# TECHNICAL AND EXPERIMENTAL DESIGN FOR ELECTRICITY CONSERVATION POLICY: CONTINUOUS INFORMATION FEEDBACK

by

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## ABSTRACT

Energy conservation programs have focused on retrofitting and energy efficient devices, rather than on changing patterns of consumption. This assumes that potential energy savings from changed behavior are minor in comparison. Research has shown that residential electricity savings can be significant when electricity use is made visible by daily feedback. An interactive energy meter/display has been designed to test the hypothesis that people will change their consumption habits if they have immediate information on the amount and cost of the electricity they are using. The technical design is reported and recommendations made for improving the meter accuracy. An experimental design to measure consumer response to the continuous in-home feedback displayed by the meter is developed.

Thesis Supervisor: Dr. L. L. Bucciarelli
Title: Associate Professor of Engineering

Dedicated to Professor Bucciarelli for the intense learning experience this project has provided all too often over the past 17 months, to Jason Reyes, Steve Dixon, and Kerry Hooks for their hardware design effort resulting in two realised models of the interactive energy meter/display, and to the Buddha, Ganesh, and Maya: they pointed out paths leading to still waters where my mind could walk, unencumbered by the frustrations of software design.

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1. 80C85 uPROCESSOR, A/D ACQUISITION, AND DISPLAY HARDWARE DESIGN (SCHEMATICS) AND PRINCIPLES OF SIGNAL PROCESSING FROM ANALOG TO DIGITAL, THE REGIME IN WHICH THE uPROCESSOR CAN MANIPULATE BITS AND CONVERT FOR USEFUL DISPLAY.

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# INTRODUCTION

## Background to the Problem

The decade following the 1973 oil crisis in the U.S. was marked by an intense interest in energy conservation policy. Subsidies and other incentives were offered for energy efficient devices, energy saving home improvements, alternative energy technologies, and research into energy conversion techniques that could displace expensive oil imports. The U.S. Department of Energy published pamphlets and manuals designed to inform consumers about how to make energy efficient purchases, home improvements, and minor changes in energy consumption habits. It was thought that energy savings due to conservation could constitute a major new energy source for America (Hayes, 1976).

The assumption underlying these policies was that since the prices of heating oil, gasoline, and electricity were rising dramatically, and a larger share of consumers' incomes were going to cover these costs, people would be sensitive to any information that could help them reduce energy consumption without suffering inconvenience or change of lifestyle. The many economic analyses that estimated price elasticities of demand in various energy use sectors (industry, business, and residential) were partly based on a classic assumption which underpins dominant schools of economic thought, namely: consumers have perfect information on alternative supplies. As most consumers had, at best, a rough idea of what they could do to cut their own energy costs in the long run, and could not make well informed decisions about whether or not the additional costs of efficient devices could be recouped in energy savings, perfect information did not exist in the energy end use and supply marketplaces. Hence, the energy conservation information campaign was put into practice under the Carter Administration.

Two schools of thought dominate the literature on the role that information can play in motivating conservation in the residential electricity sector: economics and social/behavioral science. Both schools assume that consumers will act in accordance with rational models of decision making by judging the costs vs. benefits of energy efficient instruments and changes in energy consumption patterns. Both recognize that information is critical for consumers to make reasonable choices, but the form of information studied and recommended can be quite different. Cost-effectiveness and expected value of return on investment information has been analyzed in aggregate (regional and national) studies by economists, while field experiments by social scientists have focused on frequent feedback of energy consumption data coupled with goal-setting and price incentives in local studies.

Economics: Price elasticity of demand was thought to be quite inelastic due to the low price of electricity before 1973. Since then, it has been shown to be more elastic among consumers whose monthly budget share for electricity is significant (above 2%) [Bittle, et al., 1979; Hayes & Cone, 1977; Winkler and Winett, 1982]. In all-electric homes, the electricity bill can constitute a major household expense. Such households would benefit from home improvements to cut electricity costs if it were shown that their payback in energy savings due to the improvement would occur over a short time (1-5 years). Consumers could use payback information if it were freely available on cost saving home improvements (insulation, thermal pane windows, etc.), efficient appliances (energy consumption ratings on refrigerators and water heaters, watt-saving light bulbs, night-day thermostats, etc.), and alternate energy conversion systems (heat pumps, solar hot water heaters, wood stoves, photovoltaics, etc.). These items flourished in the market until the mid-eighties, partly because the government initiated an information campaign which detailed these and many other ways of saving energy and subsidized some of them via tax credits. Tax credits that amounted to price signals were sent to the marketplace to encourage conservation via energy efficient devices and capital improvement - a technical fix to the energy crisis.[1]

While capital improvement is one approach to long-term energy conservation, another economic strategy is to shift demand by instituting time-of-day pricing. This is commonly done in the industrial and commercial sectors by pricing high during peak demand times , when the marginal cost of producing electricity is at a maximum, and pricing low when base load plants (with cheaper per unit energy cost than the peaking plants) are able to supply a diminished demand. If this were done in the residential sector, some activities could be shifted to cheaper rate, nighttime hours. This kind of shift could result in net energy system savings, as efficient base load power plants could be utilized more fully (during off-peak nighttime hours) and the less efficient peaking plants would be needed less often.

Experimental Psychology: Incentives for capital improvement and demand management in electricity end-use sectors are the domain of the economist and the policy planner. Economic incentives are readily instituted in government policy, as we have seen in the decade following the oil crisis. Nonetheless, these do not exhaust all possible approaches to resource conservation.

During that very decade, experimental psychologists produced an impressive number of studies that showed further conservation was possible by using a different kind of

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[1] Note: the conservation information was not exclusively designed for a technical fix, as it also encouraged conservation by slowing down to 55 MPH, taking public transport, carpooling, lowering the winter thermostat setting, and other small changes in patterns of energy consumption.

information: feedback. [See bibliography citations for Becker, Bittle, Hayes, Seligman, Stern, Winkler, and Winnett]. It was noted that electricity is quite an invisible form of energy from the household's perspective. Commonly, the consumer is reminded of electricity use only at the end of the month by an aggregate bill. A hypothesis was proposed that if consumers were given more frequent reminders of their electricity consumption, they may become more conscious of their unproductive uses and conserve by changing habits. Well over 25 field studies, following experimental procedures developed by psychology and the social sciences, were produced (see Winkler, 1982). The results were mixed, contingent on experimental design, the population studied, and the type of information given as feedback.

Some common modes of electricity use feedback studied were: teaching the consumers to read their own meters daily, delivering postcards daily detailing the previous day's consumption and its relation to an average daily consumption figure drawn from a control group, and less frequent feedback with rebates for meeting target reduction goals. Only one study [McClelland & Cook, 1980] used continuous in-home feedback of electricity consumption. The results of that study indicate a different kind of conservation was induced by the continuous meter than resulted from other forms of feedback.

McClelland & Cook posit that their Fitch Energy Meter, giving continuous in-home display, was used by consumers to discover what individual household appliances were costing them, and were thereby sensitized to the costs of running non-heating or cooling appliances. It was found that the largest % reductions in electricity consumption showed up in off-peak months during the spring and fall when heating and cooling demand are less significant. Many of the other studies using daily or less frequent feedback of aggregate daily consumption data show largest reductions during the peak heating and cooling load months. This suggests that continuous information display may be more effective in motivating non-heating or cooling based electricity conservation than the other forms noted above.

Time-of-day pricing, the monthly utility bill, and daily feedback on electricity consumption share the disadvantage of aggregate numbers. When the consumer receives an aggregate consumption statistic, whether monthly, weekly, or daily, it is not apparent how much each home device has contributed to the total. With continuous in-home display, for the first time the consumption characteristic of each device can be seen. The type of conservation that results may well be quite different from those induced by a conservation information campaign, time-of-day pricing, or daily aggregate consumption feedback. The McClelland & Cook study did not conduct a values survey nor ask the users of the Fitch electricity meter how they used the device. This information could be quite useful in evaluating the underlying effectiveness of continuous in-home feedback of electricity consumption as a method for conservation.

Presentation of Technical and Experimental Design: As shown by McClelland & Cook, continuous feedback of electricity consumption information could be a significant mode for electricity conservation in the residential sector. This thesis reports the design of a feedback device and proposes an experimental design to test the potential effectiveness of continuous in-home feedback on electricity conservation. A values questionnaire has been developed to assist in this evaluation. The field experiment is designed to show: whether or not feedback can induce significant changes in electricity consumption; the factors bearing on information effectiveness; and the underlying causes for success or failure of immediate feedback to instill conserving patterns of electricity consumption.

The design, development, and testing of the 80C85 microprocessor based interactive energy meter/display and photovoltaic simulator is reported in Part I of the thesis. Both hardware and software are fully documented and a short history of how the design was affected by different views of the end use of this device in Chapters 1 and 2. Results of the field prototype test conducted in mid-April 1986, are presented and recommendations of design modifications necessary before deployment in an actual feedback experiment are made in Chapter 3.

A review of the literature and design of a field experiment constitutes the main body of Part II of the thesis. Chapter 4 is a discussion of the methods used in the social science paradigm of experimentation. In Chapter 5, methods and results of previous energy conservation experiments are presented.

In addition to the effect of immediate feedback on electricity consumption, we are interested in what effect, if any, decentralized renewable resource technologies might have on energy use awareness. To date, no field study of consumer response to decentralized generation system information feedback has been reported in the literature. The proposed experiment in Chapter 6 employs a simuated photovoltaic (PV) system and actual PV energy data (for houses with PV arrays) as continuous feedback treatment factors. A values survey is presented in Appendix 6 to be used before the study. A post study survey should be conducted to learn how the households used the feedback information. It is hoped that these surveys will yield insight into the causal relationships underlying any statistically significant correlations in the results. Though the actual field study will not be undertaken at this time, this section of the thesis should serve as a design guide for such, with recommendations on participant selection, setup of treatment groups, crossing treatments to test for experimental group equivalence, and evaluation of the results.

# CHAPTER 1 ENERGY METER/DISPLAY HARDWARE

This chapter contains a general description of the hardware design of the electricity meter to be used as a feedback device for energy conservation in the home. Conceptual design of the meter and motivation for its eventual deployment in a residential setting has been guided by Professor L.L. Bucciarelli (Ph.D 1966). The original design was done by Steve Dixon (B.S. 1965) and Kerry Hooks (B.S. 1985). Jason Reyes has added substantial modifications to develop a working prototype. The first unit was tested in mid-April, 1986 in Gardner, Massachusetts. Results of that test are presented in Chapter 3.

