing reaction pathway, also microelectrode concentration will affect reaction pathways by changing the intermediate concentration of chemical product(s)).

▸ ***Anode Depolarization.*** A few important anode depolarizer materials will be considered and characterized under the nonpulsed DC and pulsed DC conditions as outlined below.

(a) The anodic process of solid metal oxides formed at potentials lower than those required for oxygen evolution are of particular interest. Once formed, the oxide is then removed from the electrolytic cell, and the anode substrate is subsequently regenerated by chemical reduction or by thermal dissociation. The anodic reaction involves either a metal/metal oxide couple of a lower/higher oxide couple. The thermal reduction phase is thus described as:

$$MO_s \rightarrow MO_{s-x} + \frac{x}{2} O_2 \qquad (17)$$

Among the oxides that will be studied are oxides of lead, tin, and cobalt. Chemical reduction of the oxides at medium temperature (e.g. by carbon monoxide) will also be considered. Following established favorable equilibrium behavior, the kinetics of the anodic process are of great importance. After a favorable kinetic behavior is demonstrated, the investigation will turn to other features relevant to the chosen process. These include oxide coherence (minimize degradation of substrate weight ratio), oxide layer conductivity, and thermal reduction parameters.

(b) Sulfur dioxide as an anode depolarizer will also be considered. Although this has been well documented, the process will be examined from the point of view of a new cell design (dispersion of ultramicroelectrodes) and the use of pulsed DC power as discussed below.

(c) Study of the anodic products in biomass slurry electrolysis. The principle variable would be current density, electrocatalysis via dispersion of ultramicroelectrodes, pulsed DC parameters. Ascertaining the nature of the products would be the primary aim, while the secondary aim would be determining the current efficiency of their production. During this study, hydrogen product data would be collected because of the interaction the anodic products have upon hydrogen economics. The study of the anodic products in slurry electrolysis by using non aqueous solutions will be conducted. DMSO, dimethylformamide, acetonitrile, and their systems with water will be used. Other organic systems will also be sought.

▸ ***Nonpulsed DC Power.*** Initial testing will be made using nonpulsed DC power to determine the electrolyzer baseline performance. The baseline performance is to be used for comparison with the anode depolarization and pulsed DC performances. The effects of electrolyte concentration and temperature will be examined. In this testing, linear sweep cyclic voltammetry will be performed to measure current-voltage curves. These curves will allow us to study the qualitative and quantitative changes in the electrolyzer behavior. Hydrogen yield will also be measured to facilitate comparison of the actual hydrogen generation rate. Measurements of double-layer charge time will be recorded using an oscilloscope in a storage mode.

Subtask 1b. Pulsed DC Power

Using the same conditions tested in subtask 1a, pulsed DC power will be examined for both anodically depolarized and nondepolarized cells. To help reduce the size of the test matrix, the cell performance under pulsed DC power will be examined at two hydrogen yields which will be determined from the baseline data for low and medium ranges. Under this subtask, combinations of duty cycles, frequencies, and waveforms will be examined. Consideration will be given to the effects of the waveform's rise-time and the combination of pulsed and nonpulsed DC formations.

Task 2. Theoretical Modeling

Theoretically-based relationships for hydrogen evolution rate, limiting current density, overpotentials, pulsed DC power, and double-layer charging will be pursued. Applicable theories which will be considered include: mass transfer, activation energy, and Butler-Volmer theory. These are grouped into two main thrust areas for theoretical development.

▸ ***Reacting Ion Mass Transfer.*** One of the important advantages of pulsed electrolysis frequently cited by investigators is the enhancement of mass transfer. Since mass transfer limitation can be reduced very effectively by pulsed DC electrolysis, a mass transport model for the reacting ions can be used to obtain quantitative ion discharge information. The concentration of the reacting ions in the double-layer depends on the transport characteristics of the system as well as the applied current density and is independent of reaction kinetics. It can be calculated by solving the convective diffusion Equation subject to Fick's law of diffusion as a boundary layer. Several mass transport theoretical models under pulse conditions which can be adapted to this research needs are available in the literature. For example, Popov et al [36] studied mass transfer under pulsed conditions in both stirred and unstirred solutions for electrodeposition. The mass transport modeling results will help us better understand the behavior and the characteristics of the double-layer under pulsed DC conditions, determining the maximum rate of electrolysis, and will lead to the kinetic study of the electrode reactions.

▸ ***Oxidation Kinetics.*** The modeling of the electrode reaction kinetics will provide a wealth of information. This information will help us to understand the anodic oxidation process. Parameters that can be calculated include the number of electrons involved in the reaction, double-layer thickness, and diffusion coefficient. For this modeling to be useful, mass transfer limitations must either be negligible or be quantitatively accounted for. The mass transfer limitations can be obtained from the mass transfer model while the rate of reaction can be represented by the Butler-Volmer Equation.

Task 3. Develop Quantitative Description

The information gathered in the Task 1 experiments and in the Task 2 modeling must be analyzed to provide quantitative descriptions of electrolyzer performance along with basic insights for the physical processes which are occurring. Task 3 of this effort will be data analysis.

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APPENDIX A

WAVEFORMS' DIGITIZED DATA

Approximate 10 Hz, 10% Duty Cycle
December 13, 1991, (time in milli-seconds)

Time	Source V	Time	Current	Time	Cell V
0.0000	0.00000	0.0000	0.00000	0.0000	1.92754
0.0862	0.30387	0.2152	0.12837	0.0434	4.13913
0.1725	1.98101	0.5595	4.33552	0.3476	6.22029
0.2587	2.71147	0.9899	7.22392	0.6082	6.28116
0.3018	3.73411	1.3772	7.22392	1.5206	6.22609
0.4743	4.94960	2.3671	7.46900	2.6067	6.73333
0.7330	7.33966	4.8204	7.16557	4.5183	6.20870
1.4661	7.75457	5.5951	7.44566	5.4741	6.64058
3.2340	7.31045	6.1976	7.38731	7.4292	6.26667
4.2688	7.92988	7.6179	7.06054	8.4284	6.59710
5.9505	7.29291	8.4356	7.41065	9.1235	6.44348
6.9854	7.88897	10.3293	7.10722	9.7318	6.29275
8.9689	7.30460	10.7167	3.11597	9.8621	5.96812
9.9606	7.85975	11.2332	0.00000	10.2531	4.04058
10.2193	7.17604	114.0000	0.00000	10.4269	2.42899
10.4781	4.04383			11.0351	2.37391
10.8661	1.03433			11.5999	2.31014
10.9955	0.00000			12.9033	2.26377
114.0000	0.00000			14.3804	2.22899
				16.2051	2.19420
				18.4209	2.17391
				20.2890	2.15362
				22.8957	2.12464
				25.3287	2.09855
				27.8920	2.08406
				31.4110	2.06087
				34.8432	2.04928
				37.5368	2.04638
				42.5765	2.04638
				47.4858	2.03188
				51.0049	2.01449
				56.2618	1.99130
				59.9981	1.98261
				65.2116	1.97391
				70.2078	1.96522
				74.8130	1.95942
				79.9830	1.95944
				85.5440	1.94203
				114.0000	1.92754

500 Hz, 10% Duty Cycle
November 13, 1991, (time in micro-seconds)

Time	Source V	Time	Current	Time	Cell V
0.0000	0.00000	0.0000	0.00000	.0000	2.10000
1.1343	3.38528	1.0333	0.00000	.5175	2.25519
3.2998	5.93567	2.1700	0.21761	1.1385	2.42188
7.5277	5.83846	13.1232	2.92054	2.6909	2.60293
11.5494	5.82702	26.1431	4.56979	4.5538	2.75813
22.3769	6.25590	43.7096	5.90408	6.1063	2.96505
28.9765	6.32452	54.5595	6.33357	8.3832	3.16335
59.1905	6.83345	69.0261	6.61417	10.1426	3.36739
80.3300	7.06219	85.3526	6.75161	12.8335	3.56857
107.9660	7.18227	105.5025	6.90623	15.4209	3.77836
128.8992	7.26233	141.0488	6.92341	18.3188	3.95367
155.2978	7.34239	174.5285	6.98067	21.6306	4.14909
196.5455	7.40529	196.4350	7.03794	25.4600	4.37038
199.4328	2.65332	197.8817	6.99785	30.4278	4.58880
200.7734	2.31594	198.9150	6.90623	36.2236	4.80147
203.6607	2.46462	209.0416	4.02577	40.9844	4.94804
205.5169	2.25304	221.3382	1.47173	45.9522	5.10898
206.8574	2.29878	231.1547	0.06299	52.9899	5.28716
210.9822	2.29307	296.6675	0.05727	59.9241	5.45672
231.3998	1.64689	320.0000	0.00000	67.9968	5.58030
232.9466	0.71480	2000.0000	0.00000	74.6205	5.67513
266.2542	0.24589			81.3477	5.77860
301.0054	0.12009			88.7994	5.83320

339.1596	0.00000			93.7673	5.89355
2000.0000	0.00000			100.7015	5.96252
				107.5322	5.99989
				113.7420	6.04299
				118.9167	6.07461
				123.7811	6.09185
				130.3013	6.12059
				137.1320	6.15220
				152.8634	6.18381
				161.4535	6.22692
				173.0451	6.22692
				180.8073	6.25854
				188.6730	6.26428
				194.2617	6.26716
				197.0561	5.86481
				199.0225	5.51994
				200.4715	5.26704
				201.9204	4.97103
				204.1973	4.65490
				206.6812	4.34452
				211.8560	3.72376
				215.4784	3.41912
				219.5147	3.10587
				222.8266	2.85584
				226.2419	2.63742
				226.2419	2.63167
				228.9328	2.43912
				234.9356	2.43625
				251.2879	2.41901
				260.9131	2.39314
				276.4374	2.37877
				295.6877	2.37302
				325.0805	2.35291
				449.6895	2.29543
				2000.0000	2.10000

1 kHz, 10% Duty Cycle
November 13, 1991, (time in micro-seconds)

Time	Source V	Time	Current	Time	Cell V
0.0000	0.00000	0.0000	0.00000	0.0000	2.19274
1.3385	0.04644	2.9897	0.00000	0.4132	2.19274
2.0592	0.22061	4.5361	0.12192	2.7893	2.19274
2.6770	2.41509	5.3608	0.48766	4.8554	2.20718
3.5006	4.83019	6.7010	0.96952	5.8884	2.27363
5.4569	6.56604	9.0722	1.50363	6.7149	2.47586
10.5019	6.60668	10.4124	1.95646	7.9545	2.68097
12.7671	6.50798	12.5773	2.42671	9.6074	2.89476
19.4595	6.75181	15.1546	3.01306	11.1570	3.10565
24.2986	7.03628	18.2474	3.54136	13.7397	3.31077
29.6525	7.05370	22.6804	4.27866	15.7025	3.52167
47.3616	7.40203	28.2474	4.95210	18.1818	3.79323
66.9241	7.70972	32.1649	5.49202	20.1446	3.98102
85.0450	7.87808	36.5979	5.86938	22.3140	4.22369
97.9151	7.88970	40.7216	6.20610	25.5165	4.40858
99.0476	5.35268	46.4948	6.54282	28.5124	4.55881
100.3861	2.94920	54.1237	6.76343	31.6116	4.72926
102.1364	2.18868	61.2371	6.89115	35.0207	4.92571
105.8430	1.85196	67.9381	6.96662	38.7397	5.07883
107.7992	1.99129	73.1959	7.04790	42.8719	5.27817
110.1673	1.80552	79.5876	7.08273	47.9339	5.48040
113.8739	1.77068	86.1856	7.11176	52.2727	5.62485
117.5804	1.68360	91.2371	7.18723	57.3347	5.76063
123.8610	1.60813	95.7732	7.18723	61.7769	5.86752
129.0090	1.48621	100.0000	7.16401	65.5992	5.97730
132.7156	1.39332	102.7835	6.96081	68.9050	6.05241
137.3488	0.59797	104.3299	6.49057	71.6942	6.10442
143.1145	0.51669	106.5979	5.96807	75.1033	6.16508
152.7928	0.41800	108.3505	5.32946	77.6860	6.21131
162.4710	0.31350	110.4124	4.71408	81.9215	6.27198
188.5199	0.24383	112.3711	4.05225	85.9504	6.32109
213.0245	0.19158	114.6392	3.46009	90.2893	6.37309
245.3539	0.14514	117.0103	2.92017	94.4215	6.42798
273.6680	0.10450	119.3814	2.31060	97.5207	6.44820
317.0142	0.00000	124.1237	1.46880	98.5537	6.48287
1000.0000	0.00000	127.9381	0.91147	100.9297	6.46843
		131.6495	0.34253	101.9628	6.35865
		133.6082	0.01161	103.6157	6.10731
		137.4227	0.00000	104.9587	5.76641
		141.9588	0.00000	105.5785	5.67107
		1000.0000	0.00000	106.3017	5.48906
				107.6446	5.29261
				108.7810	5.09327
				110.2273	4.87082

110.8471	4.65415
112.1901	4.45770
113.6364	4.23236
115.7025	4.00702
117.9752	3.77590
120.6612	3.51589
122.5207	3.31366
123.9669	3.14321
127.1694	2.90054
130.0620	2.68386
132.5413	2.53941
134.2975	2.45852
139.9793	2.43830
150.6198	2.42674
163.5331	2.41808
183.9876	2.38919
201.1364	2.36030
224.2769	2.35741
239.9793	2.34585
250.3099	2.34585
254.0289	2.34007
283.2645	2.31118
305.8884	2.31407
330.5785	2.29963
358.2645	2.29385
386.9835	2.27363
1000.0000	2.19274

5 kHz, 10% Duty Cycle
November 13, 1991 (time in micro-seconds)