The meter/display is designed to perform three distinct tasks:

1) Home power data must be accurately sensed and converted into digital information that the microprocessor can use.[2]

2) This raw digital power data [currents (i) and voltages (v)] must be manipulated by the microprocessor so that accurate readings of power (i x v) and energy (power/unit time) can be accumulated in the memory.

3) Data stored in digital format in the memory must be accessed and displayed in an understandable format on demand by the user. Each of these functions is performed by a different part of the hardware as shown in Figure 1.1.

The data acquisition section employs three distinct sets of equipment and circuitry. Transducers that transform actual

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[2] Moreover, the maximum power output of a small photovoltaic panel must be determined for the PV simulation feedback. The prototype meter, Unit II, was developed for deployment in a home that has a 2 $kW_p$ array installed by the Gardner, MA Photovoltaic Project of the New England Electric Power, and so, did not include a PV simulator. Hardware and software for the PV simulator of Unit I (a demonstration unit) are presented in the Technical Appendices.

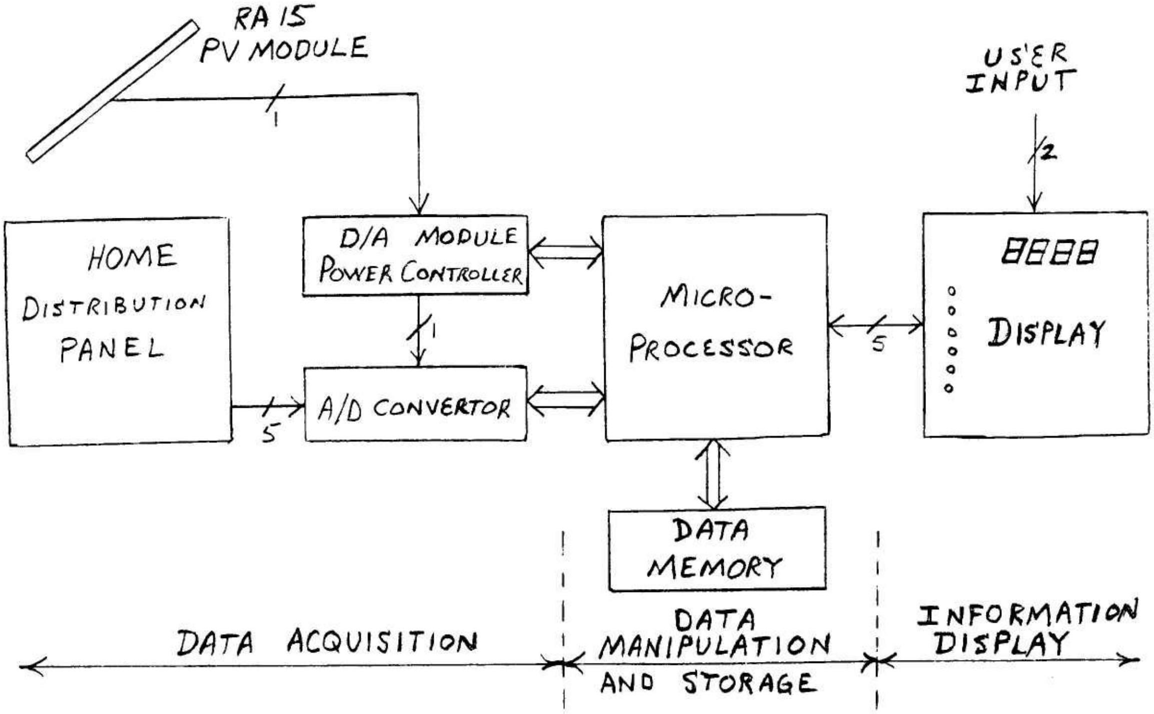


Figure 1.1 SIGNAL PROCESSING BLOCK DIAGRAM

home voltages and currents into small voltage signals comprise the first set. The RA 15 photovoltaic panel is also a part of this group of signal acquisition devices. Choice of equipment used in the prototype meter test is discussed in Section 1.1. The D/A module power controller is presented in Section 1.2. This circuitry controls the RA 15 PV panel current so that the software can determine the maximum power it would deliver if it were part of an actual PV array with a maximum power tracker. All analog signals are converted to digital values by the analog to digital circuitry. In Section 1.3, the stages of A/D conversion and some problems experienced in the prototype meter design are discussed.

All data acquisition, manipulation, storage, and display is controlled by the microprocessor through the software it follows. An 80C85 ONSET microprocessor board is employed in this design. Another 8K of memory capacity is provided by an additional memory board. Allocation of memory on the microprocessor boards is discussed in Section 1.4.

Data is sent to a portable LCD display on demand by the user. The display circuitry and its design for ease of installation and removal is discussed in Section 1.5.

## 1.1 SIGNAL ACQUISITION DEVICES

A schematic diagram showing deployment of all signal acquistion devices used in the prototype test is contained in Appendix 1.1. Also, the Appendix includes an overall view of the PV system installed by New England Electric Power in the house that the prototype test was conducted in.

Simpson amp clamps were employed to obtain voltage signals corresponding to house current. The decision was made to use amp clamps instead of conventional current transformers because, unlike transformers, amp clamps are removable and do not require an additional resistor to yield a small voltage signal. Ease of installation and removal of the entire metering and display device is specified as a design goal. It is important to make participation[3] in a field experiment as convenient as possible so that selection errors arising from refusal to participate are minimized. The use of amp clamps for current sensing meets this research design objective.

The current in each 120V house line must be converted to a maximum voltage signal of $\pm 5$ volts for digital conversion. The amp clamps were set to a ratio of 20 amps:1 volt. This setting allows measurement of instantaneous currents within the range of -100 to +100 amps (70 amps RMS). It was estimated that peak demand for the Gardner, MA home, in which the prototype meter was tested, would be ~60 amps RMS with all appliances being used at once.

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[3] See Chapter 6: Ease of Participation, and Implementation of Randomized Experiments in Chapter 4.

The line voltage of each house was reduced by the ratio 40V:1V by a pair of precision resistors. This signal reduction brings the peak voltage value for A/D conversion to well within the ±5 volt range.[4] Either direct voltage division, as used here, or an isolation transformer with a potentiometer can be used in the future. The ease of installation and removal design objective would best be reached by using isolation transformers that can be simply plugged into an existing 120 volt socket.

The current from the array invertor in the prototype test was obtained from existing circuitry in the invertor junction box. A 50 amp:0.1 amp current transformer across a 30 OHM resistor gave a 16.67 amp:1 volt signal to the A/D circuit input. Since the maximum output from the 2 $kW_p$ array was expected to be ~8.3 amps RMS (~12 amps peak), the prototype was modified to include a x5.5 op amp to amplify this signal before A/D conversion. The effective transformer ratio was then, 3 amps:1 volt (16.67/5.55). In order to standardize future meters, it is recommended that amp clamps be used to measure <u>all</u> currents.

It was not necessary to measure the array voltage (240V RMS) separately. The array line-to-line voltage is just the difference between the 120V lines, $V_2$ and $V_1$, or, $V_{21} = V_1 - V_2$. Hence, the software has been written to obtain $V_{21}$ from alternating samples of $V_1$ and $V_2$ for computing array power.

Technical specifications for the RA 15 PV panel are included in Appendix 1.1. The characteristic i v curves show a maximum power point for most efficient operation. Circuitry designed to find this point ($P_{NO}$) under varying sunlight intensity and temperature is described in Section 1.2.

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[4] Peak voltage of a 120V house line is ~170V. 170V/40 = 4.24V.

## 1.2 D/A PV MODULE POWER CONTROLLER

In the original design, the 15 $W_p$ PV module was to serve as a reference panel for the software to simulate the operating characteristics of an array of any size. Moreover, when the panel was not being tested to find the normal operating point, it would serve to charge the battery that provides enough storage capacity for six days of operation without recharging. In this way, the meter was to be powered entirely by energy from the RA 15 PV panel. The original D/A and power supply circuitry schematic is included in Appendix 1.2. In addition to PV module control, this board regulates battery voltage, generates +10V and -10V reference voltages, and emits a low battery signal when battery voltage drops below 11.6 volts.

The D/A PV module controller was designed to draw specified currents from the PV panel after electronically removing the panel from the battery charging circuit. It was to draw from 0 to 1.27 AMPS in .01 AMP steps. Once a PV amperage was specified by the microprocessor, the circuit was to draw that current from the panel. Then, a PV voltage was obtained, PV power was calculated, and that value was compared to a previous power. The maximum power obtained in this fashion was to be kept and used as the PV power output. After testing, the PV module was to be switched back into the battery charging circuit.

For a number of reasons, the low power comparator at the heart of the circuit never worked as designed. A redesign using two op amps drew as much power as the entire rest of the device and would have reduced battery storage capacity down to less than three days of meter operation. In the prototype unit, the array was replaced by small DC power supply as shown in the updated schematic for Unit II in Appendix 2.1. As of this writing, the PV power controller circuitry must be revised before a full array can be simulated to test one of the experimental hypotheses proposed in Chapter 6.

## 1.3 ANALOG TO DIGITAL CONVERSION

The analog to digital conversion circuitry determines measurement accuracy of the interactive electricity meter/display. All small voltage signals between -5V and +5 volts are converted into digital values between 00H and FFH (00 and 255) by the MP7574 A/D chip. Conversion is necessary because the microprocessor works only with discreet integers, not continuous levels. Hence, the microporcessor can record real values (power and energy) only as accurately as the digital values from the A/D chip correspond to the analog signals. A/D conversion timing is controlled by the 82C53 timer chip on the A/D board. This timer also generates the 1/4 second interrupt pulse which keeps the meter on time.