Time	Source V	Time	Current	Time	Cell V
0.0000	0.00000	0.0000	0.00000	0.0000	2.30000
0.5350	0.02331	2.7207	0.00000	1.3652	2.57930
0.8230	0.14569	3.0505	0.06997	2.7718	2.92770
1.3169	2.05128	5.4002	1.10204	4.2611	3.23292
2.1399	4.71445	8.9866	2.76968	5.5436	3.44599
2.9218	7.26690	14.2219	4.53644	7.1570	3.78576
3.5802	7.99534	19.0450	5.87172	8.8531	4.07082
4.4856	8.64802	21.0237	6.37318	10.7975	4.35300
6.3374	8.65385	23.0024	6.37901	12.3282	4.55743
6.7901	8.59557	25.1872	5.72012	13.7761	4.75899
8.8477	8.61888	28.9797	4.27405	15.5550	5.00374
10.7819	8.57226	33.1020	2.94461	17.2098	5.19953
12.0165	8.57226	37.8839	1.76093	18.9474	5.35790
14.9383	8.76457	43.0780	0.74052	19.8161	5.46732
16.6667	8.84033	46.4170	0.27405	21.5537	5.18226
18.8889	8.99767	49.8385	0.00000	23.4153	4.81370
20.8230	9.03846	200.0000	0.00000	24.4909	4.61790
21.1111	7.93124			26.4767	4.32420
21.7695	5.57692			27.9660	4.07370
22.8395	2.96620			30.2827	3.77136
24.0741	1.58508			32.5580	3.50934
24.3210	1.46270			34.9989	3.24156
24.6502	1.40443			37.9361	3.00545
25.2675	1.38695			40.8734	2.75206
26.0082	1.52098			43.8934	2.52747
26.8724	1.46270			46.3342	2.41230
28.0658	1.34033			53.7807	2.37774
29.6296	1.30536			64.1646	2.37774
30.7819	1.42774			81.4158	2.36911
32.1399	1.44522			111.2020	2.34895
33.1276	1.32284			142.9740	2.32016
37.4486	1.32867			167.5063	2.33167
38.8066	1.16550			180.0000	2.30576
40.7819	1.16550			200.0000	2.30000
43.7449	1.13054				
47.2016	1.10140				
47.9835	0.94406				
48.8066	0.29720				
49.2181	0.25641				
50.1235	0.36713				
51.9342	0.27389				
52.9218	0.30303				
54.1152	0.25641				
62.5926	0.19814				
79.2181	0.13403				
90.0134	0.00000				
200.0000	0.00000				

10 kHz, 10% Duty Cycle
November 13, 1991 (time in micro-seconds)

Time	Source V	Time	Current	Time	Cell V
0.0000	0.00000	0.0000	0.00000	0.0000	2.30218
0.2684	0.02900	1.4859	0.00000	0.8073	2.30218
0.3304	0.13340	1.8367	0.08687	1.6352	2.30791
0.5575	1.33398	2.4146	0.17954	2.3597	2.29644
1.0943	3.82214	4.1481	1.15251	2.6909	2.35092
1.7550	6.37989	5.4896	2.05019	3.1877	2.47706
2.4157	8.57806	8.1312	3.50965	3.6224	2.59461
2.9319	9.45964	10.2775	4.54054	4.1398	2.75516
3.4687	10.12663	11.2474	4.95753	4.2019	2.74656
4.0262	10.43403	11.5983	5.01544	4.3882	2.83830
5.3889	10.43403	11.9491	4.96911	4.7401	2.92144
5.6573	10.38183	12.2380	5.00386	5.1334	3.05046
8.2175	10.35863	12.6920	4.95174	5.5267	3.19094
9.9931	10.35283	13.0016	4.94595	5.6923	3.18234
10.1376	10.32383	14.6732	4.30888	5.9200	3.32569
10.2822	10.23103	15.0860	4.29730	6.2305	3.34576
10.8190	8.31126	16.1385	3.84556	6.6237	3.47477
11.4178	5.60851	20.3485	2.49614	6.9756	3.56651
11.9546	3.68874	22.9489	1.88224	7.1826	3.65826
12.2849	3.04495	25.1983	1.33205	7.5138	3.71846
12.7392	1.94297	25.9000	1.14672	7.9071	3.75860
13.2347	1.32818	26.4572	1.14093	8.5281	3.90195
13.3999	1.25278	26.8700	0.99614	8.8178	3.98509
14.2051	0.97438	27.3240	0.98456	9.3767	4.12844
14.7213	1.05558	28.9956	0.63127	9.7079	4.20298
15.7330	1.37458	29.7386	0.58494	10.2461	4.30906
17.2815	1.36878	30.2958	0.34749	10.5566	4.35780
17.9628	1.24698	30.8737	0.31274	11.0534	4.46101
19.7385	1.26438	32.0500	0.18533	11.4259	4.54989
20.3166	1.33398	33.0612	0.04633	11.9227	4.66743
22.2161	1.32238	86.3265	0.00000	12.0676	4.71904
23.1039	1.25278	100.0000	0.00000	12.8956	4.73624
23.3310	1.18318			13.5373	4.65023
24.1982	1.17738			13.7443	4.65023
24.9209	1.53697			13.9305	4.56995
26.5520	1.44418			14.4066	4.51835
27.9972	1.37458			14.6757	4.44667
29.0502	1.23538			15.0690	4.35206
29.6490	1.09038			15.7521	4.26892
31.1975	1.13098			16.1247	4.17431
32.7254	1.14258			16.6421	4.10837
32.9319	0.40599			17.4908	4.01376
33.1590	0.82939			17.9048	3.93349
33.3655	0.48719			18.5051	3.86181
33.5719	0.67859			19.4365	3.75573
33.9642	0.07540			19.8919	3.69553
34.1707	0.72499			20.8441	3.59805
34.3152	0.31319			21.4029	3.51491
34.7075	0.37699			21.9204	3.43463
34.9346	0.22620			22.1688	3.36009
35.1411	0.35959			22.8312	3.28268
35.2650	0.21460			23.3487	3.21674
35.5127	0.26680			23.7213	3.18234
36.3386	0.15660			24.4664	3.13073
36.8135	0.22620			25.2323	3.04186
38.0936	0.26680			25.7705	2.98452
40.5506	0.25520			26.7226	2.89278
44.8658	0.20300			27.3229	2.81823
45.7123	0.16240			27.9025	2.77523
46.0427	0.02320			28.7305	2.67775
46.6621	0.13340			29.7240	2.61468
47.0544	0.01160			30.5313	2.55161
47.5912	0.06960			31.1109	2.49713
48.2312	0.00000			32.0009	2.44839
48.9332	0.05220			32.8496	2.40539
49.3462	0.02320			33.5534	2.36239
88.5960	0.00000			33.9673	2.35092
100.0000	0.00000			34.1950	2.38245
				34.6504	2.36812
				35.4163	2.39679
				36.1201	2.36812
				38.2107	2.38245
				42.0814	2.35952
				46.9250	2.36525
				51.1270	2.36239
				54.9770	2.32798
				59.3031	2.32225
				63.5879	2.32511
				67.8726	2.32511
				73.0681	2.31651
				76.2351	2.32225

79.4641	2.33085
82.8174	2.33085
86.3983	2.29644
90.0621	2.32511
91.8629	2.30505
93.7466	2.30505
100.0000	2.30218

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25 kHz, 10% Duty Cycle
November 13, 1991 (time in micro-seconds)

Time	Source V	Time	Current	Time	Cell V
0.0000	0.00000	0.0000	0.00000	0.0000	2.33218
0.0718	0.04636	1.0103	0.00000	0.0829	2.33218
0.1744	0.12169	1.2577	0.00572	0.5805	2.32350
0.2462	0.28974	1.3505	0.04292	1.0158	2.32928
0.5848	2.25993	1.6186	0.04292	1.4097	2.33218
1.0259	4.68791	1.8247	0.10300	1.6792	2.32928
1.3234	6.58278	1.9794	0.10300	1.8658	2.35822
1.7543	8.85430	2.1856	0.18312	2.1353	2.44213
2.3904	11.46772	2.4124	0.29185	2.4877	2.58681
2.8520	12.59768	2.6082	0.40916	2.6432	2.72280
3.2316	13.21192	2.8247	0.55222	2.9852	2.90509
3.6112	13.72185	2.9897	0.69814	3.3895	3.06713
4.0010	13.87831	3.2474	0.87268	3.7834	3.22627
4.1139	13.87252	3.4536	1.04149	4.1047	3.41435
4.2780	13.70447	3.6495	1.21602	4.4467	3.54167
4.4832	13.04387	3.8969	1.38197	4.8199	3.68345
4.8320	11.13742	4.0309	1.54793	5.0790	3.81076
5.1500	8.65149	4.2680	1.69099	5.3589	3.91204
5.7040	5.42964	4.3196	1.81688	5.4833	3.96701
6.5453	2.70613	4.5361	2.01717	5.7735	3.97280
7.0172	1.51821	4.6907	2.13734	6.1363	3.97569
7.3865	0.90397	4.8144	2.30043	6.4369	3.88600
7.6019	0.86341	5.1134	2.40629	6.8412	3.84259
7.7866	0.74172	5.3093	2.58655	7.2143	3.80208
8.1457	0.67219	5.4639	2.70672	7.5460	3.73553
8.5560	0.62583	5.5773	2.79542	7.9295	3.65162
8.6689	0.70695	5.7732	2.91845	8.2197	3.58507
9.0793	0.70695	5.8969	2.98712	8.8209	3.51852
9.4281	0.89818	6.1649	3.07868	9.1941	3.43461
9.7358	0.94454	6.4639	3.15021	9.6916	3.35069
10.5360	0.97930	6.6598	3.14449	10.3032	3.30440
12.1467	0.94454	6.8454	3.18455	10.6038	3.23206
12.6494	0.93295	7.1237	3.18169	11.0288	3.19155
12.8443	1.15894	7.1856	3.15594	11.5470	3.14815
13.3470	1.17053	7.4021	3.14163	11.8269	3.11343
13.4906	1.39652	7.5670	3.07582	12.2415	3.07002
13.6753	1.30960	7.9381	3.01860	12.5110	3.04688
13.8087	1.29222	8.1649	2.96137	12.9360	3.00347
13.9215	1.43709	8.4536	2.88984	13.2988	2.96007
14.1370	1.41970	8.6289	2.80973	13.5994	2.93981
14.3421	1.30381	9.0412	2.69242	14.0451	2.89063
14.5576	1.49503	9.4742	2.52647	14.4804	2.84144
14.7833	1.42550	9.9897	2.42060	15.0091	2.78646
15.0090	1.48924	10.2784	2.33190	15.3511	2.75174
15.4604	1.41391	10.6392	2.22604	15.7554	2.71123
17.0095	1.44868	10.8557	2.15737	16.1804	2.67072
17.1121	1.37914	11.2680	2.04578	16.7194	2.63310
18.9382	1.35017	11.6289	1.91989	17.1340	2.60417
20.4668	1.27483	11.8454	1.89700	17.5486	2.56076
20.5694	1.12417	12.2062	1.82260	17.7041	2.56076
20.6412	0.00000	12.4227	1.73104	17.9217	2.51736
20.7438	0.69536	12.7216	1.70815	18.2638	2.49421
20.8771	0.69536	12.9794	1.61373	18.8235	2.45660
20.9284	0.00000	13.0928	1.56795	19.1760	2.42188
21.0310	1.08361	13.2577	1.52790	19.7771	2.39005
21.1234	0.99089	13.4639	1.51359	20.2747	2.35532
21.2157	0.13907	13.7320	1.41059	20.7515	2.31481
21.4106	0.84023	13.9175	1.39342	21.3527	2.27141
21.5850	0.01159	14.3711	1.29041	21.4460	2.35822
21.7081	0.67798	14.8351	1.18455	21.6325	2.33218
21.8825	0.00000	15.1546	1.09299	21.9746	2.35532
22.0467	0.43460	15.7216	0.98712	22.4514	2.34954
22.2006	0.02897	16.1856	0.89843	23.3221	2.34375
22.3032	0.30132	16.4639	0.82403	24.2446	2.33507
22.4878	0.11010	16.8454	0.73247	25.2397	2.34664
22.5904	0.21440	17.0309	0.72389	26.3177	2.33507
22.7853	0.00000	17.3196	0.63233	27.3024	2.34664
40.0000	0.00000	17.5670	0.58369	28.3908	2.33218
		18.0206	0.54650	29.0956	2.33507
		18.2680	0.47210	29.8005	2.34375
		18.5567	0.40343	30.8992	2.32639
		18.8351	0.37196	32.0912	2.32060

19.1649	0.32046	32.7339	2.34664
19.4948	0.26896	33.5113	2.33507
19.8454	0.18312	34.4960	2.32350
20.0825	0.16309	35.0143	2.34086
20.3402	0.12303	36.1441	2.32928
20.6392	0.06867	37.0770	2.32928
20.9691	0.02575	37.9477	2.35243
21.3299	0.02289	38.7354	2.33507
21.7216	0.02289	39.5232	2.33218
22.7216	0.01431	40.0000	2.33218
23.3814	0.02289		
24.1031	0.02289		
39.9278	0.05722		
40.0000	0.00000		

500 Hz, 25% Duty Cycle
November 13, 1991, (time in micro-seconds)

Time	Source V	Time	Current	Time	Cell V
0.0000	0.00000	0.0000	0.00000	0.0000	2.17366
2.2738	0.99652	5.5849	0.00000	9.2903	2.76883
5.1677	2.98667	9.9288	0.49913	19.8194	3.09373
5.5811	3.96002	14.0657	0.96924	25.6000	3.19436
15.0896	3.93975	19.0301	1.31747	35.3032	3.36688
23.7712	4.09907	27.5109	1.76146	41.0839	3.45026
35.5535	4.19467	37.2328	2.09228	48.7226	3.53939
54.9839	4.33951	49.4369	2.43180	55.5355	3.60265
67.5930	4.38297	65.7780	2.69878	61.7290	3.64577
89.7106	4.44380	90.5999	2.86419	72.6710	3.71765
110.7947	4.48146	124.9368	2.98317	80.1032	3.72340
128.5714	4.50174	152.4477	3.05572	92.6968	3.76366
140.1470	4.54809	218.0188	3.04701	109.0065	3.79528
163.9182	4.54809	297.4489	3.04701	124.4903	3.82979
194.0974	4.58575	406.4583	3.04701	138.9419	3.85854
222.8296	4.58575	506.1595	3.04411	152.3613	3.89017
264.1709	4.57706	525.1896	0.00000	186.4258	3.89304
308.6128	4.59154	2000.0000	0.00000	220.9032	3.90454
341.2724	4.60023			279.5355	3.91892
388.6082	4.63789			335.4839	3.94192
444.4189	4.61761			400.1032	3.95630
503.5370	4.60023			451.3032	3.97355
507.6711	3.24739			486.4000	3.97930
511.3918	1.57300			499.2000	3.94192
520.4869	1.44844			515.5097	2.48994
524.2076	0.04056			584.6710	2.40943
607.9238	0.00290			665.8065	2.36343
636.7347	0.00000			745.0839	2.32892
2000.0000	0.00000			798.9677	2.31167
				2000.0000	2.17360

1 kHz, 25% Duty Cycle
November 13, 1991 , (time in micro-seconds)

Time	Source V	Time	Current	Time	Cell V
0.0000	0.00000	0.0000	0.00000	0.0000	2.19364
0.5106	0.06560	3.9604	0.00000	4.3488	2.47110
0.7660	0.34985	4.8521	0.13439	8.6977	2.68208
1.0213	0.98154	5.7885	0.33476	12.8394	2.84104
1.1915	1.76142	8.2571	0.59866	17.9130	2.97399
1.7872	2.42468	11.2364	0.91142	22.0548	3.13006
2.3830	3.18756	14.5563	1.19487	28.0603	3.22832
3.7447	3.97473	17.3654	1.42944	36.6544	3.39306
4.3404	4.06706	19.5786	1.62004	47.1123	3.54335
11.3191	4.07677	23.0687	1.76665	55.3958	3.63295
14.2979	4.14723	27.8357	2.02566	66.6820	3.72254
17.3617	4.20554	34.7308	2.29688	81.0746	3.79769
20.2553	4.23955	38.5614	2.43128	98.2628	3.87572
23.9149	4.29057	42.1366	2.51436	120.3175	3.91329
27.6596	4.31973	48.0953	2.68051	139.6802	3.95665
31.0638	4.35374	57.0334	2.82468	160.0782	3.97977
35.6596	4.39018	64.4392	2.94930	181.0976	4.00867
40.4255	4.42420	68.2698	2.96885	217.7520	4.00578
45.7872	4.45092	70.0575	3.02260	239.4961	4.00578
47.5745	4.48251	72.6963	3.03971	250.1611	4.01734
54.5532	4.48980	74.3137	3.07147	265.5891	2.45665
55.4043	4.52381	79.5914	3.08369	303.7966	2.39595
61.7872	4.52381	80.6129	3.11790	342.3148	2.37861
64.4255	4.55782	86.9972	3.12523	370.1680	2.35549
72.5106	4.56268	90.6576	3.19853	398.1247	2.32659
73.6170	4.60398	103.7668	3.19365	427.5311	2.30636
88.7660	4.61127	104.6180	3.23519	450.2071	2.30636
90.6383	4.64529	113.4710	3.23274	1000.0000	2.19364

98.4681	4.64286	114.7478	3.26940
102.6383	4.64772	125.8140	3.28161
103.6596	4.67930	133.4752	3.31827
109.7872	4.67930	146.1588	3.32315
119.4043	4.68659	160.2043	3.34026
127.3191	4.68902	173.2283	3.35736
128.8511	4.70845	188.6359	3.35247
137.8723	4.72303	206.2567	3.35736
145.5319	4.72546	219.4509	3.35736
158.2128	4.72546	234.8585	3.34270
160.2553	4.74976	251.2875	3.34270
162.8936	4.75705	252.9900	3.11790
164.9362	4.72546	254.0115	2.76848
167.6596	4.73032	256.0545	2.27245
168.9362	4.76433	258.0975	1.75932
170.8936	4.74247	260.8214	1.15333
172.8511	4.76676	264.6520	0.46671
174.6383	4.73761	266.6950	0.06842
176.3404	4.75948	267.4612	0.02688
181.8723	4.75948	273.5050	0.00000
205.1064	4.76190	1000.0000	0.00000
227.6596	4.76190		
241.2766	4.76676		
249.1915	4.76676		
249.7021	4.55539		
249.7872	4.25413		
250.2979	3.75364		
250.4681	3.42323		
251.0638	3.01506		
251.3192	2.38095		
252.1702	1.82459		
253.3617	1.43586		
254.8936	1.40185		
257.3617	1.33139		
259.4893	1.35326		
261.2766	1.30224		
262.2128	1.30709		
264.0000	1.25121		
265.6170	1.27794		
266.5532	1.27065		
267.1489	1.23907		
267.3192	1.06657		
268.2553	0.82362		
269.3617	0.47376		
270.9787	0.31098		
272.5957	0.39845		
276.0000	0.28183		
278.0425	0.34014		
280.0000	0.26725		
282.8085	0.26968		
284.2553	0.30126		
285.9575	0.23324		
286.8936	0.25267		
291.4043	0.20408		
299.0638	0.19193		
302.2128	0.17493		
303.1489	0.14334		
304.3404	0.20651		
305.8723	0.15306		
311.1489	0.13362		
312.1702	0.15063		
313.6170	0.13120		
321.8723	0.11905		
323.3192	0.10933		
324.9362	0.05831		
327.1489	0.10933		
328.7660	0.08260		
330.2128	0.11176		
334.6383	0.08746		
337.9575	0.08989		
338.7234	0.11176		
339.8298	0.07775		
341.7021	0.07046		
344.0000	0.08260		
347.4043	0.05345		
349.1064	0.08260		
350.9787	0.05588		
354.0425	0.08017		
355.7447	0.06074		
358.3830	0.07289		
360.1702	0.05831		
361.3617	0.07289		
364.0000	0.03887		
368.7660	0.03644		
371.1489	0.07775		
372.8511	0.04859		

378.7234	0.04130
385.8723	0.02915
393.9575	0.00972
400.0000	0.00000
1000.0000	0.00000

5 kHz, 25% Duty Cycle
November 13, 1991 , (time in micro-seconds)

Time	Source V	Time	Current	Time	Cell V
0.0000	0.00000	0.0000	0.00000	0.0000	2.31139
0.5093	0.06960	3.5000	0.00000	1.0204	2.41470
1.2733	1.36800	3.8396	0.18204	2.8061	2.56127
1.9525	2.58240	4.9488	0.43114	5.1871	2.76309
2.2920	3.54720	7.1672	0.78802	9.2687	3.01778
2.9711	4.14720	10.0683	1.20958	12.4150	3.20279
3.6503	4.57920	13.9079	1.64790	16.2415	3.36857
4.5840	4.85760	18.2594	2.06228	18.1973	3.44065
6.4516	4.86960	23.6348	2.50539	19.5578	3.44065
7.7250	4.90560	28.5836	2.81198	20.3231	3.50553
9.5076	4.92720	31.5700	2.97725	23.5544	3.67852
12.7334	4.94160	33.1058	3.11856	25.4252	3.68333
14.2615	4.98960	36.8601	3.25988	26.3605	3.73138
16.9779	5.03040	37.1160	3.31018	28.7415	3.77463
18.6757	5.06160	38.6519	3.32216	32.3129	3.85872
21.8166	5.07120	40.1877	3.42515	34.8639	3.91158
22.2411	5.10000	41.6382	3.44671	37.4150	3.98126
25.8065	5.10720	45.6485	3.60479	40.9014	4.03652
26.8251	5.04720	46.8430	3.61677	43.1122	4.07496
29.6265	5.07360	48.2935	3.71976	45.5782	4.11821
31.5789	5.14320	50.4266	3.71976	46.6837	4.15906
37.1817	5.15280	50.9386	3.63832	47.8741	4.15906
40.7470	5.22720	51.5358	3.58563	48.8095	4.13023
44.5671	5.22480	52.8157	3.30060	49.1497	4.06055
46.3497	5.25840	53.9249	3.00838	50.4252	3.84671
49.0662	5.25840	54.9488	2.72335	52.7211	3.60884
49.4907	5.14080	56.3140	2.35928	54.4218	3.38299
49.4907	4.83600	58.2765	1.90659	57.3129	3.09467
49.9151	4.27920	60.1536	1.42994	59.5238	2.82556
50.3396	3.93840	63.2253	0.91257	62.6701	2.61893
50.9338	3.52320	66.3823	0.39521	65.7313	2.41711
51.2733	2.84160	68.7713	0.05988	75.1701	2.40029
51.6129	2.20800	76.1945	0.01916	93.0272	2.38107
52.4618	1.60080	100.0000	0.00000	109.7789	2.35704
53.5654	1.30320	200.0000	0.00000	131.3775	2.34983
54.6689	1.29360			151.7007	2.32580
57.4703	1.18560			167.0918	2.32340
60.6112	1.17360			200.0000	2.31139
62.6486	1.11120				
63.7521	1.13280				
65.2801	1.06320				
67.3175	1.05600				
67.9117	1.00800				
68.0815	0.70560				
68.6757	0.00720				
69.4397	0.31200				
70.6282	0.17520				
73.1749	0.16800				
75.1273	0.25440				
76.4856	0.16560				
79.4567	0.15840				
80.8998	0.12000				
81.5789	0.14640				
82.5976	0.10560				
84.2105	0.12480				
88.2003	0.12000				
91.1715	0.05760				
93.0390	0.04800				
93.8879	0.08880				
96.6893	0.07680				
98.1324	0.04560				
100.5942	0.04560				
106.2818	0.04320				
116.4686	0.04080				
127.1647	0.04080				
133.7012	0.04320				
135.9083	0.00000				
200.0000	0.00000				

10 kHz, 25% Duty Cycle
November 13, 1991, (time in micro-seconds)

Time	Source V	Time	Current	Time	Cell V
0.0000	0.00000	0.0000	0.00000	0.0000	2.22730
0.2048	0.04069	2.7380	0.00000	0.9129	2.21873
0.3754	0.09813	3.6780	0.06593	1.6183	2.22159
0.5802	0.64380	4.2092	0.16054	2.1577	2.23015
0.7167	1.09613	4.8631	0.32680	2.7801	2.27299
0.8191	1.61308	5.9256	0.59627	3.8589	2.37293
1.0580	2.14200	7.2742	0.85141	4.3568	2.45288
1.2628	2.67092	8.4185	1.09508	4.6888	2.45003
1.6382	3.32190	9.6036	1.29575	4.8548	2.54997
1.9454	3.86996	10.7479	1.51362	5.5187	2.57853
2.4915	4.49701	12.0147	1.71715	6.4315	2.70702
2.9352	4.99960	13.6085	1.95509	6.7635	2.70417
3.2765	5.17192	14.9980	2.10989	7.4274	2.78127
3.7884	5.28680	16.0196	2.28476	7.8008	2.83267
3.8908	5.30834	17.4908	2.45963	8.2988	2.81268
5.6997	5.30834	18.3081	2.58576	8.9627	2.87550
6.2457	5.27722	19.2072	2.70330	9.9170	2.96688
6.5188	5.27962	20.1880	2.74343	10.4564	3.02113
6.8259	5.30594	20.8010	2.84377	11.3278	3.08395
8.0887	5.30834	22.2313	2.98997	11.7427	3.11251
11.8089	5.31073	23.5799	3.12470	12.2407	3.13535
12.1843	5.34663	24.3564	3.14477	13.1950	3.22102
12.8328	5.38492	24.7650	3.21070	13.7344	3.24385
14.1638	5.38492	25.5006	3.27090	14.5643	3.26385
14.5051	5.41125	25.8275	3.31104	14.8133	3.31239
14.9829	5.39210	26.8901	3.31390	15.7261	3.38664
15.5973	5.42800	28.0752	3.16197	15.9751	3.42020
16.3481	5.47108	29.3012	2.86383	16.7635	3.44089
16.7577	5.49262	31.3854	2.33063	17.3444	3.50942
17.0307	5.50459	32.6931	1.94075	17.9668	3.51228
17.8157	5.51177	34.0008	1.63688	18.5477	3.57796
19.6246	5.55006	35.3494	1.34735	19.8340	3.60937
20.1706	5.57399	37.2701	0.96894	21.3278	3.68361
20.5802	5.56203	38.4552	0.80268	22.2822	3.70360
21.2969	5.63383	38.4961	0.68227	22.8216	3.76642
21.9795	5.63383	39.5995	0.51601	23.7344	3.80069
22.4573	5.59793	40.1716	0.38700	24.4813	3.83495
22.9010	5.62665	41.0298	0.30674	25.3112	3.90205
24.2662	5.62665	42.4193	0.06880	26.5000	3.91205
24.6075	5.55724	43.1140	0.03440	26.8050	3.84066
24.9147	5.41364	44.7078	0.00573	27.3859	3.77499
24.9829	5.21260	47.1189	0.01433	28.6722	3.66933
25.1536	4.93498	56.4365	0.02007	28.7552	3.60080
25.3584	4.56163	65.8766	0.01433	29.5851	3.49229
25.6314	4.09733	98.8966	0.01147	30.2490	3.40091
25.8703	3.65696	100.0000	0.00000	30.6224	3.32953
26.1775	3.24531			31.4108	3.20388
26.3140	2.88392			32.3237	3.10394
26.8601	2.26406			33.6100	2.99258
27.3720	1.84523			34.9793	2.85551
27.7474	1.52692			36.1826	2.77841
27.8840	1.43598			37.3859	2.68418
28.2594	1.38572			38.4232	2.59852
28.5324	1.33307			39.9170	2.47858
28.7372	1.29956			40.6639	2.38150
29.4198	1.32110			41.4938	2.34152
29.7611	1.32349			41.7427	2.33581
30.4437	1.40247			42.4481	2.27299
31.1263	1.33785			43.3610	2.25585
31.8430	1.33067			43.6100	2.31868
32.4915	1.29717			43.9419	2.25871
33.0375	1.33067			44.2739	2.32153
33.8567	1.33067			44.7718	2.29298
34.4027	1.40965			47.0954	2.30725
35.7679	1.41683			50.2075	2.30440
36.1775	1.39051			53.5685	2.29869
37.1672	1.38093			58.9627	2.27299
37.6792	1.30195			63.8174	2.28000
38.2594	1.28999			69.1286	2.28441
38.7031	1.32110			74.9793	2.28641
39.3857	1.26366			80.4149	2.27299
39.8635	1.28520			82.2822	2.26728
40.3072	1.25648			82.6556	2.27870
40.9215	1.25648			83.5685	2.25300
41.2969	1.25648			85.2697	2.25390
41.8430	1.17750			87.3029	2.26728
42.4915	0.00000			90.9544	2.25014
43.1741	0.86398			93.3195	2.25871
44.0614	0.10531			95.3112	2.25300
44.4710	0.22736			97.8008	2.25014
44.6758	0.16514			99.9585	2.25871