A/D board schematic diagrams, two A/D conversion data tables, and some oscilloscope photographs of signals in the A/D circuit are included in Appendix 1.3. The tabulated data and signal traces show errors due to: i) non-linear +5 volt shifting; ii) a non-zero bias introduced by the sample/hold chip; and iii) lag in the circuitry resulting in A/D conversion while the A/D input is changing. The data presented in the Appendix do not show another pernicious error which causes the A/D chip to yield intermittent random readings from 2 to 4 bits higher than the average readings. Despite these manifest difficulties in the A/D conversion circuit, the laboratory test results show that the meter displays power values within 1% of what it should display for non-zero voltage inputs.[5] For very

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[5] Laboratory accuracy can differ as much from accuracy in an actual home as clinical practice differs from that of a barefoot doctor. Indeed, the field test results presented in Chapter 3 show an <u>estimated</u> accuracy of 5% high: far outside of the design goal of 1% accuracy tolerance. This discrepancy could be a result of a high percentage of very small current signals over an average day in a typical residence. (The meter is not as accurate at small signals).

small input signal voltages, the random bit error mentioned above dominates the true readings.

The decreased accuracy at very small signal inputs leads to an immediate recommendation for redesign. The present design employs a +5V shifter before A/D conversion so that the ±5V input signals are raised to between 0 and 10 volts at the A/D input. If the shifter (designed to be linear but operating in a non-linear fashion) does not add exactly 5 volts to a very small input signal, the bias error can result in a large percentage error in computed power. In future designs it is recommended that the need for a shifter be eliminated by setting up the A/D chip to convert analog voltages between +5 volts and -5 volts. With such a design, a grounded signal input will result in a digital value that corresponds to ground, without exception. Moreover, the causes of delay in A/D circuit response, bias during Hold mode, and random A/D chip errors must be addressed if meter accuracy is to be improved.

## 1.4 MICROPROCESSOR AND MEMORY

Digitized signals from the A/D board are sent to the microprocessor board through the system bus and a connecting cable. The onset 80C85 microprocessor board has its own system clock port decoders, 5 volt reference voltage regulator, 2K random access memory and 2K read only memory. Currently, the meter command program resides in a 2K EPROM on a peripheral memory board with 8K of memory space. Memory allocation, port assignment, and schematic diagrams of each board are included in Appendix 1.4.

The original on-board 80C85 memory allocation has not been altered for the prototype. The 80C85 monitor program, which allows a terminal to communicate with the microprocessor and contains a number of useful utilities for debugging software, occupies the 2K on-board ROM. Future models of this meter could place the command program on board (in place of the monitor program), thereby extending memory storage capacity 73% from 116 days to 201 days without data compression.

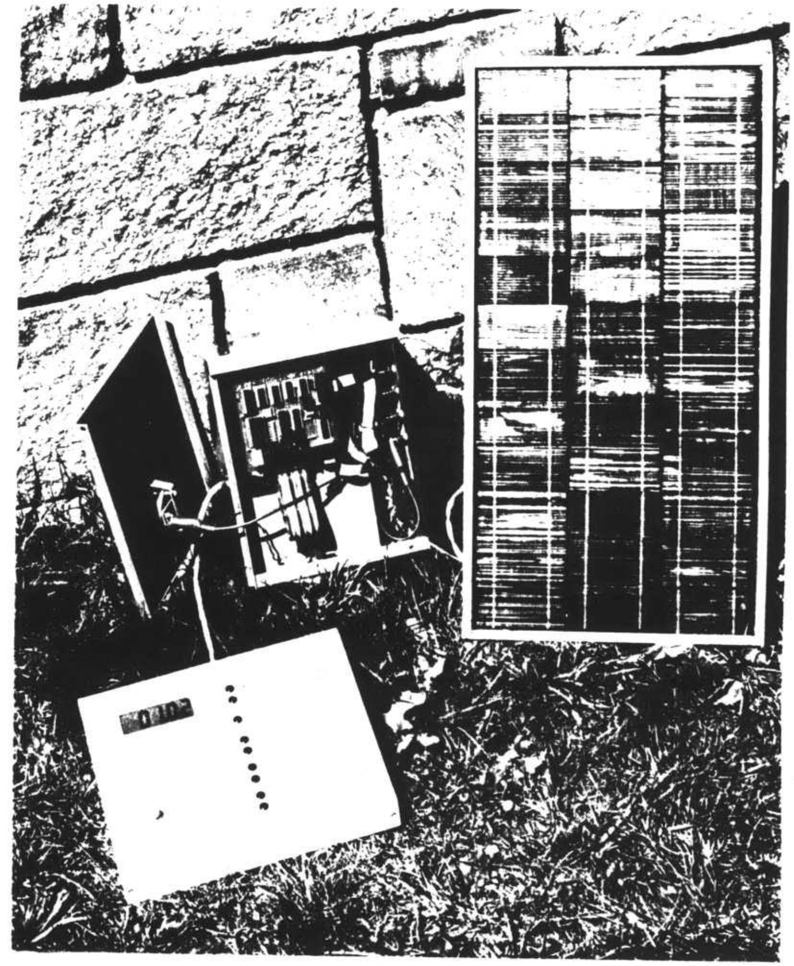
Just as the essence of any person is not in brain tissue or wrinkles of the cerebrum, the essence of the microprocessor is not in its address lines or substrate architecture, but rather in the software that it executes. In this light, with apologies to microprocessor systems designers, the software documentation of Chapter 2 should be considered as the natural continuation of this section.

## 1.5 PORTABLE LCD DISPLAY

From the perspective of a researcher interested in the effect on energy consumption of continuous in-home electricity information display, the display is the most important part of this device. In order to conserve on data lines, data is sent serially from the memory to the display through output port B. Every 1/4 second, new data is sent to the display where it is loaded into decoder/drivers for each digit. Data must be sent in an appropriate sequence to tell the display when a data send has begun, when all data has arrived, and what LEDs to light. Moreover, every 1/4 second, the microprocessor checks to see if either of the two buttons on the display have been set. If so, it responds by sending the appropriate data string to the display and lights the next LED. Two generations of displays are shown in Figure 1.2. Technical specifications and schematic diagrams for both can be found in Appendix 1.5.

The display of the prototype electricity meter is capable of displaying instantaneous array power (kW) and house demand (kW), daily energy consumption and supply by the array (kWh), the daily net bill ($), and an equivalent daily bill ($) for a house w/o a PV array. Also, it can display daily values as far back as 116 days. The unit is designed to be installed in a home with an existing PV array. If the difficulties mentioned


Prototype (Unit II)
Interactive Energy Meter/Display



Its Predecessor: A Stand-Alone
PV Array Simulator (Unit I)

FIGURE 1.2 TWO GENERATIONS OF DISPLAYS

in Section 1.2 can be surmounted, the same display could be used to show simulated data of a full scale array.

The six parameters for display were decided upon after long discussions, and are a subset of the nine display items on the first unit. The first unit was not designed as a feedback device, but rather as a solar powered demonstration unit. It has been suggested that a projected monthly bill based on each day's electricity costs would be a useful displayable parameter since it would relate daily consumption to a monthly bill. Normally, people have a much better idea of how much electricity costs them in one month than daily usage costs. To display a simulated monthly bill on the basis of electricity demand in one day would entail minor changes in the software and relabelling one LED on the face of the display. Such changes could be made in the middle of a field experiment by inserting a new EPROM with the appropriate software on it. The ease of changing the parameters for display, of installing and removing the display (attached to the microprocessor through a long, six line telephone cable with removable connectors: see Figure 1.2) and of installing and removing the microprocessor unit itself (via amp clamps and isolation transformers), makes this meter/display a most flexible research tool.

## CHAPTER TWO INTERACTIVE ENERGY METER PROGRAM

The main program for the interactive energy meter (without PV simulation) is stored on an EPROM at 4000H to 47FFH on the memory board. It uses memory space as shown in figure 2.1 below.

| | |
|---|---|
| 4000 - 47FF | Main Program EPROM |
| 4800 - 4FFF | Data Storage RAM |
| 5000 - 57FF | Data Storage RAM |
| 5800 - 5DFF | Data Storage RAM |
| 5E00 - 5EA4 | i,v Reading Temporary Storage |
| 5F5A - 5F7F | Default Database Values |
| 5F80 - 5FC2 | Non-Default Address Storage |
| 5FC3 - 5FFF | Stack |

Figure 2.1 Memory Allocation For Main Program

As mentioned in Section 1.4, future models could move the main program onto the microprocessor board and replace the monitor program. This move would free up an additional 2048 Bytes for data storage (68 additional days of storage @ 30H/day). In any case, some reworking of the program will be necessary to fit the whole package, including PV array simulation, onto one 2K EPROM as the main program without array simulation occupies 1948 Bytes of 2048 available on a 2K chip.

Moreover, the program now stores <u>daily</u> energies and cost data, only. To test Hypothesis II.(iii),[6] disaggregate data will be required. While hourly energy use data would certainly be sufficient to examine which times of day correspond to the most significant changes in electricity consumption, this detail may not be necessary. Data on at least two time periods

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[6] See proposed experimental design hypotheses in Chapter 6.

each day, however, are required for this purpose. A minor alteration in the program would enable separate storage of electricity use data from 9 AM to 6 PM and 6 PM to 9 AM.

As of this writing, to meet research objectives, the software must be streamlined to permit the program, including the PV array simulation routine, to fit onto one 2K EPROM and it must be altered slightly to store energy use data during at least two distinct times of day. The rest of this chapter will guide the reader through the main program initialization and 1/4 second interrupt routines, all detailed flow diagrams and full program documentation being consigned to Appendix 2.

## 2.1 INITIALIZATION

After the meter is turned on and connected to the terminal, the monitor program for the microprocessor is ready to receive commands. The initialization routine is loaded at 4000H in memory. To start the program, the microprocessor must be told to go to 4000 and execute the commands stored there. Once this is done, the initialization software takes over.[7]

Essentially, the initialization routine sets up the stack and memory allocation of Figure 2.1, copies default database values from the end of the main program on EPROM into RAM (5F5A - 5F7F) so that they can be changed before the main program is invoked, loads initial values into peripheral data acquisition devices and the display, clears the first day's memory locations to begin data accumulation, and sets up the timer chip for 1/4sec interrupts. The block diagram of this routine is shown in Figure 2.2 below.

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[7] See lines 4012 through 403D of the program in Appendix 2.