45.2218	0.15796	100.0000	2.22730
46.2799	0.08377		
47.2014	0.07898		
47.7133	0.15317		
48.8055	0.15317		
49.0785	0.18907		
49.5222	0.15796		
50.3072	0.12684		
51.2628	0.08616		
51.9795	0.08616		
52.2526	0.10770		
53.5495	0.10770		
56.0068	0.10531		
57.2014	0.08855		
59.4198	0.08616		
62.5939	0.08855		
64.0614	0.08137		
64.8464	0.07419		
65.4949	0.04069		
68.1229	0.03829		
72.1160	0.03351		
75.5290	0.02393		
77.1672	0.01436		
80.0000	0.00000		
100.0000	0.00000		

25 kHz, 25% Duty Cycle
November 13, 1991, (time in micro-seconds)

Time	Source V	Time	Current	Time	Cell V
0.0000	0.00000	0.0000	0.00000	0.0000	2.35193
0.3042	0.06318	2.2593	0.00000	0.2269	2.35193
0.7099	0.06804	2.6161	0.13880	0.8045	2.34907
0.8282	0.34994	2.8029	0.13880	1.2584	2.35479
1.0986	1.34629	3.4485	0.28003	1.9185	2.35479
1.3521	2.19684	4.0430	0.46510	2.3724	2.37768
1.6225	3.05225	4.5866	0.71591	2.7849	2.42918
1.8761	3.77643	5.0453	0.82062	3.2800	2.52647
2.2310	4.62697	5.5379	1.02516	3.8783	2.63519
2.6535	5.45808	6.2005	1.22727	4.5384	2.73820
2.8732	5.87606	7.0498	1.46591	5.4048	2.85837
3.1606	6.18226	7.7973	1.69724	6.0031	2.95565
3.4310	6.47874	8.6806	1.93831	6.6013	3.04149
3.7521	6.70717	9.4621	2.16477	7.2202	3.13591
4.0732	6.87728	10.1586	2.32305	7.6122	3.15021
4.3268	7.01823	10.7871	2.48377	7.9010	3.19599
4.6817	7.01823	11.2967	2.58604	8.3961	3.27039
6.2873	7.00851	11.5006	2.59091	9.0562	3.33619
6.6085	6.95018	11.6874	2.62257	9.6545	3.40200
6.9296	6.93074	12.1631	2.63474	10.2114	3.47926
7.1831	6.78007	12.6897	2.52760	10.7684	3.54220
9.4986	6.77035	12.9615	2.51299	11.3254	3.60229
9.6507	6.70717	13.3692	2.39123	12.1300	3.57082
10.0901	6.62454	13.5051	2.39123	12.5219	3.53076
10.2592	6.65857	13.7429	2.29870	12.8314	3.48498
10.5127	6.60996	13.8958	2.29870	13.2027	3.43062
10.6817	6.47388	14.2016	2.18182	13.5946	3.35908
10.8676	6.25030	14.4054	2.17451	14.2960	3.26752
10.9859	5.83232	14.7622	2.02841	14.5642	3.20172
11.1042	5.50182	15.5096	1.86282	15.2862	3.13591
11.2901	4.95747	16.1891	1.68263	16.0908	3.05579
11.5437	4.27217	16.9026	1.50487	16.6684	2.98999
11.7296	3.89307	17.3443	1.36851	17.7411	2.87840
12.0000	3.24666	17.5821	1.36364	18.6900	2.80401
12.3380	2.71689	17.8199	1.28328	19.4740	2.73248
12.6423	2.17254	18.5674	1.12500	20.5467	2.64950
13.0986	1.60875	19.7225	0.89610	21.2068	2.58083
13.4873	1.22965	20.4700	0.73539	22.2589	2.48355
13.7408	1.12758	21.1495	0.56250	23.3729	2.40629
13.8592	1.05954	21.8460	0.46266	24.3631	2.32904
13.9775	0.99149	22.4236	0.35552	25.2708	2.32904
14.2479	0.98177	23.2729	0.22159	26.3435	2.35479
15.5662	0.98663	23.9864	0.06575	28.1382	2.35193
15.8197	1.14702	24.5470	0.02679	29.2934	2.35193
17.7127	1.06440	26.1224	0.00000	31.0469	2.36910
18.0000	1.01580	40.0000	0.00000	33.2336	2.36624
18.5408	1.01094			35.6679	2.34907
18.6930	1.05468			36.5962	2.35765
18.8451	1.00122			37.8752	2.36338
19.3183	1.00122			38.5147	2.36338
19.7408	1.07412			39.3192	2.35765
20.6704	1.06440			40.0000	2.35193
21.5155	1.13244				
21.5324	1.08870				

22.9014	1.07412
23.4254	0.93317
23.6958	0.92345
23.8648	0.97205
24.3211	0.93803
24.5577	0.89429
25.0310	0.82139
25.2169	0.11179
25.4197	0.51033
26.0282	0.35480
26.2310	0.05346
26.4169	0.32564
26.6535	0.03402
26.8056	0.01458
26.9239	0.13609
27.3972	0.06318
27.9549	0.02430
28.5972	0.00000
40.0000	0.00000

500 Hz, 50% Duty Cycle
November 13, 1991, (time in micro-seconds)

Time	Source V	Time	Current	Time	Cell V
0.0000	0.00000	0.0000	0.00000	0.0000	2.15518
2.0471	1.00724	9.1978	0.00000	24.4648	2.54097
5.1177	2.01158	19.4175	0.50794	39.7554	2.77883
15.3531	3.21852	33.7251	1.00866	57.0846	2.99057
31.7298	3.37482	51.0986	1.30880	70.3364	3.10370
47.0829	3.47902	59.2744	1.38240	84.6075	3.17041
65.5067	3.56874	71.5381	1.45166	102.9562	3.21392
92.1187	3.62084	80.7358	1.49495	146.7890	3.21972
122.8250	3.63821	92.9995	1.53824	188.5831	3.21392
156.6018	3.65557	175.7793	1.54690	209.9898	3.19072
245.6499	3.66425	230.9658	1.52525	293.5780	3.16171
344.9335	3.67004	380.1737	1.48485	503.5678	3.17041
498.4647	3.66136	561.0629	1.47042	704.3833	3.15881
770.7267	3.68162	753.1937	1.46032	864.4241	3.15301
939.6111	3.67873	910.5774	1.46898	1005.0969	3.13851
991.8116	3.69030	997.4451	1.47475	1015.2905	2.72951
1021.4944	0.22576	1017.8845	0.00000	1024.4648	2.40174
1038.8945	0.00000	2000.0000	0.00000	1046.8909	2.34953
2000.0000	0.00000			1093.7819	2.30602
				1152.9052	2.27701
				1222.2222	2.23640
				1367.9918	2.21030
				1516.8196	2.19579
				1692.1509	2.16389
				2000.0000	2.15518

1 kHz, 50% Duty Cycle
November 13, 1991, (time in micro-seconds)

Time	Source V	Time	Current	Time	Cell V
0.0000	0.00000	0.0000	0.00000	0.0000	2.13888
2.0000	1.01010	8.1716	0.03324	7.3052	2.22793
2.0429	2.00866	11.8488	0.23988	8.9286	2.35557
3.6772	3.01299	14.7089	0.48121	16.6396	2.50695
8.5802	3.32756	17.9775	0.62572	23.5390	2.64349
16.3432	3.33911	23.6977	0.79191	35.3084	2.76519
22.8805	3.43723	28.6006	0.97688	49.5130	2.85127
35.5465	3.50072	35.9551	1.11561	66.5584	2.95219
56.7926	3.54690	45.3524	1.24566	80.3571	2.99078
80.0817	3.59885	52.2983	1.34971	97.8084	3.05015
119.7140	3.64502	59.2441	1.40607	113.6364	3.07686
173.2380	3.67388	69.8672	1.44942	136.7695	3.09170
271.2972	3.69697	82.5332	1.50000	162.3377	3.11248
358.3248	3.70851	95.6078	1.53324	189.5292	3.11248
422.4719	3.72006	110.7252	1.55347	226.8669	3.10951
470.6844	3.72294	163.8407	1.56069	257.7110	3.12435
496.4249	3.70851	210.4188	1.55925	306.0065	3.11248
500.5107	3.37374	290.5005	1.54913	333.1981	3.10358
502.1451	2.55700	351.3790	1.54046	372.1591	3.10951
508.6823	1.38240	411.8488	1.52168	408.6851	3.11248
513.9939	0.25397	483.3504	1.49855	437.9059	3.10654
522.9826	0.19625	503.7794	1.49855	465.5032	3.10654
530.3371	0.21068	510.3167	1.10694	487.0130	3.10951
535.6486	0.13276	512.7681	0.71243	497.1591	3.10358
552.4004	0.11544	518.3673	0.00000	502.4351	3.00562
576.5067	0.10678	1000.0000	0.00000	504.0584	2.75925
595.9183	0.00000			507.3052	2.49804
1000.0000	0.00000			511.3636	2.31104

545.8604	2.26355
584.4156	2.23090
636.3636	2.19528
676.1364	2.18044
740.2598	2.14482
810.0649	2.16559
871.7532	2.16263
917.2078	2.15966
954.9513	2.14185
976.4611	2.14185
1000.0000	2.13888

5 kHz, 50% Duty Cycle
November 13, 1991, (time in micro-seconds)

Time	Source V	Time	Current	Time	Cell V
0.0000	0.00000	0.0000	0.00000	0.0000	2.20000
0.5111	0.11264	5.1783	0.00000	2.9561	2.22943
1.1073	0.67825	6.4450	0.15196	4.8986	2.27748
1.1925	1.10485	8.5934	0.33898	8.2770	2.40240
1.5332	1.50749	11.1509	0.45149	9.9662	2.47688
1.7888	1.98922	12.6854	0.57569	11.4865	2.50571
2.4702	2.60755	15.1407	0.66774	14.1892	2.58739
2.9813	3.07969	18.5166	0.84015	16.8074	2.67387
3.7479	3.42960	21.9949	0.96727	20.1014	2.72192
4.0034	3.50150	25.8824	1.08416	23.7331	2.77477
4.5145	3.52786	28.6445	1.18352	26.4358	2.83243
7.7513	3.53026	33.2481	1.28434	31.0811	2.89249
8.6031	3.56141	37.2379	1.37347	35.8953	2.94775
10.0511	3.53505	42.2506	1.46259	40.7095	3.01261
11.4140	3.52786	47.1611	1.54734	42.8209	3.06306
13.6286	3.60695	51.9693	1.59848	46.1149	3.09910
17.3765	3.60695	57.5959	1.64962	48.6486	3.10631
18.4838	3.64769	63.5294	1.68177	53.9696	3.09670
22.6576	3.64530	68.7468	1.72414	56.5878	3.11832
23.7649	3.68364	75.9079	1.76651	62.8378	3.12793
32.5383	3.69083	82.8644	1.79866	66.7230	3.17117
33.7308	3.72678	88.2864	1.81327	72.5507	3.18318
39.1823	3.73877	91.6624	1.83372	75.8446	3.18799
41.2266	3.77711	94.5269	1.84249	81.6723	3.19760
47.7002	3.77711	98.5166	1.85272	88.9358	3.20721
52.2146	3.80827	102.3018	1.84833	93.9189	3.21201
67.1210	3.81067	104.5524	1.70076	98.3108	3.22643
69.3356	3.84182	105.0639	1.55026	101.1824	3.22643
99.5741	3.86818	106.0870	1.32379	102.2804	3.21922
100.6814	3.46794	106.9054	1.14553	103.2939	3.07027
101.3629	2.58119	107.7238	0.92344	104.7297	2.91652
102.5554	1.72798	109.2583	0.72618	105.9966	2.77718
103.3220	1.32774	110.4859	0.52162	107.1791	2.62823
104.6848	1.21270	111.7136	0.27469	108.8682	2.49369
106.1329	1.24626	112.2251	0.05114	110.3041	2.39039
107.3254	1.20791	114.2857	0.00000	111.4865	2.27748
109.2845	1.26303	200.0000	0.00000	112.6689	2.28949
110.2215	1.26303			115.4561	2.28949
110.8177	1.20312			120.9459	2.29429
112.6917	0.18214			124.8311	2.29670
114.5656	0.17735			126.3513	2.25586
115.4174	0.11504			129.6453	2.27267
116.6951	0.13901			138.1757	2.27267
118.6542	0.11744			142.9899	2.27267
120.5281	0.08388			152.2804	2.26787
121.2947	0.03116			155.9966	2.26787
123.5094	0.10785			161.9932	2.26306
126.0647	0.07909			165.2027	2.26306
127.6831	0.12463			174.1554	2.25826
128.9608	0.14859			179.1385	2.25826
131.3458	0.07909			183.6993	2.24144
132.1976	0.11025			191.0473	2.22222
133.8160	0.07430			200.0000	2.20000
136.6269	0.07430				
139.6082	0.00000				
200.0000	0.00000				

10 kHz, 50% Duty Cycle
November 13, 1991 , (time in micro-seconds)

Time	Source V	Time	Current	Time	Cell V
0.0000	0.00000	0.0000	0.00000	0.0000	2.27378
0.1652	0.09632	2.7435	0.00000	0.0208	2.27378
0.3304	0.32107	6.0440	0.32351	0.7897	2.27666
0.5163	0.74431	8.9319	0.53871	2.0781	2.28242
0.6815	1.11208	11.9849	0.73368	3.0341	2.31412
0.9706	1.54991	13.3257	0.80878	4.3849	2.37464

1.1358	1.88558	14.6253	0.88533	5.9850	2.42939
1.3217	2.13076	16.1105	0.96620	7.0657	2.47262
1.5489	2.41097	17.0594	1.03408	8.0840	2.49280
1.7760	2.70286	19.4935	1.11496	9.6841	2.56196
2.0858	2.96848	21.3912	1.21028	10.9934	2.64265
2.3543	3.22825	23.2890	1.28827	12.5520	2.68300
2.4989	3.42966	25.5168	1.35471	14.7340	2.72334
2.8706	3.52306	27.4559	1.42114	16.4589	2.76369
3.0978	3.63106	29.7043	1.49769	18.2668	2.79251
3.5108	3.69235	32.2828	1.56990	19.3890	2.82709
3.6966	3.73322	34.7582	1.63200	21.0723	2.86455
3.9032	3.77408	37.1717	1.66956	22.9011	2.90202
4.8118	3.77408	39.9977	1.72010	24.2934	2.93084
5.9683	3.76824	42.0605	1.76921	26.3924	2.98271
8.1161	3.76532	44.1439	1.80965	28.1380	3.02305
10.6356	3.77700	47.2794	1.85442	28.6783	3.04035
11.8128	3.79451	49.0534	1.86453	30.6733	3.05475
12.9899	3.79743	50.4767	1.87753	31.9202	3.07205
14.5801	3.79743	51.1987	1.87753	33.5827	3.08069
15.5507	3.83246	51.6319	1.87753	35.6401	3.12680
16.5420	3.84121	52.1476	1.83420	37.2402	3.14986
17.9463	3.85289	52.8283	1.70422	38.8820	3.16715
18.6898	3.88792	53.5916	1.56268	41.6459	3.18156
21.1886	3.88208	54.2104	1.41392	44.0150	3.19885
22.7994	3.89083	54.7261	1.30560	44.4306	3.22190
24.5961	3.89959	55.5719	1.13807	45.2411	3.18444
26.4341	3.90835	56.3763	0.96187	46.1139	3.21902
28.4167	3.92878	57.2840	0.80589	47.3192	3.21902
30.3373	3.92878	58.1504	0.63403	48.5245	3.24496
31.3699	3.96381	59.0374	0.48382	50.0000	3.27378
33.2492	3.97548	59.9656	0.29896	51.1845	3.27378
35.2524	3.99883	60.8526	0.14876	52.4522	3.20749
35.8100	3.99299	61.8221	0.01878	53.5952	3.08646
37.9784	4.00759	62.2347	0.00000	55.0083	2.94813
39.7132	4.01343	100.0000	0.00000	56.5046	2.78386
41.6957	4.00175			57.7515	2.65706
43.1827	4.00175			59.1022	2.55620
45.3304	4.01635			60.7440	2.41787
47.5195	4.03386			61.7207	2.33718
48.9032	4.04262			62.6351	2.30259
49.4195	4.05429			64.6509	2.29683
49.9771	4.05721			67.0615	2.28530
50.2249	4.05429			69.8670	2.28530
50.3694	4.01635			73.6700	2.28242
50.5140	3.90835			76.8080	2.28242
50.6379	3.80911			80.9435	2.27378
50.7618	3.66900			84.8088	2.28530
51.0303	3.35377			88.6741	2.29683
51.0509	3.23409			92.0615	2.25072
51.1542	3.14069			95.3034	2.27089
51.1955	3.00934			98.2128	2.27089
51.2781	2.91302			99.9377	2.27378
51.3401	2.77875			100.0000	2.27378
51.4433	2.65616				
51.5879	2.55692				
51.6292	2.39930				
51.7118	2.30882				
51.7738	2.22125				
52.0216	2.08990				
52.1661	1.92936				
52.2487	1.84764				
52.2900	1.78926				
52.4966	1.76299				
52.6824	1.54991				
52.9715	1.49737				
53.1987	1.41856				
53.3846	1.37186				
53.5498	1.28722				
53.7150	1.22008				
54.0454	1.19089				
54.2313	1.21133				
54.7269	1.22008				
54.9541	1.25511				
55.2226	1.17630				
55.7389	1.16754				
55.9041	1.22300				
56.1106	1.19381				
56.9573	1.19089				
57.4530	1.18214				
57.9073	1.16170				
58.2997	1.15879				
58.6921	1.17338				
58.9605	1.19381				
59.3736	1.22008				
59.8073	1.22008				
60.3442	1.21716				

60.7779	1.21424
61.1703	1.21424
61.3974	1.20841
61.6246	1.12960
61.7485	1.04203
61.7898	0.97782
62.1615	0.00000
62.3681	1.15295
62.7398	0.04086
62.9670	0.66258
63.2354	0.01751
63.4419	0.33567
63.7517	0.26562
63.9376	0.22767
64.1235	0.17513
64.3300	0.11384
64.6191	0.12843
65.0734	0.10216
65.3213	0.07005
65.7136	0.06130
66.0028	0.08465
66.6843	0.07881
67.4897	0.08465
68.1092	0.10216
68.5223	0.11967
69.2864	0.08465
69.8027	0.03503
70.3809	0.01459
71.1037	0.01168
71.8472	0.02627
72.4461	0.02919
72.9624	0.04378
73.4374	0.02335
74.1602	0.04378
74.7591	0.05254
75.1927	0.05254
76.2460	0.04670
77.3199	0.05546
77.6503	0.06713
78.3525	0.09924
78.8481	0.09340
79.1992	0.06421
79.8807	0.05546
80.2111	0.05838
80.5828	0.07005
81.0785	0.06130
81.5948	0.04086
82.5861	0.03795
83.4121	0.04962
84.3001	0.03503
84.7338	0.02043
85.5186	0.02043
86.4273	0.02919
87.3153	0.03211
88.1620	0.04670
88.7196	0.02627
90.0000	0.00000
100.0000	0.00000

25 kHz, 50% Duty Cycle
November 13, 1991 , (time in micro-seconds)

Time	Source V	Time	Current	Time	Cell V	time	Lead DV
0.0000	0.00000	0.0000	0.00000	0.0000	2.32425	0.0000	0.00000
0.1342	0.01739	0.1651	0.01583	0.3214	2.31277	0.5752	0.00000
0.2168	0.05507	0.5986	0.01439	0.6221	2.31277	1.1505	0.00000
0.3511	0.31014	1.1558	0.01871	0.8709	2.30129	1.4792	0.00000
0.7124	1.04348	1.7337	0.01871	1.2442	2.29842	1.6025	0.00000
1.1461	2.06087	2.2601	0.01439	1.7937	2.30703	1.8285	-0.06975
1.5694	2.75942	2.4458	0.03166	2.1047	2.32425	2.2599	-0.18998
1.8379	3.12754	2.8277	0.05613	2.4780	2.36155	2.6502	-0.31304
2.1786	3.50725	3.1682	0.09067	2.9549	2.37877	2.9173	-0.37032
2.3025	3.53913	3.8803	0.18854	3.3074	2.41894	3.1228	-0.39301
2.5297	3.77101	4.6336	0.29793	3.7636	2.44763	3.3282	-0.40265
2.7568	3.95652	5.6140	0.44617	4.3961	2.48207	3.5336	-0.42079
2.9427	4.07246	6.4499	0.55699	4.7589	2.51363	3.8007	-0.43951
3.1492	4.11594	7.1207	0.65343	5.3810	2.54519	5.0334	-0.43951
3.4590	4.19420	7.8122	0.73546	5.7024	2.58250	5.0950	-0.42703
3.6758	4.24928	8.9164	0.85636	6.0135	2.60832	5.5265	-0.41456
3.9133	4.28116	9.8142	0.95423	6.6874	2.63702	5.7524	-0.40038
4.1404	4.30145	10.7224	1.05354	7.0710	2.66858	6.1428	-0.39641
4.6980	4.31304	11.7853	1.16005	7.4857	2.69727	6.6769	-0.37996
6.4739	4.31304	12.4458	1.22913	8.2219	2.71162	7.0262	-0.37089
7.2380	4.37391	13.7874	1.34715	8.6366	2.73458	7.6836	-0.37032
11.1926	4.37681	15.3148	1.46661	9.1239	2.75753	8.1972	-0.35728

13.4435	4.37971	16.8524	1.57311	9.6423	2.78910	8.5876	-0.35217
16.2519	4.42319	18.3488	1.66091	10.3370	2.80918	8.9985	-0.34310
17.9866	4.44928	19.5666	1.75302	10.9279	2.85796	9.3066	-0.33006
20.0310	4.46957	20.3612	1.80628	11.5604	2.88092	10.0462	-0.32779
20.1342	4.41739	20.6708	1.82642	12.2447	2.89813	10.7653	-0.31304
20.2272	4.32754	21.7131	1.83506	12.8357	2.94978	11.4432	-0.30567
20.3614	4.18841	21.9505	1.80915	13.5200	2.97561	11.9158	-0.29943
20.4853	3.98841	22.7141	1.68826	14.3494	3.01291	12.4088	-0.28922
20.8983	3.34493	23.3333	1.56736	14.8678	3.03874	13.0252	-0.28242
21.3629	2.59130	23.9525	1.43638	15.2100	3.06169	13.7237	-0.27675
21.6107	2.31594	24.7059	1.26223	15.8424	3.06456	14.3811	-0.26881
21.8379	2.08116	25.2528	1.13126	16.5785	3.09900	14.6276	-0.25860
22.0547	1.87826	25.8411	0.99885	17.1488	3.09900	15.1207	-0.25633
22.2509	1.67536	26.6254	0.84485	17.7605	3.11047	15.4905	-0.25180
22.4677	1.52174	27.4200	0.69229	18.3307	3.12482	16.2917	-0.25123
22.7672	1.37391	27.9360	0.58290	18.6936	3.16786	16.6615	-0.24216
23.1492	1.26667	28.3385	0.49223	19.0876	3.18221	17.2573	-0.23648
23.5312	1.16812	28.9061	0.40155	19.9689	3.21090	17.8942	-0.23025
23.8720	1.13913	29.3911	0.30512	20.4873	3.21951	18.4284	-0.22344
24.3263	1.13623	29.8555	0.21733	21.0368	3.22812	18.9625	-0.21720
25.4104	1.13043	30.3302	0.15256	21.3167	3.21951	19.3734	-0.21607
26.4223	1.12464	30.5263	0.09355	21.8351	3.18795	19.7637	-0.21210
27.2173	1.13043	31.2281	0.09211	22.1980	3.14491	20.0514	-0.21607
28.0124	1.12754	31.4345	0.02303	22.4469	3.12482	20.1746	-0.20699
28.5700	1.13333	31.8266	0.01439	22.9549	3.07317	20.3390	-0.19509
29.4683	1.16522	32.5387	0.01295	23.4215	2.99570	20.4828	-0.17807
30.0465	1.16522	32.8277	0.02447	23.8362	2.95839	20.9348	-0.02382
30.3975	1.17971	33.6429	0.01000	24.2820	2.91822	21.1813	0.12250
30.6970	1.17681	34.4066	0.00000	24.6345	2.86083	21.5100	0.25803
30.7383	1.12464	36.2126	0.00000	24.8730	2.82353	21.9414	0.38847
30.8725	-0.77681	37.3065	0.00000	25.2981	2.79770	22.3112	0.50416
31.0274	1.02029	38.3488	0.00000	25.7128	2.72310	22.8454	0.62268
31.2235	-0.17681	39.6078	0.00000	26.3453	2.68580	23.0508	0.65785
31.3371	1.41159	40.0000	0.00000	26.9155	2.65710	23.3385	0.68053
31.5333	-0.17971			27.6516	2.53659	23.6672	0.69924
31.6262	0.71304			28.1908	2.50502	23.9548	0.70888
31.8327	-0.28696			29.1654	2.42181	24.3041	0.71229
32.0496	0.54783			29.8393	2.37303	24.5300	0.70888
32.1322	-0.11014			30.3888	2.35294	25.1258	0.69924
32.3283	0.48406			30.7102	2.31564	25.5573	0.68393
32.4522	0.02899			31.2182	2.28694	25.6189	0.67259
32.6000	0.00000			31.7885	2.32712	25.9682	0.65217
40.0000	0.00000			32.4728	2.32999	26.1325	0.63516
				33.4577	2.33285	26.6256	0.61985
				34.2354	2.32425	27.1186	0.60397
				35.2307	2.32425	27.4474	0.59603
				36.1120	2.32712	28.1253	0.58526
				40.0000	2.32425	28.6184	0.57221
						29.0498	0.55350
						29.3785	0.54499
						29.8100	0.51664
						30.1387	0.49905
						30.4058	0.48715
						30.6934	0.47354
						30.9399	0.44234
						30.9605	0.34367
						30.9605	0.22741
						31.1864	0.20813
						30.9399	-0.50246
						31.4330	0.07713
						31.5973	-0.17240
						31.9055	0.08450
						32.3780	-0.07146
						32.4397	0.04310
						32.9122	-0.04764
						33.1587	0.02042
						33.7750	-0.01304
						34.4530	0.00964
						35.1721	0.00681
						36.0760	0.00000
						37.0005	0.00000
						37.7401	0.00000
						38.5208	0.00000
						39.0550	0.00000
						39.5069	0.00000
						40.0000	0.00000