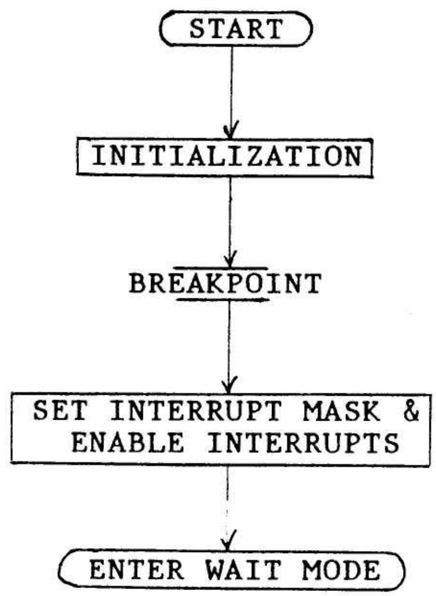


Figure 2.2 Flow Chart of Main Initialization Routine

The breakpoint, after all memory values and peripheral devices are initialized, stops the program and returns to the terminal screen. The operator can then change default values in the database.[8] Usually, the clock initial values (seconds, minutes, and hours) and the cost/kWh for electricity from the utility and sold back to the utility, must be entered at this time. Once the desired clock and electricity rate values are set in memory, the program can be continued.

The software takes over at this point and the meter will not 'talk' to an externally connected terminal until the reset switch is keyed. In order to download data from the meter's memory into a terminal or portable computer, the reset switch must be keyed to take the microprocessor out of the main interactive energy meter program, back into the monitor program

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[8] See lines 4776 through 479B at the end of the program for default values.

on the 80C85 board so that it can communicate with the external device.

After the program is continued from the breakpoint, an interrupt mask is set and the meter goes into wait mode. The 80C85 microprocessor is able to service four separate interrupts.[9] Since, the main program uses only one interrupt, the 1/4 second interrupt signal generated by the 82C53 timer chip, the other three must be hidden from the microprocessor. This is done by setting an interrupt mask for all but the 1/4 second interrupt. The 80C85 board is equipped with a wait mode that consumes less power than the normal operating state. When the power calculations are finished every 1/4 second, the program places the microprocessor into wait mode until the next 1/4 second interrupt arrives to wake it up. This timing sequence is flowcharted in Figure 2.3 below and is shown on the oscilloscope traces of Figure 2.5 in the next section.

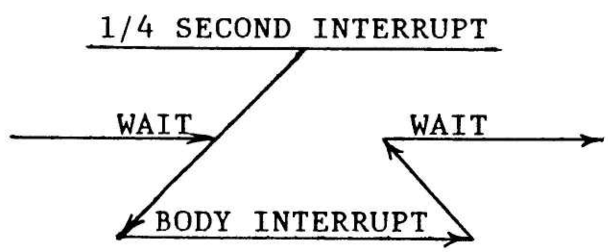



Figure 2.3 Interrupt Service of Main Program

In sum, the initialization routine prepares the memory space and external devices for operation, loads counter values into the 82C53 timer chip for A/D processing time and the system 1/4 second clock pulse, and allows changes to initial values (time, electricity demand charge, buy back rate, etc.).

---

[9] See the schematic diagram of the 80C85 board in Appendix 1.4. Note the interrupts A, B, C, and a non-maskable interrupt, each feeding directly into the microprocessor chip.

## 2.2 BODY INTERRUPT ROUTINE

Upon receiving a 1/4 second clock pulse, the microprocessor program counter is sent to location 10CD in its own on-board RAM. As this location is determined by the monitor program, it could easily be changed to the exact address of the body interrupt routine in future models. Nonetheless, the prototype program loads a statement at 10CD during initialization that tells the microprocessor to jump to 400C, and from 400C to 4040,[10] where the body interrupt program starts.

Body interrupt (BODINT) is the command module of the interactive energy meter program. The BODINT module calls subroutines from the body of the main program to perform timing, data acquisition, manipulation, and display functions and then returns to wait mode every 1/4 second. The flow chart for BODINT is shown in Figure 2.4 below and timing traces from an oscilloscope display of an induced signal on an unconnected line on the microprocessor board are shown in Figure 2.5

At the 1/4 interrupt, the microprocessor is rudely awakened and BODINT is invoked. The SECOND routine decrements a counter that counts down from 4. Upon reaching zero (four 1/4 seconds have elapsed), the increment time (INCTIM) routine is called. The INCTIM routine, which places new power values in memory, adds per second energy values to cumulative energy locations, and resets the down counter to 4, is presented in Section 2.3.

---

[10] See set interrupt routine at line 40B7 and body interrupt routine at line 4040 of the main program in Appendix 2.

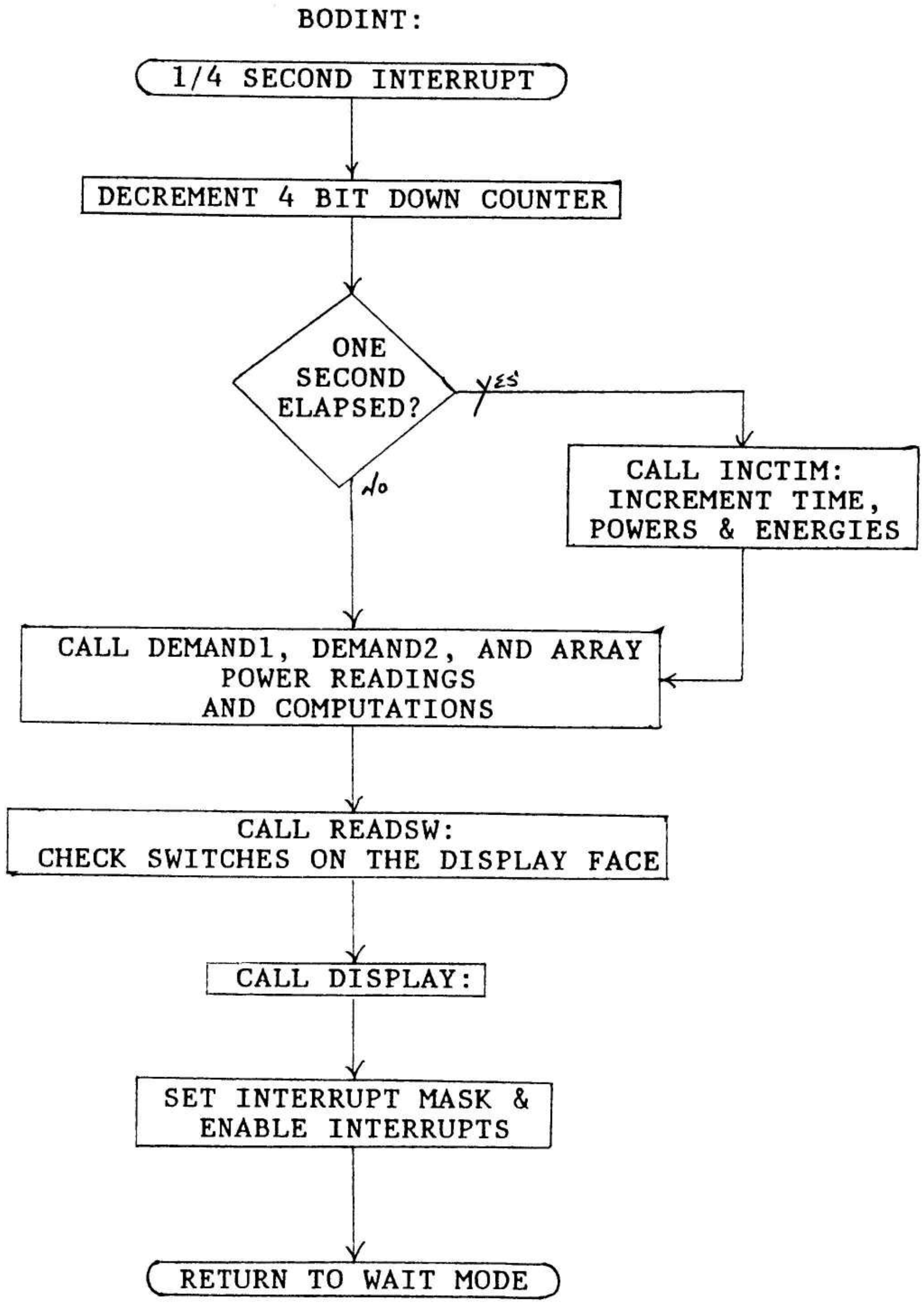
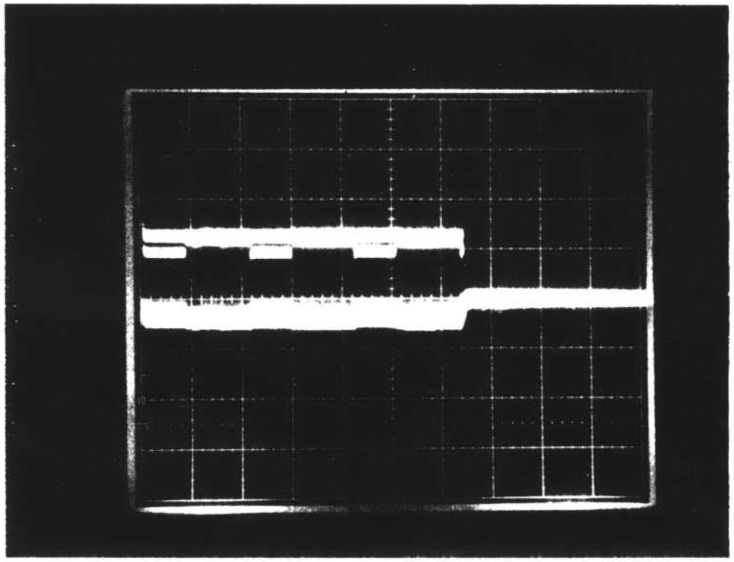
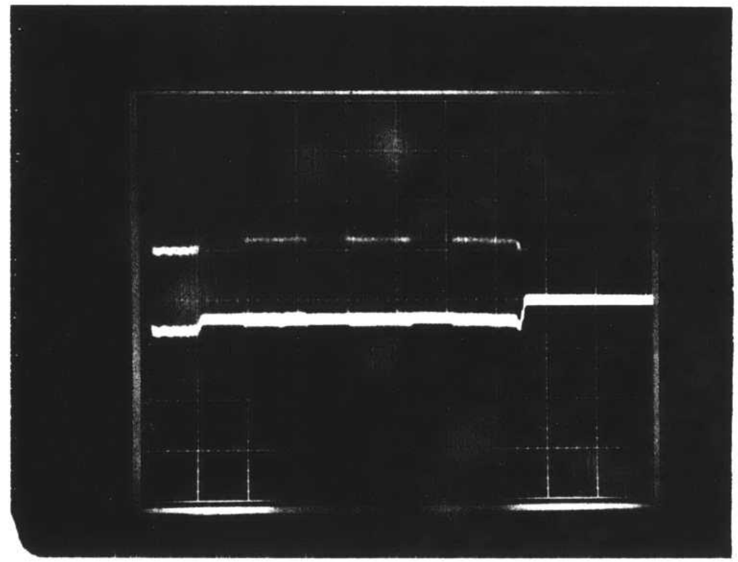



Figure 2.4 Flow Chart of Main 1/4 Second Body Interrupt Routine



Basic 1/4 Body Interrupt Service



One Second Service with Role and
Display of Data

FIGURE 2.5 MAIN PROGRAM TIMING REQUIREMENTS

Next, power readings are taken for each house line and the array invertor output. If the PV array simulation routine were included in this package, the max power point of the RA 15 panel would also be calculated at this time.[11] The power readings and calculations for two house lines and one invertor line consume the vast majority of microprocessor time as shown in Figure 2.5. The first oscilloscope trace of Figure 2.5 shows 2 distinct phases of microprocessor activity for each line measurement signal reading and power computation.