40 kHz, 50% Duty Cycle
November 13, 1991 , (time in micro-seconds)

Time	Source V	Time	Current	Time	Cell V
0.0000	0.00000	0.0000	0.00000	0.0000	2.33333
0.1253	0.22284	2.0408	0.00000	0.3857	2.35774
0.2036	0.42652	2.1739	0.05187	0.6428	2.43217

0.2193	0.60144	2.3945	0.07841	0.8999	2.41297
0.3133	0.75000	2.6544	0.10736	1.0884	2.44418
0.3994	0.91054	2.8670	0.14475	1.2513	2.47059
0.4699	1.16933	3.0482	0.17973	1.4741	2.47539
0.5404	1.32748	3.2451	0.22919	1.6112	2.52101
0.6109	1.53834	3.5050	0.27503	1.7912	2.50420
0.6971	1.74920	3.7571	0.32207	2.1255	2.52341
0.7989	2.01518	3.9225	0.35826	2.6054	2.56423
0.8772	2.22604	4.0879	0.40531	2.9654	2.59544
1.0338	2.50399	4.2927	0.44632	3.3339	2.62905
1.1278	2.75799	4.4660	0.47889	3.7796	2.66747
1.1905	2.86821	4.6786	0.52111	4.2081	2.70108
1.2845	3.04313	4.8598	0.55971	4.6538	2.73469
1.3471	3.19649	5.0646	0.60193	5.1080	2.77311
1.4176	3.33546	5.2930	0.65259	5.5451	2.80672
1.5194	3.44808	5.5372	0.68758	5.8708	2.80432
1.6369	3.56070	5.7498	0.72376	6.1536	2.85234
1.7466	3.68770	5.9861	0.77684	6.7964	2.87635
1.7544	3.78115	6.1437	0.80217	7.0963	2.90996
1.8640	3.90815	6.4587	0.85163	7.7477	2.93878
1.9737	4.04473	6.6871	0.88902	8.1162	2.96038
2.0677	4.16933	6.9313	0.93245	8.4676	2.98920
2.1695	4.28195	7.1755	0.97346	8.8190	3.01080
2.2713	4.39217	7.3882	1.00241	9.3075	3.04202
2.4514	4.48802	7.6402	1.05308	9.7446	3.07803
2.5376	4.56230	7.8765	1.09168	10.3017	3.10684
2.6707	4.66294	8.1364	1.12786	10.6531	3.11405
2.7882	4.72045	8.4200	1.18456	11.0644	3.15006
3.0232	4.81150	8.6484	1.22316	11.3901	3.17167
3.2738	4.91214	8.9792	1.25694	11.6730	3.17167
3.4461	4.94808	9.2234	1.29674	11.9643	3.14286
3.6497	4.95527	9.4912	1.33896	12.4272	3.09724
3.7751	4.95767	9.7511	1.37515	12.9242	3.06363
3.9004	5.00080	10.0898	1.41496	13.1985	3.03241
3.9944	4.97204	10.4049	1.45476	13.6442	2.97959
4.2841	4.96486	10.6884	1.48975	14.0555	2.93397
4.6288	4.95767	10.9011	1.51870	14.3812	2.88836
4.8324	4.95767	11.1216	1.55006	14.8440	2.83073
4.9499	4.93131	11.3343	1.56333	15.1611	2.79952
5.5060	4.91693	11.5469	1.59469	15.6154	2.75870
6.0542	4.92412	11.9408	1.62485	16.0267	2.72269
6.3910	4.92173	12.1377	1.64777	16.4296	2.68187
6.6181	4.92412	12.3976	1.66827	16.9266	2.63866
6.8139	4.92412	12.7914	1.67310	17.4666	2.58583
6.9236	4.96486	13.0356	1.66586	17.8180	2.53061
7.1977	4.96965	13.2561	1.63932	18.3151	2.48259
7.4013	4.96486	13.4452	1.62244	18.7350	2.45378
7.5345	4.98163	13.6342	1.59952	19.0778	2.42257
7.7773	4.99361	13.8390	1.56815	19.5235	2.40816
8.3647	4.99361	14.0517	1.52232	19.7635	2.35774
9.0852	4.99121	14.2643	1.47889	20.0463	2.34814
9.6335	4.98882	14.3904	1.43546	25.0000	2.33333
10.0642	4.99121	14.6030	1.39445		
10.1974	4.98882	14.8314	1.34741		
10.2209	5.01757	15.0284	1.29916		
10.6125	5.02955	15.2568	1.21834		
10.9101	5.03195	15.3592	1.18094		
11.1059	5.03195	15.4852	1.15682		
11.2625	5.05351	15.7294	1.09288		
11.3800	5.03435	15.8396	1.06755		
11.4583	5.00559	15.9578	1.03016		
11.5445	4.94329	16.1704	0.97829		
11.5993	4.90016	16.4461	0.92521		
11.6306	4.83786	16.5879	0.89264		
11.6776	4.76118	16.7454	0.85645		
11.8108	4.50240	16.8951	0.82027		
11.9753	4.27955	17.0920	0.77081		
12.1084	3.94888	17.3677	0.71291		
12.2024	3.70447	17.5567	0.67310		
12.3120	3.51757	17.7930	0.62485		
12.4608	3.20847	17.9820	0.56936		
12.5783	2.92812	18.1159	0.54403		
12.7898	2.56629	18.3365	0.49940		
12.9934	2.29553	18.5964	0.45356		
13.2754	1.93610	18.8563	0.41013		
13.5103	1.62460	18.9981	0.37636		
13.6591	1.44968	19.2265	0.33052		
13.8706	1.31070	19.3919	0.28468		
14.0038	1.20288	19.5810	0.24970		
14.1291	1.15016	19.8330	0.20265		
14.3014	1.04712	20.0063	0.16405		
14.4424	1.00160	20.2583	0.12425		
14.6382	0.94169	20.4789	0.07961		
14.7713	0.92013	20.6364	0.03498		
15.1472	0.90815	20.9357	0.01086		
15.5858	0.89856	21.0539	0.01930		

15.9226	0.89856	21.3059	0.00965
16.1654	0.90335	21.6997	0.00965
16.4630	0.93211	22.0069	0.00483
16.9251	0.92492	22.6530	0.00000
17.2541	0.91773	25.0000	0.00000
17.9746	0.91294		
18.2566	0.90815		
18.6404	0.90335		
19.1338	0.89617		
19.5254	0.89617		
20.0580	0.88898		
20.2929	0.88419		
20.4809	0.88898		
20.7707	0.00000		
21.1153	0.90096		
21.4051	0.00000		
21.6635	0.43610		
21.9455	0.00000		
22.0395	0.17252		
22.3058	0.23722		
22.6530	0.00000		
25.0000	0.00000		

10 Hz, 80% Duty Cycle
December 10, 1991 , (time in milli-seconds)

Time	Source V	Time	Current	Time	Cell V
0.0000	0.00000	0.0000	0.00000	0.0000	2.09483
0.2079	0.67393	0.0414	0.07826	0.2484	2.76149
0.2910	1.87654	0.4549	0.85507	1.1592	2.80460
0.4157	3.29412	0.7857	1.21014	1.9044	2.83621
1.2887	3.40450	2.6466	1.01449	2.7738	2.89080
2.4528	3.33479	2.7707	1.13768	3.8916	2.82184
3.7415	3.41031	4.2594	0.92174	4.4298	2.87069
5.0302	3.30283	5.9135	1.15217	5.9616	2.87931
6.4437	3.44808	6.9474	0.91884	7.8660	2.94253
7.6077	3.31155	8.7256	1.07536	9.4392	2.82184
9.6447	3.49746	9.6353	0.91884	10.5984	2.88793
10.6009	3.37545	10.7105	1.01159	12.0474	2.79598
12.4301	3.49165	11.2068	1.14203	12.7512	2.80172
13.6357	3.32317	12.6128	0.86812	14.1174	2.93391
15.2154	3.50617	13.2744	0.93913	15.0282	2.79023
16.5873	3.30864	14.0188	1.05797	16.3116	2.92529
17.8760	3.43355	15.2594	0.77101	17.5950	2.78161
19.2479	3.27088	15.8383	0.90435	19.3752	2.95115
20.6198	3.43355	16.9135	1.04348	20.3688	2.81034
22.0748	3.27959	18.2368	0.78406	21.6522	2.94540
23.5299	3.52360	19.6842	1.11594	23.0184	2.81034
24.7354	3.27959	20.9662	0.80000	24.4674	2.93391
26.2736	3.52360	22.5789	1.10870	25.9164	2.81034
27.5624	3.31736	23.7782	0.82029	26.8686	2.89368
29.2252	3.50617	24.1090	0.98261	27.9451	2.88218
30.3477	3.32317	24.9774	0.97826	28.5247	2.79598
31.8443	3.52070	25.2669	1.08841	29.4355	2.79310
33.2577	3.31155	26.4662	0.85942	30.3463	2.89080
34.5049	3.45389	27.2519	0.97101	31.4227	2.82184
36.0015	3.23312	27.9962	1.10870	32.1265	2.80172
37.2902	3.46550	29.3609	0.79420	33.0787	2.93966
38.5374	3.28540	29.6090	0.92029	34.2793	2.79310
39.7846	3.45970	30.1053	0.92029	35.2729	2.86494
41.1980	3.23602	30.7669	1.05652	36.1009	2.95402
42.9856	3.51489	32.2143	0.73333	37.0945	2.82471
44.3575	3.35512	32.7519	0.90435	38.8747	2.92529
45.9788	3.49746	33.2481	0.92609	39.4957	2.91667
46.8934	3.37836	33.4549	1.06087	39.9511	2.84770
48.3484	3.53232	34.8195	0.75362	41.2759	2.93678
50.2608	3.31445	35.3985	0.90870	43.0147	2.82184
51.5079	3.45098	35.5639	0.93043	43.8013	2.89943
52.5057	3.29702	36.3083	1.09565	45.4159	2.78161
54.3764	3.46841	37.6316	0.74203	46.6579	2.83908
55.2494	3.30574	37.9211	0.92464	47.1961	2.96264
56.9123	3.51198	38.2932	0.95072	48.2725	2.79023
58.3673	3.32898	39.0789	1.12899	48.9349	2.79310
59.0741	3.35222	40.4850	0.80145	49.7629	2.91667
59.7808	3.52360	40.6504	0.97681	51.0049	2.78736
60.8201	3.35222	41.2707	0.97681	51.5431	2.87069
61.9841	3.44808	42.0150	1.09130	52.0813	2.87356
62.7740	3.44517	43.3383	0.85362	52.7437	2.94828
63.7302	3.35222	44.5789	1.08841	53.8201	2.81897
65.1436	3.52651	46.0263	0.79855	54.5653	2.88218
66.5986	3.34060	46.3985	0.92174	55.7245	2.92816
68.0121	3.43646	46.8947	0.92609	56.5939	2.86494
69.3840	3.27669	47.4323	1.03623	57.9187	2.93678
69.7997	3.38417	48.8797	0.77971	59.3677	2.80747

70.6727	3.38126	50.5338	1.05797	59.9473	2.87069
71.1716	3.44808	51.6504	0.81594	60.8167	2.90230
72.0446	3.28540	52.9323	1.09130	62.3071	2.80460
73.3749	3.46841	54.3383	0.81594	63.6733	2.93678
74.7468	3.29993	55.8271	1.12029	64.8325	2.74138
76.5760	3.50617	56.9850	0.88696	65.5777	2.79885
77.6568	3.33479	57.5226	0.98696	66.4471	2.92529
79.1119	3.52941	58.1429	0.98986	67.4407	2.80172
80.1927	3.36383	58.6391	1.08841	69.1381	2.94540
81.8556	3.53522	59.5902	0.90145	70.0489	2.89080
83.0612	3.31736	61.0789	1.11449	71.4151	2.88218
84.5994	3.44227	62.7744	0.87681	72.2017	2.95115
86.1376	3.25054	64.0150	1.03333	73.4437	2.83621
87.5094	3.44517	65.0902	0.80725	74.6443	2.92241
88.9645	3.27378	66.6617	1.03478	76.3831	2.82759
90.1285	3.46841	67.8609	0.79130	77.4181	2.89368
91.4172	3.32607	69.5150	1.10580	78.4117	2.79023
91.6251	2.05374	70.8797	0.80000	79.9435	2.80460
91.8367	0.00000	72.2857	1.11884	80.2747	2.90517
110.0000	0.00000	73.5677	0.85942	81.5582	2.76149
		75.0977	1.08986	83.0486	2.93103
		76.1729	0.87536	83.7523	2.81322
		77.9098	1.13043	84.8288	2.81034
		79.1090	0.82754	85.8638	2.96552
		80.5977	1.05217	87.2714	2.81897
		81.8383	0.74348	87.7268	2.87931
		83.4925	1.05942	89.0102	2.93391
		84.6917	0.73623	89.7554	2.85920
		86.3045	1.09420	90.7076	2.90230
		87.4211	0.74493	91.1630	2.91954
		87.9586	0.92899	91.4528	2.36782
		88.4962	0.95652	92.6948	2.30172
		89.3233	1.13478	94.4336	2.23851
		90.3571	0.79420	96.2138	2.19828
		91.1842	0.98551	98.1596	2.19540
		91.8367	0.00000	100.5608	2.15230
		110.0000	0.00000	102.7964	2.13218
				105.2390	2.11494
				106.5224	2.12069
				110.0000	2.09483