A detailed view of signal sampling during one reading cycle is shown in Figure 2.6. Each trace shows the A/D chip input for an alternating voltage on the voltage input and a grounded current input. The traces were triggered by the first read pulse of the reading cycle.

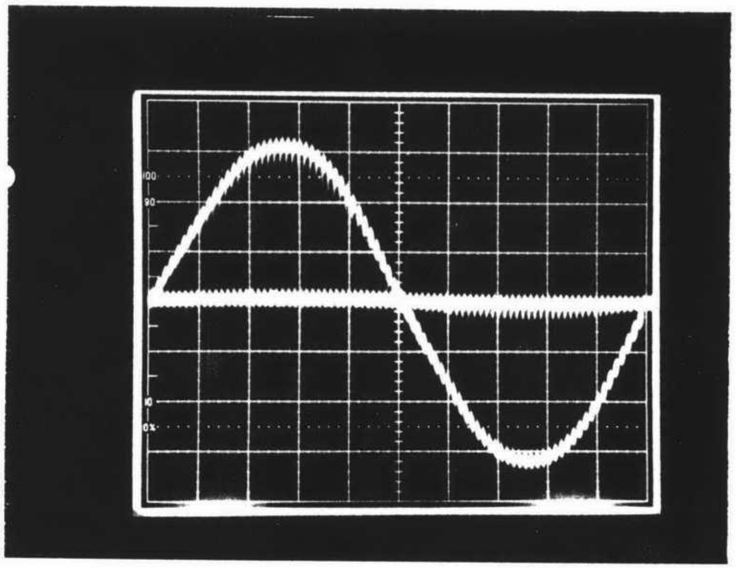
One signal reading cycle takes 165 readings over one full voltage cycle (1/60 sec. or 16.67 milliseconds). 83 current

---

[11] The power routine for house lines starts at line 43BA and the array power routine starts at line 4473. Both are flowcharted and documented in Appendix 2. Appendix 2a includes a PV array simulator routine entitled "Solar" and the corresponding lines in the 'Role' routine that converts raw PV data into simulated powers and energies. The Solar routine reads the PV panel open circuit voltage, $V_{oc}$ and short circuit current, $i_{sc}$. From the RA 15 i v characteristic curves contained in Appendix 1.1, it can be seen that the normal operating point for the panel is about 0.7 x ($i_{sc}$ x $V_{oc}$) for most levels of insolation and temperature. "Solar" calculates and uses this estimate of max power for the power and energy calculations.

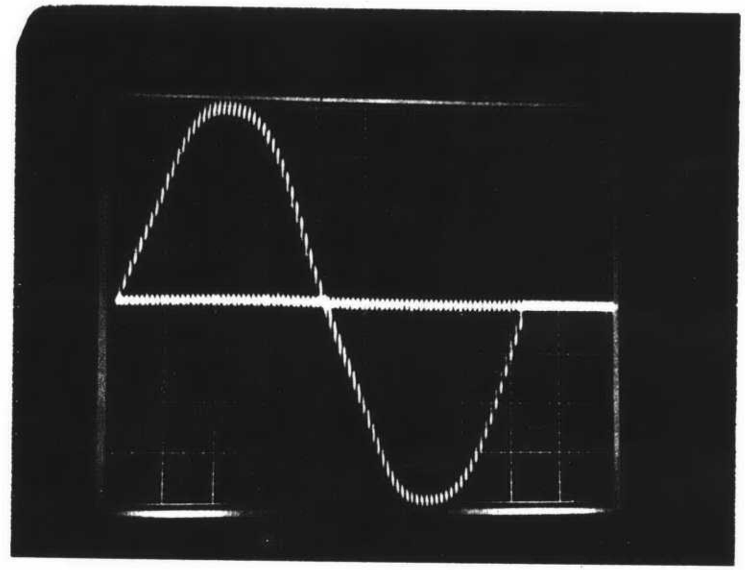
A more precise routine that requires more calculation time is found in Appendix 2b. This program, written by Kerry Hooks (B.S. 1985), is an untested power optimization routine. It computes power at a particular PV current and compares it to the power at 1/2 of this current. It retains the highest power and jumps to a PV current 1/2 of the previous current change in the direction of higher power. In this way it would take a maximum of 8 steps ($2^8$ = 256 possible current values) to reach the exact PV max power point.

The difficulties experienced with the D/A module power controller made stepping through PV currents impossible. Moreover, due to a component failure before the prototype field test that disabled accurate measurement of $V_{oc}$, both PV simulation routines were put on, hold pending hardware redesign.



$i_1$ = Ground    $v_1$ = 8v p-p

1.25 v/div, 10 div = 1/60 sec



$i_1$ = Ground    $v_1$ = AC Voltage Signal

1 v/div, 2 msec/div

FIGURE 2.6 INPUT SIGNAL READING CYCLE: A/D INPUT readings and 82 voltage readings are taken alternately and stored at 5E00 - 5EA4 in memory. The timing of the signal reading cycle is important and must correspond closely to an integral multiple of 1/2 voltage cycles. This is so because power flows in cycles of 1/2 the period (twice the frequency) of the system voltage. From Figure 2.6, it can be seen that the time required for 165 alternating readings is very close to one full voltage cycle (two full power cycles).

Power computations for each i v pair are carried out next. The compute loop starts at line 4427 in memory.[12] The current obtained immediately before and after each voltage reading is averaged. Each voltage reading is multiplied by its corresponding average current to obtain a power reading. Positive powers are accumulated separately from negative powers. Once all 82 i v pair products have been computed and added to separate + or - power locations, the power reading and computation cycle for the particular line is complete. In Figure 2.5, the computation cycles appear to require ~30 milliseconds each. Combined read and computation cycles require ~47 milliseconds/line. This results in the characteristic ~140 milliseconds required to complete 3 lines of power readings as displayed in Figure 2.5. Recall that power readings are taken every 1/4 second. Hence, power readings require ~60% of the 250 milliseconds available in each 1/4 second.

The Read Switch routine checks the switches on the display face to see if the user wants the next parameter to be displayed. If so, a pointer (DSPADR) is moved to the appropriate bytes for display in memory and the display register (DSPREG) is formatted appropriately. A flow chart for this routine is included in Appendix 2, along with detailed documentation in the body of the program at line 4450.

---

[12] Detailed documentation for the computation loop is found in the comments in the program itself and the power flow chart in Appendix 2.

Finally, the Display routine is called. Contingent upon which LED is lit on the display, the Display routine obtains data from memory, puts it into a proper format, and sends it to the display. Detailed documentation for the display routine and the subroutines that it calls (BCD and DSP), begins at line 45C9 of the program in Appendix 2. According to Figure 2.5, the trace with role and display of data shows a max time for the Display routine of ~4 milliseconds.

Once the new data is sent to the display, the BODINT routine goes back into wait mode for the rest of the 1/4 second. As the microprocessor is obtaining, manipulating, and sending data for nearly 60% of the time, and the microprocessor is clocked by a 6 MHZ crystal, this device generates a fair amount of radio frequency noise. Problems caused by this noise and implications for ultimate deployment of the interactive energy meter are discussed in Chapter 3.

## 2.3 INCREMENT TIME ROUTINE

The Increment Time (INCTIM) routine is called by BODINT every second. The flow chart for this routine is shown in Figure 2.7. INCTIM is stored at line 4116 in the memory. The 1/4 second counter that has counted down to zero is replenished to a value of 4. Then, Role routine is called to update all power and energy displayable locations. A flow chart for Role is included in Appendix 2 and the routine begins at line 4159 of the main interactive meter program. Once the powers, the energies, and cost locations have been updated with information gathered during the past second by the power reading routine, the seconds register is incremented. If the new seconds value is 60, the seconds register is cleared and the minutes register is incremented. Likewise, the hours register is incremented for a new minute value of 60. When the hour value is incremented to 24, the register is cleared, and the Ripple routine is called. Ripple, located at line 4316 in the program, moves 30H (48) bytes up in the memory for the new day's memory locations, clears those locations, and assigns labels to each new power, energy, and cost storage location.

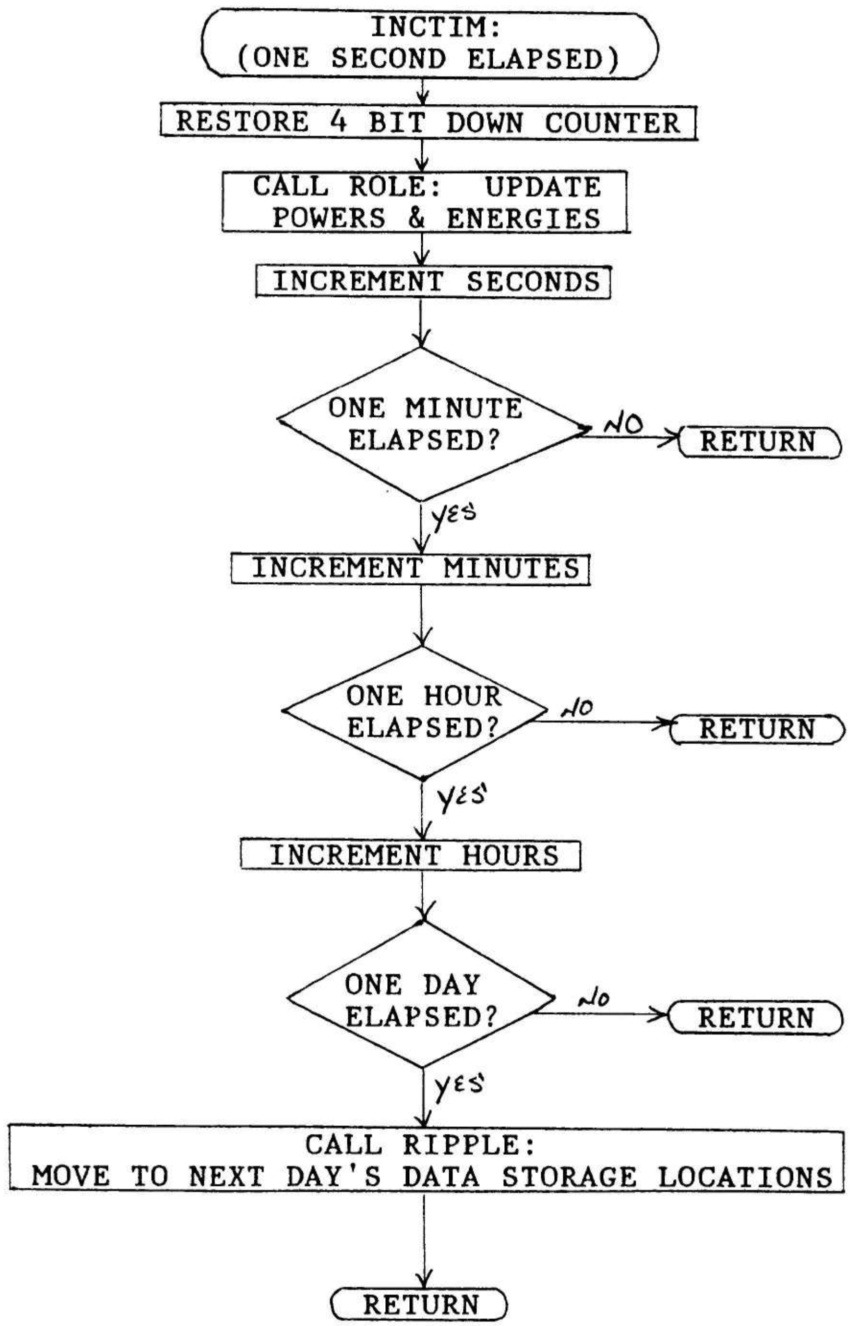



Figure 2.7 Flow Chart of Increment Time Routine

The Role routine is fully documented with a flow chart and detailed program annotation in Appendix 2. The mission of Role is to convert each of the raw power sums accumulated over the past second from the house electricity feeds and the array output[13] into data that reflects actual power and energy consumption for display. To do this, the turns ratio of each signal acquisition device must first be converted into a bit strength (V/bit and i/bit). Instantaneous i v products can then be interpreted in terms of real instantaneous power (Watts/bit). Finally, since the sums of 82 real power readings, accumulated 4 times each second, correspond to an average power used that second: (Each one second raw power sum) x (Power bit strength)/(82 x 4) = Average Power consumed (generated) during the past second.

This is the method used to calculate real powers and energies from raw data. The bit strength calculations are presented in detail in the body of the Role routine.

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[13] Actual array output data is gathered in this case, but Role would work in the same fashion with a single panel output to simulate a full scale array.

# CHAPTER THREE PROTOTYPE TEST RESULTS

From Thursday 10 April until Sunday 20 April 1986, the prototype interactive energy meter/display was installed in a home in Gardner, MA. The home had a 2 $kW_p$ array installed as part of the Gardner Photovoltaic Project of New England Electric Power Company (NEEP). Installation of the meter was subsidized by NEEP.

The homeowner, Leon Rice, was pleased to receive the display and learned to use it with only a few minutes of instruction. During the 11 day test, the display was almost always left on kW Array Power display. The Rice family was quite enthusiastic about seeing their (standard) electricity meter run backwards during a sunny day and were equally interested in what this meant in 'dollars and cents' as displayed by the 'net bill for the day' selection.

After Tuesday, 15 April, the 2 $kW_p$ array output dropped by 1/2 in full sunlight. After a few days, Mr. Rice called Prof. Bucciarelli to report the change, and to register his concern. On Monday 21 April, the meter/display power supply was disconnected in an attempt to eliminate the RF interference emanating from the meter and blocking the reception of television channels 4, 5, and 7. The interference was not mitigated. Only a few hours later, the program stopped running, probably due to a low battery voltage. The unit was turned off that evening.

Before unplugging the power supply, Mr. Rice read all displayable data to Prof. Bucciarelli over the phone. This data is tabulated in Table 3.1

Listed along with the display memory data for 11 full days is the percent sunshine measured at the U.S. National Weather Service station in Concord, N.H. This measure should correspond generally to the energy delivered by a PV system in Gardner, MA. Indeed, the daily energy supply delivered by the

TABLE 3.1 FIELD TEST ENERGY DATA FROM INTERACTIVE METER MEMORY

| DATE: APRIL | Th 10 | F 11 | Sat 12 | Sun 13 | M 14 | Tue 15 | W 16 | Th 17 | F 18 | Sat 19 | Sun 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| House Load (kWh) | 14.93 | 15.39 | 25.58 | 18.74 | 15.94 | 15.99 | 15.99 | 16.44 | 16.35 | 24.38 | 20.46 |
| Array Supply | 5.69 | 5.90 | 6.99 | 11.60 | 12.92 | 11.08 | 1.28 | 5.25 | 6.64 | 6.72 | 6.05 |
| % Sunshine (Concord, N.H) | 55% | 44% | 41% | 87% | 100% | 93% | 48% | 86% | 85% | 100% | 92% |

TABLE 3.3 ENERGY DATA: HOUSE kWh METERS

| TIME: APRIL | 9 (1:50 PM) | 22 (NOON) | ENERGY USED |
|---|---|---|---|
| House Load | 96799 | 96937 | 138 kWh Bought |
| Array Supply | 581 | 664 | 83 kWh Generated |

11 Days Total Demand 221 kWh

2 $kW_p$ array does correspond well with the Concord, N.H. statistics as shown in Figure 3.2.

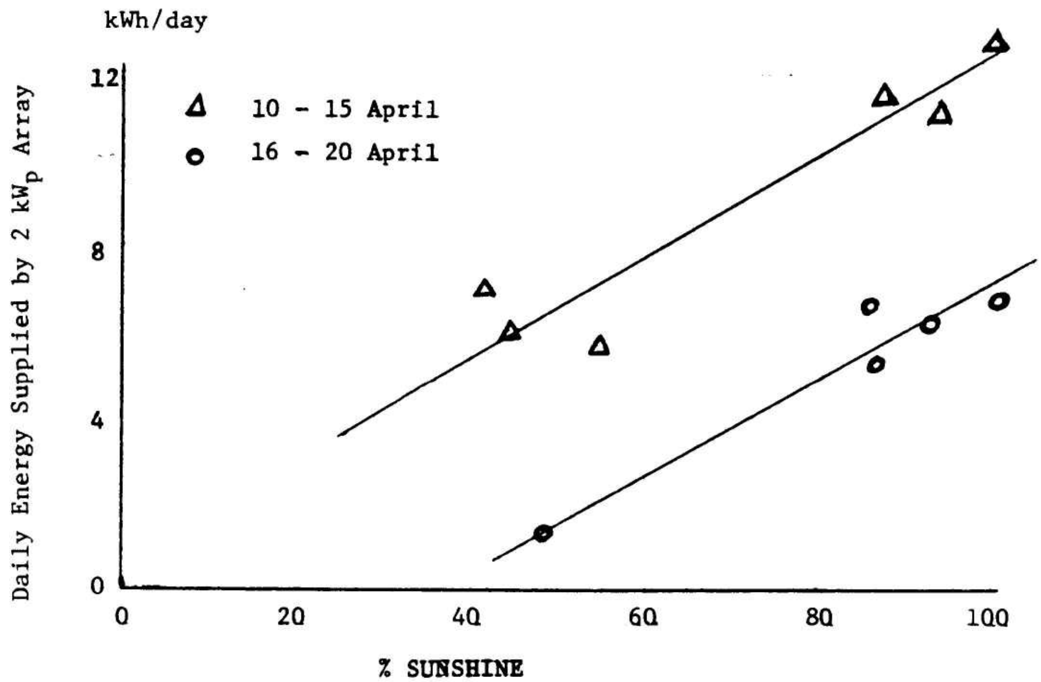


Figure 3.2 Percent Daily Sunshine at Concord, N.H. vs. Daily kWh Array Supply from 2$kW_p$ at Gardner, MA. 10 April - 20 April, 1986

In Figure 3.2, % daily sunshine (Concord, N.H.) is plotted against kWh/day produced by the Rice home's 2 $kW_p$ array (Gardner, MA) for 10-20 April, 1986. PV energy delivered relative to % sunshine from April 10 to 15 April is 2 times greater than daily PV energy / % sunshine from 16-20 April.[14] Mr. Rice had good cause to be concerned!

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[14] Daily data 10-15 April are fit to the line, $y = 0.115x + .97$. At 100% sun, this regression predicts the array will generate 12.5 kWh. For data after 15 April, $y = 0.108x - 3.7$ describes the linear regression which predicts 7.1 kWh @ 100% sun. Hence, after 15 April, the array output dropped by ~57%.

Unfortunately, the ill-timed PV system problem occurred during the data collection test designed to gage the accuracy of the interactive energy meter/display. The house meters (net house demand and PV energy supply) were read upon installation of our device at 1:50 PM Wednesday 9 April and again at noon 22 April, after the meter/display had been turned off. Hence, the meter memory data for 10 full days, tabulated in Table 3.1, must be compared with about 12 days of energy consumption / generation data from the Rice home electricity meters. This data is presented in Table 3.3.