500 Hz, 80% Duty Cycle
November 12, 1991 , (time in micro-seconds)

Time	Source V	Time	Current	Time	Cell V
0.0000	0.00000	0.0000	0.00000	0.0000	2.16667
4.1173	1.97353	16.4779	0.00148	2.0534	2.24638
3.0880	2.45000	17.5077	0.28994	3.0801	2.39130
2.0587	2.85882	21.6272	0.37574	10.2669	2.46667
4.1173	3.02059	24.7168	0.47633	15.4004	2.54493
5.1467	3.10000	27.8064	0.52515	21.5606	2.63478
14.4107	3.17647	28.8363	0.57249	35.9343	2.72754
25.7334	3.22941	35.0154	0.63757	56.4682	2.81159
48.3788	3.27353	38.1050	0.69970	75.9754	2.83768
65.8775	3.29412	43.2544	0.76036	105.7495	2.85797
93.6696	3.31471	49.4336	0.80473	143.7372	2.87536
134.8430	3.32941	59.7322	0.85799	166.3244	2.88406
173.9578	3.33529	70.0309	0.90976	200.2053	2.88986
208.9552	3.30882	80.3296	0.94379	233.0596	2.88986
234.6886	3.32941	115.3450	0.95414	284.3943	2.89855
283.0674	3.33529	155.5098	0.96154	339.8357	2.90145
320.1235	3.33529	193.6148	0.95414	388.0904	2.91594
370.5610	3.34706	225.5407	0.95562	416.8378	2.91594
427.1745	3.33824	268.7950	0.95266	462.0123	2.91884
490.9933	3.34118	325.4377	0.95118	495.8932	2.92174
528.0494	3.34118	382.0803	0.95414	524.6407	2.91015
578.4869	3.33235	438.7230	0.95414	588.2957	2.91884
625.8364	3.33529	490.2163	0.94527	625.2567	2.92754
685.5378	3.32059	541.7096	0.94231	652.9774	2.91304
733.9166	3.32059	578.7847	0.94527	716.6324	2.92464
826.5569	3.31471	634.3975	0.94083	758.7269	2.91594
878.0237	3.31471	688.9804	0.93787	790.5544	2.91594
928.4611	3.32941	750.7724	0.93935	802.8748	2.90725
995.3680	3.32941	829.0422	0.93935	866.5298	2.91015
1044.7761	3.32647	898.0433	0.93639	914.7844	2.91015
1088.0082	3.33824	974.2534	0.94379	976.3860	2.90435
1143.5924	3.34412	1022.6570	0.94379	1044.1478	2.91015
1182.7072	3.34118	1098.8672	0.94083	1121.1499	2.91594
1230.0566	3.34118	1165.8085	0.94231	1191.9918	2.90725
1300.0515	3.34706	1228.6302	0.94379	1253.5934	2.90435
1352.5476	3.34412	1289.3923	0.94379	1317.2484	2.90725
1400.9264	3.34412	1377.9608	0.94231	1362.4230	2.91015
1449.3052	3.34412	1425.3347	0.94231	1411.7043	2.91594
1488.4199	3.35000	1487.1267	0.95118	1477.4127	2.91594
1529.5934	3.34412	1541.7096	0.95118	1516.4271	2.91304

1564.5908	3.33824	1578.7848	0.95710	1549.2814	2.91015
1589.2949	3.34412	1607.6210	0.95266	1574.9486	2.90435
1606.7936	3.34412	1618.9496	0.90680	1588.2957	2.90435
1608.8523	3.12353	1617.9197	0.86538	1593.4292	2.89855
1609.8816	2.84706	1617.9197	0.78107	1597.5359	2.81159
1612.9696	2.50588	1617.9197	0.67751	1600.6160	2.73043
1612.9696	2.00294	1618.9496	0.57840	1601.6427	2.66667
1616.0576	1.74412	1615.8600	0.43491	1602.6694	2.59130
1613.9990	1.37647	1621.0093	0.32692	1603.6960	2.47826
1618.1163	0.71176	1626.1586	0.24408	1607.8029	2.42609
1620.1749	0.16765	1623.0690	0.17604	1618.0698	2.39420
1621.2043	0.07059	1621.0093	0.11095	1629.3634	2.36522
1632.5270	0.03529	1621.0093	0.06953	1647.8440	2.34203
1639.7324	0.02647	1621.0093	0.02219	1664.2710	2.33333
1657.2311	0.00882	1625.1288	0.00444	1685.8317	2.33043
1673.4694	0.00000	1643.6664	0.00000	1701.2321	2.31594
2000.0000	0.00000	2000.0000	0.00000	1715.6057	2.29565
				1744.3531	2.29565
				1776.1807	2.28406
				1798.7679	2.27826
				1833.6755	2.26667
				1861.3964	2.25797
				1872.6899	2.25217
				1905.5442	2.24058
				1929.1581	2.22899
				1939.4250	2.22899
				1956.8789	2.23768
				1967.1458	2.23188
				2000.0000	2.16667

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1 kHz, 80% Duty Cycle
November 12, 1991 , (time in micro-seconds)

Time	Source V	Time	Current	Time	Cell V
0.0000	0.00000	0.0000	0.00000	0.0000	2.30747
0.4117	0.79066	2.8866	0.00000	0.4122	2.38021
0.8234	1.19912	5.7732	0.01744	2.0610	2.41513
1.6468	1.62801	7.0103	0.03343	4.9464	2.46460
2.0585	2.39825	9.0722	0.17151	7.4196	2.49370
2.8818	2.72794	11.5464	0.27180	8.6562	2.54898
4.1169	3.00219	12.3711	0.34157	11.5416	2.58390
5.3520	3.18308	13.6082	0.39244	16.0758	2.63919
11.9391	3.20642	16.0825	0.44622	18.9613	2.68865
18.9378	3.24143	17.3196	0.49855	22.6711	2.71775
28.4068	3.24726	19.7938	0.54942	27.6175	2.73521
38.6991	3.31437	22.6804	0.60320	37.5103	2.76140
53.5200	3.31729	28.8660	0.67733	45.3421	2.78758
72.0461	3.32312	31.3402	0.72238	52.7617	2.80795
86.4553	3.32604	34.6392	0.76453	59.7692	2.82250
92.6307	3.34938	39.1753	0.80378	70.0742	2.85160
96.3359	3.34063	43.2990	0.82994	72.5474	2.86033
102.5113	3.35813	48.6598	0.86337	84.9134	2.87779
107.8633	3.33479	56.4948	0.91279	96.4551	2.88943
115.6855	3.36105	65.1546	0.94477	107.9967	2.89816
120.6258	3.33771	75.8763	0.97093	121.5993	2.89816
125.9778	3.35230	84.1237	0.98256	131.0800	2.90689
131.7415	3.34938	106.3918	0.98983	140.9728	2.92144
139.5636	3.32604	120.8247	1.00145	151.2778	2.92144
145.7390	3.36397	143.5052	1.00872	171.0635	2.92435
159.7365	3.36105	168.2474	1.00872	178.0709	2.91853
164.6768	3.32604	190.9278	1.00581	191.6735	2.91562
177.4393	3.32604	221.4433	1.00436	206.5128	2.92144
184.8497	3.36105	238.7629	1.00145	232.8936	2.92144
191.0251	3.35522	273.8144	1.00000	244.8475	2.91853
196.3771	3.33187	294.4330	0.99855	255.9769	2.91853
206.2577	3.36689	327.8351	0.99855	268.7552	2.91853
210.7863	3.33771	352.9897	0.99855	284.8310	2.92435
214.0799	3.34938	383.5052	0.99855	301.7312	2.92726
229.3125	3.35230	416.0825	0.99855	312.8607	2.92726
249.4854	3.35813	435.0515	0.99855	327.6999	2.92726
271.7168	3.35230	464.7423	0.99855	341.7148	2.92726
286.9494	3.35522	489.4845	1.00291	353.2564	2.93307
298.8884	3.34938	504.3299	1.02035	373.0421	2.93307
317.4146	3.35230	531.1340	1.01017	383.3471	2.93016
331.4121	3.35522	558.7629	1.01308	390.3545	2.93016
348.2915	3.35813	596.7010	1.01453	407.6669	2.93016
375.8748	3.35522	620.2062	1.02035	418.7964	2.93016
397.6945	3.35230	658.1443	1.01890	429.1014	2.93016
415.3973	3.34646	691.1340	1.02035	449.2993	2.93307
442.1573	3.34646	710.9279	1.01744	463.3141	2.93307
465.2120	3.34646	731.5464	1.02180	482.6876	2.93016
487.4434	3.35230	764.9484	1.02471	500.8244	2.93016
512.9683	3.34063	781.0309	1.02180	512.7783	2.92726
536.0231	3.34063	792.1650	1.01744	526.3809	2.92144

549.1972	3.34354	804.1237	1.00000	550.2885	2.93016
576.3689	3.33187	809.0721	0.99128	560.5936	2.92726
592.8365	3.33479	810.3093	0.94477	577.9060	2.92726
620.8316	3.32604	811.1340	0.87645	602.6381	2.92726
638.9460	3.31729	812.3712	0.55669	614.5919	2.92144
658.2956	3.32896	814.4330	0.45640	629.0190	2.92144
677.2335	3.32604	815.6701	0.31977	640.9728	2.92435
691.6426	3.32604	817.7319	0.11047	653.7510	2.92144
708.9337	3.33479	819.3815	0.03924	667.3537	2.91853
722.5195	3.32896	820.2062	0.00000	676.8343	2.91562
731.1651	3.35813	1000.0000	0.00000	686.3149	2.93307
735.6937	3.34646			695.7955	2.90980
744.3392	3.35813			708.9860	2.90980
751.3380	3.33187			735.3669	2.90980
758.7485	3.32896			746.9085	2.91271
764.5121	3.34354			771.2283	2.91271
768.2173	3.35230			784.4188	2.91853
779.3331	3.35813			795.9604	2.90689
790.4487	3.35813			798.8458	2.90689
799.9177	3.35230			801.7313	2.90398
804.4463	3.34938			802.5557	2.83705
806.5048	3.33187			803.7922	2.77886
806.9164	3.19767			804.6166	2.70029
807.7398	3.08972			805.8533	2.61591
808.9749	2.25821			806.6777	2.55771
810.6216	1.79723			807.0898	2.48788
811.0333	1.61050			809.5630	2.44132
811.8568	1.40919			819.0437	2.41513
812.2684	1.30124			823.1657	2.41222
813.9152	0.85485			828.9365	2.38894
815.1503	0.65062			833.4708	2.37730
817.6204	0.47265			841.7148	2.36857
816.7971	0.33260			849.9588	2.35694
816.3853	0.17797			859.4394	2.35694
817.6204	0.06127			867.6834	2.35112
819.2672	0.00292			877.9885	2.35112
826.6777	0.00000			893.2399	2.35112
1000.0000	0.00000			905.1937	2.33948
				920.4452	2.32784
				932.3990	2.32493
				946.4139	2.32493
				957.1311	2.31620
				962.4897	2.31620
				968.6727	2.30747
				1000.0000	2.30747

5 kHz, 80% Duty Cycle
November 12, 1991, (time in micro-seconds)

Time	Source V	Time	Current	Time	Cell V
0.0000	0.00000	0.0000	0.00000	0.0000	2.22222
0.4124	0.05535	3.4038	0.00000	1.0315	2.30858
0.7216	0.29716	4.3321	0.01017	1.9598	2.33173
0.9278	0.57684	5.2604	0.02471	3.3007	2.35776
1.4433	0.89731	5.6730	0.04360	5.1573	2.38669
1.3402	1.07793	5.7762	0.06250	6.6013	2.40984
1.6495	1.27021	6.1888	0.11919	8.1485	2.44455
1.7526	1.52367	6.6013	0.15843	9.9020	2.47927
1.9588	2.15586	7.2202	0.18750	11.2429	2.50241
2.3711	2.33066	8.2517	0.22674	12.7901	2.52845
2.4742	2.53460	9.2831	0.26017	14.7499	2.56027
2.5773	2.73270	10.6240	0.29651	15.7813	2.57473
2.8866	2.79971	12.0681	0.35320	17.5348	2.60077
3.2990	2.92498	12.9964	0.38953	20.7323	2.63838
3.5052	3.05900	14.0278	0.42733	23.1047	2.65574
4.4330	3.16096	15.5750	0.46948	26.1991	2.68177
4.6392	3.20757	16.6065	0.50291	27.3337	2.68756
6.7010	3.22505	18.4631	0.54506	30.1186	2.70781
8.4536	3.25127	19.8040	0.58285	32.1815	2.71938
10.6186	3.25127	20.6292	0.59593	34.8633	2.73385
12.2680	3.27749	21.9701	0.59302	38.0609	2.73385
13.5052	3.25710	23.0015	0.63808	41.9804	2.74542
14.5361	3.28915	24.0330	0.67006	43.2182	2.75410
15.7732	3.26001	25.5802	0.69477	45.5905	2.78303
17.0103	3.28332	27.4368	0.71512	46.6220	2.78592
18.0412	3.25710	29.8092	0.74564	48.2723	2.78592
19.4845	3.28332	31.4595	0.76308	50.1289	2.78303
21.5464	3.28332	33.8319	0.78343	52.9139	2.78592
22.4742	3.26001	36.3074	0.81686	55.6988	2.78303
23.0928	3.30371	38.3703	0.83721	57.9680	2.79460
24.8454	3.27167	40.9489	0.86192	61.6813	2.80617
27.1134	3.30954	42.9087	0.88372	64.6725	2.81196
30.1031	3.32411	45.7968	0.90552	67.1480	2.81485
34.8454	3.32993	48.9943	0.93023	70.0361	2.81196