Note that the utility meter data includes almost two full weekdays (two hours short) more electricity consumption data than the data gathered by the meter/display. Hence, if it is assumed that the family consumed at the average weekday rate of 15.86 kWh/day,[15] the interactive meter/display estimated demand from 1:50 PM on 9 April to noon on 22 April = 200.19 kWh + 31.72 kWh = 231.91 kWh. This estimated demand is about 5% higher than the actual demand of 221 kWh over the 13 day period. This estimated discrepancy is much more significant than the 1% accuracy found in the laboratory (see Section 1.3)

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[15] Average demand on the seven weekdays from Table 3.1 = 15.86 (S.D. = .53), while mean daily demand during weekends = 22.29 kWh/day (S.D. = 3.22).

# RECOMMENDATIONS

From the hardware and software design discussions and the prototype test results, it is evident that modifications to the equipment and program of the interactive energy meter/display will be necessary before being deployed as a feedback device for electricity conservation.

i) The RF interference problem must be resolved.

ii) The D/A module controller must be modified to allow, at least, accurate reading of $i_{sc}$ and $v_{oc}$ of the RA 15 PV module, and preferably to enable stepping through 256 different current values.

iii) The shifting in the A/D circuitry should be eliminated and sources of bias in the S/H stage minimized.

iv) The main program must be streamlined to be accomodated on a 2K EPROM with PV simulation subroutine.

v) The program should store cumulative data at least twice daily to disaggregate electricity consumption during the daytime from evening and nighttime demand.

# PART II FIELD EXPERIMENT DESIGN

Chapter 4 is a discussion of some of the issues in quasi-experimental design as an approach to limiting experimental error, thereby strengthening causal inferences in field research. In Chapter 5 the building blocks of quasi-experiment design are presented and used to analyze some recent experiments on residential electricity conservation that use information feedback, goal setting, and price changes to induce conservation. The final chapter uses these concepts and some of the more successful experimental designs of Chapter 5 to construct a proposed field experiment. This experiment is designed to measure the effectiveness in inducing conservation of the microprocessor based energy meter/display, presented in Chapters 2 & 3 and the Technical Appendices.

## CHAPTER 4 ISSUES IN QUASI-EXPERIMENTATION

Settings for field research differ from laboratory settings in two fundamental ways: 1) the researcher usually has far less control over all stimuli impinging upon respondents in field settings than in the laboratory and; 2) it is often not possible to select samples randomly in field research. Random selection and assignment are two of the strongest tools used in both field and clinical experiments to ensure both the comparability (equivalence) of treatment and control groups and the representativeness of the experimental sample. While laboratory experiments can be conducted under strict conditions to clearly show the magnitude and direction of treatment related effects between statistically equivalent groups, field experiments may be designed to show results with more robust policy implications, since "real world" settings often lead to a clearer choice between policy alternatives. Nonetheless, this fitness for setting appropriate policy is generally gained at a price. The actual social settings of field research introduce uncontrolled events that can affect results. Hence, field experiments generally suffer a loss of statistical robustness relative to controlled experiments in the laboratory. This tradeoff between relevance for policy choice and statistical robustness showing causal relationships is the problem that quasi-experimental design addresses.

"Quasi"-experiments differ from "true" experiments not necessarily by design, but rather by degree of control over external events and the possibility of differences between experimental groups. In a "true" experiment, all events other than the treatment under study are either rigidly controlled or measured. When this is not possible, such as is often the case in a field experiment in a social setting, the assumption (of a "true" experiment) that all experimental groups experience the same events except for the treatment, breaks down. Moreover, if samples are selected in a non-random fashion, such as obtained in an energy conservation study conducted in the homes of only those who volunteered to participate, the traditional ("true" experiment) assumption of statistically equivalent samples may also break down. Experiments conducted under conditions in which either of these assumptions does not hold, are called quasi-experiments.

The term "quasi-experiment", used in the social sciences, is a modification of the term "experiment" from physics, biology, and chemistry. Not only is the term a social science modification of a term from the 'hard' sciences, but the experimental methods employed also differ. A brief digression into the history of experimental method in the social sciences is in order before presenting experimental design issues from within the social science paradigm.

## 4.1 EXPERIMENTAL PARADIGM IN SOCIAL SCIENCE

The use of experiments in behavioral research has its modern roots in the logical positivism movement of the twentieth-century, which in turn arose out of the philosophies of the Enlightenment, classical British empiricism, most notably David Hume, and the nineteenth-century positivists John Stuart Mill and Auguste Comte.

Empiricism, as a school of thought, was clearly elaborated in the works of Francis Bacon, John Locke, and David Hume. "The conception that perception is the source and the ultimate test of all knowledge is the eventual result of their work".[16] The philosophy of empiricism (as opposed to idealism or rationalism) set the stage for the rise of positivism in Continental Europe in the 19th Century.

> Today's social sciences have grown out of moral philosophy (as the natural sciences have emerged from natural philosophy). ...With the ascendancy of positivism in the early nineteenth century, especially in France, positive philosophy, or social science, took the place of moral philosophy. Positivism, according to Auguste Comte (1830-42; 1844), emphasizes the factual as against the speculative, the useful as against the idle, the certain as against the indecisive, the precise as against the vague, the positive as against the negative or critical.[17]

The methods of inquiry espoused by Mill and Comte took hold in the twentieth century. Only then did intellectual excitement at the meeting of two traditions (moral and natural philosophy) spur the ambitious endeavor of applying methods from natural science to social settings.

The Vienna Circle of logical positivists, notably including Rudolf Carnap, served as a focal point of theoretical activity in the 1920s to inject positivism into general practice. The movement held that:

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[16] Reichenbach, H., The Rise of Scientific Philosophy, Los Angeles: University of California Press, 1951, p. 78.

[17] Dahrendorf, R., "Social Science", The Social Science Encyclopedia, edited by Adam Kuper and Jessica Kuper, Boston, Routledge & Kegan Paul, 1985, pp. 784-785.

"i) explanation of facts require promises in the form of laws - and these laws depend in their validity on confirming evidence;

ii) only the data of experience can be used as grounds for validity of knowledge claims;

iii) and that it is logically possible and empirically plausible that there is a unitary set of explanatory assumptions from which the empiricial laws and even all the individual facts and events of the world could, in principle, be derived".[18]

This last thesis of physicalism or the unity of science, attributed to Carnap who proposed it more as a research approach than as a truth, contains a heavy dose of reductionism that he applied, along with B.F. Skinner, to psychology and the social sciences. In their views: "Since the testing basis of psychology, <u>if it is to be scientific</u>, must be in the data of everyday or experimental observations of behavior, the concepts and propositions of the science of mind must be "reducible" to the concepts regarding the overt behavior of organisms (man included, of course)".[19]

The experimental techniques of 'control' and 'blocking', developed in the physical and biological sciences, were first applied in a rigorous fashion to people in social settings after logical positivism started to dominate psychological experimentation in the 1930s.

What impact has positivism had on the development of social science methodology, and what are some critical responses to this development which, in Comte's words, "emphasizes the positive as against the negative or critical"? Jeffrey C. Alexander of UCLA notes that,

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[18] Herbert Feigl, "Positivism in the 20th Century", <u>Dictionary of the History of Ideas</u>, New York, Scrivener's, 1982, p. 548.

[19] ibid, p. 549.

> Although the explicit postulates of logical positivism are not accepted by most practising social scientists today, there remains an amorphous and implicit self-consciousness, a self-perception, that pervades contemporary social science practice which may be called the 'positivist persuasion'. [To advance understanding and formulate new theories in the social sciences] the positivist persuasion argues that the process of theory formation should be one of construction through generalization, a construction consisting of inductions from observation. Regarding the problem of theoretical conflict, the positivist persuasion argues that empirical tests must in every case be the final arbiter between theoretical disputes. It is 'crucial experiments' rather than conceptual dispute that determine the outcome of competition between theories. If the formulation of theories and the conflict between them can be entirely reduced to empirical material, there can be no long-term basis for structured kinds of scientific disagreement. ...By unduly emphasizing the observational and verificational dimensions of empirical practice, the positivist impetus has severely narrowed the range of empirical analysis. The fear of speculation has technicalized social science and driven it toward false precision and trivial correlational studies. This flight from generality has only contributed further to the inevitable atomization of social-scientific knowledge. What is usually proposed [as an alternative approach] is some kind of humanistic as opposed to scientific approach to empirical study: there is humanistic geography, sociology, political science, psychology, and even, most recently, the humanistic narrative approach in contrast to the analytic approach in history. These humanistic alternatives have in common their anti-scientific stances, a position which is held to imply the following: a focus on people rather than external forces; an emphasis on emotions and morality rather than instrumental calculation; interpretive rather than quantitative methods; the ideological commitment to a 'moral' society, one which fights the dangers of technology and positivist science.[20]

It is important to keep in mind that there are alternative approaches to social research and that the notion of truth and

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[20] Alexander, Jeffrey, "Positivism", <u>The Social Science Encyclopedia</u>, edited by Adam Kuper and Jessica Kuper, Boston, Routledge & Kegan Paul, 1985, pp. 631-633.

meaning through observation and reproducibility is only one of the possible ways to construe and corroborate understanding about social and behavioral phenomena.

The history of experimental methods used in the social sciences predates positivism. The following is a brief presentation of some social science experimentation terms and the branches of natural science which were their source.