39.0722	3.32411	53.0170	0.94767	73.4399	2.81774
42.4742	3.32702	55.6988	0.95494	76.6374	2.81774
45.4639	3.32702	58.6900	0.96657	79.0098	2.82064
47.1134	3.36489	62.0939	0.97965	80.7633	2.82064
49.0722	3.36198	65.0851	0.98983	82.5168	2.83799
51.7526	3.36198	68.4889	1.00291	84.7860	2.83799
54.7423	3.36489	70.5518	1.01599	87.2615	2.83510
58.0412	3.36489	73.1305	1.01890	90.1496	2.83799
63.2990	3.37655	77.4626	1.02762	92.3156	2.83510
66.1856	3.37655	80.4538	1.03052	93.5534	2.84089
73.4021	3.37072	83.2388	1.03343	96.5446	2.84957
78.6598	3.36781	86.6426	1.03488	98.1949	2.85824
84.0206	3.36781	89.8401	1.04360	100.4642	2.86114
89.6907	3.37072	93.3471	1.04360	102.7334	2.85824
97.1134	3.37655	95.8226	1.04797	104.4868	2.85824
101.9588	3.37946	98.0918	1.05523	107.5812	2.85824
105.0515	3.37363	101.4956	1.06105	111.7071	2.86403
108.7629	3.36198	106.4466	1.06250	113.0480	2.86692
113.9175	3.37655	110.8819	1.05959	115.4203	2.87271
117.5258	3.38237	114.0794	1.06250	117.9990	2.88139
121.7526	3.38237	118.9273	1.06105	119.4430	2.88139
123.5052	3.38237	122.8468	1.06105	122.7437	2.89007
126.7010	3.39111	126.4569	1.06250	125.1160	2.87850
131.0309	3.39403	135.1212	1.07122	129.1387	2.87560
134.3299	3.39694	139.1439	1.06831	132.1300	2.88428
138.0412	3.39111	142.5477	1.07267	136.9778	2.88139
140.7216	3.39111	146.2610	1.07413	142.8571	2.88139
144.8454	3.38529	148.2207	1.07413	146.5704	2.88139
149.2784	3.38529	152.6560	1.07994	150.1805	2.88139
150.0000	3.40859	157.0913	1.07703	153.0686	2.88139
153.8144	3.39403	160.1857	1.07267	155.2346	2.88428
157.2165	3.39403	162.1454	1.06977	156.7818	2.88717
159.7938	3.37363	162.8675	1.04215	158.3290	2.88428
161.0309	3.36489	163.3832	1.01599	159.2574	2.86982
161.2371	3.21049	164.3115	0.89680	160.0825	2.85535
161.7526	2.65987	164.4146	0.83866	160.4951	2.84089
162.2680	2.29862	165.0335	0.77326	161.0108	2.80617
163.0928	2.11508	165.3430	0.69622	161.5266	2.78013
163.4021	1.53532	165.8587	0.60610	162.2486	2.71360
163.8144	1.45666	166.4776	0.52616	162.8675	2.65863
164.4330	1.26730	167.3027	0.42297	163.3832	2.56895
164.6392	1.16242	168.0247	0.32558	163.8989	2.52266
165.4639	1.01967	168.2310	0.15407	164.5178	2.47059
166.7010	0.95557	168.7468	0.09593	165.2398	2.42719
167.6289	0.88857	168.8499	0.04797	165.8587	2.38380
168.1443	0.80699	169.3877	0.00000	166.1681	2.34619
168.2474	0.70211	200.0000	0.00000	167.0964	2.35198
168.5567	0.57684			168.0247	2.36066
168.8660	0.00000			169.9845	2.35487
169.3814	0.28551			174.5229	2.34040
169.6907	0.00000			177.2047	2.34040
170.2062	0.27677			180.9180	2.33462
171.6495	0.00000			188.8602	2.32305
200.0000	0.00000			191.3357	2.32594
				193.9144	2.33173
				196.5962	2.32015
				198.5560	2.31726
				200.0000	2.22222

10 kHz, 80% Duty Cycle
November 12, 1991, (time in micro-seconds)

Time	Source V	Time	Current	Time	Cell V
0.0000	0.00000	0.0000	0.00000	0.0000	2.29878
0.4479	0.17567	2.6884	0.00431	0.0822	2.29878
0.5700	0.56443	3.2994	0.02157	0.7401	2.27019
0.8143	0.83225	4.3177	0.09490	1.3980	2.25590
0.9772	1.26710	6.0285	0.18692	1.8914	2.24732
1.5879	1.74802	8.0244	0.28181	2.7549	2.27591
1.7508	1.98704	9.2057	0.33214	3.7007	2.31022
1.8730	2.20590	10.1833	0.37815	5.1398	2.35597
2.1580	2.50540	11.4460	0.41984	5.9622	2.37312
2.4837	2.73002	12.3829	0.45291	7.7303	2.39600
2.7687	2.90281	13.6864	0.49461	9.0872	2.42173
3.0007	3.02952	15.1120	0.53630	10.8964	2.44460
3.0537	3.08423	16.0489	0.56794	12.6234	2.47891
3.2573	3.13031	17.9226	0.62401	14.1036	2.49321
3.5016	3.16775	19.1853	0.65852	15.1727	2.51894
3.8274	3.23686	20.9369	0.70597	16.6941	2.53896
4.0309	3.27718	21.9145	0.72897	17.3931	2.58184
6.7997	3.30886	23.2994	0.75485	18.9145	2.59328
11.0749	3.29734	25.1324	0.79655	20.8470	2.59042
12.0114	3.32613	25.9878	0.81668	21.1349	2.61901
12.9886	3.31461	27.0876	0.83537	23.5197	2.63903

13.8436	3.33189	29.2872	0.86269	24.7122	2.65046
16.9788	3.36069	30.9572	0.90007	25.9868	2.65332
21.4984	3.38949	33.6049	0.92308	28.4951	2.67048
26.9951	3.39813	35.5601	0.95471	30.5510	2.68763
32.4511	3.38661	37.3523	0.97915	32.6891	2.70765
34.8127	3.38949	39.3483	0.99353	34.9095	2.72480
35.3013	3.43269	41.9145	1.00503	35.6497	2.73624
36.4414	3.40389	45.2138	1.02948	36.5132	2.74768
39.1287	3.41829	47.3727	1.04817	37.3355	2.77627
43.8925	3.42117	50.1833	1.05536	38.7336	2.72766
46.6205	3.42693	52.0163	1.07836	39.6382	2.74482
50.8143	3.43557	54.2974	1.08986	40.0493	2.77341
52.1580	3.47012	56.7006	1.10568	42.2697	2.74196
56.1075	3.47012	58.6965	1.11431	43.0921	2.75911
56.9218	3.43844	61.2627	1.12437	44.6546	2.75911
59.4870	3.44708	63.1365	1.13156	45.2714	2.78485
64.9023	3.46436	66.7617	1.14450	45.8470	2.75340
71.5798	3.45860	69.4094	1.15744	47.1217	2.75911
75.5293	3.45860	72.6680	1.16319	47.9852	2.80772
77.2801	3.45284	75.3564	1.16319	48.9720	2.74196
78.9088	3.46148	77.5967	1.17613	49.8355	2.81344
79.7638	3.25990	78.5743	1.18045	50.6579	2.75625
80.1303	2.89129	79.9185	1.18045	51.4803	2.83059
80.2524	2.42765	81.4257	1.05679	52.3849	2.75340
80.6189	2.03600	82.4033	0.89144	52.9194	2.79914
80.9853	1.58675	83.6253	0.60963	54.2763	2.79914
81.5961	1.17207	84.5214	0.41409	55.3454	2.80200
82.1661	1.02232	85.9878	0.17254	55.7566	2.80486
82.8990	0.93017	86.8024	0.00575	56.0855	2.76483
83.7541	0.91289	97.2709	0.00431	56.6612	2.81630
85.1792	0.88409	99.0224	0.00000	57.6480	2.81630
85.5049	0.83801	100.0000	0.00000	59.3750	2.83345
86.4414	0.84665			61.5543	2.85633
87.2150	0.00000			63.2813	2.85347
87.9072	0.52412			65.9128	2.84775
88.8844	0.00000			69.3668	2.83631
89.4137	0.04320			71.4227	2.84775
93.3225	0.01728			74.5888	2.84489
94.0147	0.03168			76.9737	2.83917
100.0000	0.00000			78.2072	2.85061
				79.8931	2.85919
				81.3734	2.78485
				82.8536	2.67334
				84.3339	2.53610
				84.9507	2.44746
				86.2664	2.37598
				87.5411	2.27591
				88.0757	2.35311
				88.6102	2.27019
				89.1036	2.33024
				90.5016	2.24446
				92.5164	2.24446
				94.3257	2.25876
				96.1760	2.25876
				97.1217	2.26162
				99.1776	2.25876
				100.0000	2.29878

25 kHz, 80% Duty Cycle
November 12, 1991 , (time in micro-seconds)

Time	Source V	Time	Current	Time	Cell V
0.0000	0.00000	0.0000	0.00000	0.0000	2.36812
0.0824	0.19144	2.6531	0.00000	0.0830	2.36812
0.1030	0.53372	2.9102	0.05630	0.5189	2.31884
0.1442	1.22988	3.2405	0.08518	1.1002	2.26957
0.2884	1.51704	3.9216	0.14148	1.2247	2.34203
0.4531	1.68528	4.5408	0.18912	1.8267	2.33623
0.5561	1.90573	5.2219	0.24398	2.6155	2.35942
0.6591	2.11168	5.9236	0.29740	3.5911	2.37391
0.7415	2.20160	6.4396	0.33782	4.5874	2.42319
0.8651	2.26541	7.1207	0.39269	5.6046	2.43768
0.9887	2.45975	8.0908	0.45476	6.7878	2.46957
1.0917	2.59608	8.6068	0.49086	8.0125	2.51884
1.3182	2.68600	9.2466	0.53850	9.2164	2.58261
1.4418	2.82814	9.8658	0.57170	9.9637	2.60870
1.5860	3.00798	10.4644	0.59769	11.0016	2.63188
1.6684	3.14141	11.1249	0.65111	11.9564	2.67246
1.7920	3.18492	11.7028	0.68431	13.6793	2.70725
2.0185	3.28644	12.7967	0.73773	15.7343	2.72174
2.3893	3.46918	13.4778	0.77093	17.7478	2.73913
2.6159	3.47788	14.1796	0.80703	19.4084	2.79130
2.8424	3.54170	14.8194	0.83446	21.7955	2.83188
3.1308	3.59971	15.4180	0.84745	24.1412	2.86957

3.3574	3.62292	15.6450	0.87777	26.4868	2.90435
4.0371	3.62872	16.2023	0.89076	29.0400	2.91884
4.4902	3.65772	16.6357	0.92397	31.1780	2.94493
5.0051	3.66062	17.4407	0.94273	32.9216	2.95942
5.5407	3.66062	18.0392	0.96728	33.7312	2.96522
6.0144	3.69833	18.8029	0.99615	34.6445	2.87536
7.2297	3.69253	19.8142	1.02791	35.5786	2.77971
7.8064	3.65192	20.3096	1.03946	36.8033	2.64928
8.8568	3.66642	21.1971	1.06833	38.0903	2.53043
9.9485	3.67223	21.9608	1.07844	39.0244	2.44348
10.7930	3.72444	22.4355	1.08277	40.0000	2.36812
11.5757	3.72154	22.8070	1.12031		
12.5438	3.72734	23.3024	1.12031		
13.7384	3.73314	23.5088	1.13908		
14.4799	3.74184	23.9422	1.14196		
15.4480	3.77665	24.3550	1.16506		
16.0659	3.77665	24.6646	1.16506		
17.0546	3.77955	24.9123	1.18239		
18.4552	3.78535	25.2219	1.18961		
19.5675	3.78535	26.1919	1.20404		
20.8033	3.78535	27.6161	1.23003		
21.5654	3.80856	28.5862	1.23725		
22.2245	3.80276	29.1022	1.27911		
22.6365	3.77955	29.9071	1.29933		
23.5839	3.78245	30.4850	1.30221		
24.5520	3.80276	31.0836	1.32243		
25.1699	3.80276	31.8266	1.32387		
26.0556	3.80566	32.7348	1.32387		
27.1679	3.80566	33.1476	1.31232		
28.6715	3.81726	33.3540	1.28633		
29.5778	3.81726	33.5604	1.24447		
30.6076	3.81146	33.8906	1.19682		
31.1226	3.81146	34.1176	1.14774		
31.4727	3.78535	34.8194	1.03802		
31.5963	3.71574	35.2735	0.93840		
31.7405	3.61131	35.6244	0.86333		
31.9258	3.39086	36.2229	0.75072		
32.0906	3.16171	36.7802	0.63956		
32.3378	2.93836	37.1723	0.57170		
32.5232	2.76722	37.5439	0.49374		
32.6056	2.61639	37.8947	0.42012		
32.9145	2.25671	38.2250	0.36670		
33.0793	2.10877	38.6997	0.28730		
33.3059	1.91153	39.1331	0.21655		
33.5118	1.75780	39.4840	0.15014		
33.6766	1.63307	39.8968	0.09528		
33.9444	1.44743	40.0000	0.00000		
34.1710	1.35170				
34.4593	1.22988				
34.6035	1.18347				
35.0154	1.07324				
35.2626	1.03263				
35.8805	0.99492				
36.7250	0.99492				
37.3841	0.98622				
37.8373	0.97172				
38.3110	0.96302				
38.9083	0.95431				
39.2997	0.94851				
39.6704	0.94851				
39.9588	0.50761				
40.0000	0.00000				