CONTROL

> The concept of control is pretty old and was quite obvious once the Renaissance had turned men's thought from theological fiat to experiment as the means for penetrating into nature's secrets. Here is a story that makes the whole matter clear.
>
> In 1648 the Torriccellian vacuum was known to physics in general and to Pascal in particular. This is the vacuum formed at the upper closed end of a tube which has first been filled with mercury and then inverted with its lower open end in a dish of mercury. The column of mercury falls in the tube until it is about 30 in. high and remains there, leaving a vacuum above it. Pascal was of the opinion that the column is supported by the weight of the air that presses upon the mercury in the dish (he was right; the Torricellian tube is a barometer) and that the column should be shorter at higher altitudes where the weight of the atmosphere would be less. So he asked his brother-in-law, Perier, who was at Clermont, to perform for him the obvious experiment at the Puy-de-Dôme, a mountain in the neighborhood about 3000 ft. ("500 fathoms") high as measured from the Convent at the bottom to the mountain's top. On Saturday, September 19th 1648, Perier, with three friends of the Clermont clergy and three laymen, two Torricellian tubes, two dishes and plenty of mercury, set out for the Puy-de-Dôme. At the foot they stopped in the Convent, set up both tubes, found the height of the column in each to be 26 old French inches plus 3 1/2 Paris lines (28.04 modern inches), left one tube set up at the Convent with Father Chastin to watch it so as to see whether it changed during the day, disassembled the other tube and carried it to the top of the mountain, 3000 ft. above the Convent and 4800 ft. above sea-level. There they set it up again and found to their excited pleasure that the height of the mercury column was only

> 23 French inches and 2 Paris lines (24.71 in.), much less than it was down below just as Pascal had hoped it would be. To make sure they took measurements in five places at the top, on one side and the other of the mountain top, inside a shelter and outside, but the column heights were all the same. Then they came down, stopping on the way to take a measurement at an intermediate altitude, where the mercury column proved to be of intermediate height (26.65 in.). Back at the Convent, Father Chastin said that the other tube had not varied during the day, and then, setting up their second tube, the climbers found it too again measured 26 in. 3 1/2 lines. These are reasonable determinations for these altitudes, showing about the usual one inch of change in the mercury column for every 1000 ft. of change in altitude.
>
> In this experiment there was no elaborate design, and it took place 195 years too soon for the experimenters to have read John Stuart Mill's Logic, but the principle of control and of the Method of Difference is there.[21]

When applied in social science, the experimental techniques of randomization, blocking, control comparisons, and adequate group size are attempts to wash away individual differences (in values, attitudes, habits, opinions, aptitudes, etc.) by the power of aggregate numbers. An entire battery of terms have entered social science discourse from experimental methods used in the 'hard' sciences in an explicit attempt to raise social science to the predictive power of natural sciences. These include: validity, dependent measure, blocking, result, effect, treatment, control, sample, operation, confound, observation, covariation, construct, bias, feedback, plausible, inference, generalization of results, response, irrelevancy, target, equivalence, etc.

CONSTRUCTS

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[21] Boring, Edwin G., "The Nature and History of Experimental Control", The American Journal of Psychology, 63, 1953, pp. 577-578, paraphrase of Blaise Pascal, The Physical Treatises of Pascal: the Equilibrium of Liquids and the Weight of Mass of the Air, trans. 1937, 103-108.

Constructs are models of behavior, labels, or hypothetical entities whose existence can be inferred only from their causes, consequences, or manifestations. "When employed self-consciously and critically, constructs constitute a legitimate and frequently invaluable device for analysing and explaining human behavior. When used without a clear identification and awareness of their nature as hypothetical categories, they may be reified and confused with 'reality', i.e. observable phenomena".[22]

## SAMPLE SURVEYS

The modern sample survey evolved from the Victorian social survey movement, which assembled facts about urban poverty. Other sources were the development of the statistical theory of probability, and the early attempts to carry out straw polls before elections. ...Sample surveys are intended to provide information about a larger population. The probable accuracy of generalizations from a sample survey to its population can be calculated using the mathematics of signifance testing, if certain conditions are met. The most important condition is random sampling, in other words, every member of the population sampled must stand an equal chance of being elected for the sample. ...[However] human subjects complicate sampling by ageing, changing social characteristics, and shifting residence: they are sometimes not available or not willing to respond to surveys.[23]

## RELIABILITY

Reliability is used by social scientists in the sense of degree of stability or reproductibility of empirical results. Science is based on the assumption that its findings are not unique but can be duplicated under identical conditions. Experience, however, has shown that identity is an ideal which can only be approximated in the empirical world. No matter how controlled the conditions,

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[22] Chinoy, Ely, "Constructs", A Dictionary of the Social Sciences, edited by Julius Gould and William L. Kolb, New York, UNESCO Publication, 1964, p. 134.

[23] Goyder, John, "Sample Surveys", A Dictionary of the Social Sciences, op cit., p. 722-723.

> measurements vary. This variation may be due to systematic influences (non-random or constant errors) or to non-systematic influences (random or variable errors). The latter are the ones of importance in a determination of reliability, although both are of concern to the validity of the results. Thus reliability is a necessary though not sufficient factor in determining validity, for without stability of results their relevance to the purpose of the research could not possibly be determined.[24]

VALIDITY

> Validity is used by social scientists in a variety of senses: a) soundness or strength of argument or proof; b) confirmation, corroboration or substantiation of evidence; c) the quality of being well-founded and applicable to the circumstance. ...Usage in the third sense is the most recent and certainly the most technical. ...The common element in all three uses of the term is the degree of relevance of the concepts, data or research techniques to the research objectives for which they have been developed, and hence the degree of confidence we should have in them.[25]

The terms: treatment, observation, and blocking come from medicine, biology, and agronomy. The notions: validity, cause-effect, plausible, and inference are grounded in logic and physics. Covariation, dependent variable, sample, bias, and equivalence are from statistics. However, caution must be exercised in applying any of these concepts to define the limits of what will be acceptable as truth - they all are supported by the positivist view of truth and meaning above.

Is there any meaning to a sample size of 1? Under the social science experimentation paradigm, the individual is plagued with 'hazards' or threats to generalizability inherent in personal idiosyncracies. Attitudes and values of one person

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[24] Bowers, Raymond V., "Reliability", A Dictionary of Social Sciences, op cit., 587-588.

[25] Bowers, Raymond V., "Validity", A Dictionary of the Social Sciences, op cit., 742-743.

have no relevance or meaning in this paradigm, as it is precisely these irrelevancies that aggregate numbers and experimental methods are supposed to remove. It is relevant, at this point, to recall the humanist alternatives to social science mentioned above by Alexander. I find that what is meaningful to me is necessarily contingent upon my values, emotions, and attitudes, and not at all upon some average attitude exhibited by a representative sample of Cambridge, MA.

Nonetheless, in designing an experiment to address the social science literature on energy conservation due to feedback, one is already on the experimentalist, reductionist turf. With these reservations in mind, the following chapters discuss issues in quasi-experimental design (in field settings with non-equivalent groups for comparison); present some previous feedback experiments; and offer a design of an experiment to test the effectiveness of the interactive energy meter/display presented in Chapters 1 - 3.

The rest of this chapter draws mostly from the work of Cook & Campbell on experimental design.[26] Four types of experimental validity and the many hazards that field settings pose to validity are discussed. Then, four methods used in experimental design to reduce experimental error and to ensure the integrity and generalizability of any results are presented.

## 4.2 TYPES OF CAUSAL VALIDITY

The design of any field experiment must account for two logically distinct types of validity: internal and external. Internal validity of experimental results concerns the power of the researcher to infer causality in relationships between independent and dependent variables. External validity,

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[26] Cook, Thomas D. and Campbell, Donald T., Quasi-Experimentation: Design and Analysis Issues for Field Settings, Houghton Mifflin Company, Boston, 1979.

conversely, refers to the degree to which results can be generalized to other populations, settings, and times.

Internal validity can be divided into two parts:

i) statistical conclusion validity deals with questions about the statistical significance of the relationship being studied or the covariation of dependent with independent variables, while

ii) internal validity is invoked when causality is inferred from independent to dependent variables (from treatment to effect).

In like manner, two types of external validity can be distinguished:

i) construct validity is invoked when abstract constructs are generalized from particular research operations[27], while

ii) external validity operates in the sphere of inferential logic by placing limits on the researchers' ability to generalize particular findings of cause ==> effect relationships to different settings, people, or times.[28]

STATISTICAL CONCLUSION VALIDITY

The statistical power of samples drawn in an experiment is derived from i) sample size, ii) the standard error of the results, and iii) the magnitude of any covariance found between the measured dependent variables of different experimental

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[27] For example,"information feedback" is the abstract construct to be generalized from the particular experimental operation of continuous in-home information display.

[28] The distinction between internal and external validity was first presented by Campbell & Stanley in Experimental and Quasi-Experimental Designs for Research, Chicago, Rand Mcnally, 1971. Only in the later work, Cook & Campbell, 1979, does Campbell distinguish statistical conclusion validity, from internal validity and construct validity from external validity. These classifications, though not logically distinct, are quite useful in the design and analysis of experiments.

groups. Hence, an experiment is said to have statistical conclusion validity if there is covariance between experimental variables which is statistically significant within a stated confidence interval. "Statistical conclusion validity is concerned not with sources of systematic bias [factors which affect the value of the mean], but with sources of random error [factors which increase variability in observations]".[29]

i) Treatment and control groups must be of sufficient size for an experiment to yield statistically significant results. The minimum group size recommended in standard statistical texts is contingent upon the expected size of the difference of the observed behavior of control and treatment groups, the standard deviation around the mean of the dependent variable being measured for each group, and the confidence level required to accept or reject experimental hypotheses.[30] Sample size is a critical design parameter in any field study since the statistical sensitivity of the experiment usually increases with sample size as does the cost. Since reasonable statements about covariation are what the researcher is after, minimum sample sizes must be carefully estimated to enable inference of covariation at minimum cost.

ii) Standard error refers to the distribution of observations around a mean. Observations that show a tight clustering about a mean value support causal claims much more readily than those that are spread loosely. Why this is so becomes intuitively obvious when the concept of standard error is combined with the magnitude of covariance.

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[29] Cook and Campbell, op cit., p. 80.

[30] See chapter 4.2 for equations to compute recommended minimum sample size experiments. See Chapter 6 for an application to an electricity conservation experimental design. In the feedback experiments reported in Chapter 5, the dependent variable is kWh consumed/unit time, and the difference in mean kWh consumed between groups (difference in observed behavior) is said to be the 'effect' of feedback, goal-setting, or price changes (the treatment).

iii) The magnitude of covariance found between means of dependent variables of different experimental groups is commonly cited alone in support of claims that there is a causal connection between treatment and effects. However, the magnitude of difference between experimental means and the standard error of sample observations can be combined to yield the statistical significance of experimental results. An experiment obtains statistical conclusion validity when it is designed with the necessary sample sizes for the results to be statistically significant (covariation is confirmed or rejected within a required confidence level given the standard error of the observations).

Hypotheses tested in field experiments are not proven nor disproven, but only confirmed or rejected within a range of probabilities. The logic of inference states that there is no number of observations or sample size that could "prove" or "disprove" a hypothesis with 100% confidence. There will always be a chance, however small, that when statistical analysis shows covariation between two variables, this is a result of an unusual sample. The result in this case could lead to a type I error: false confirmation of an incorrect hypothesis due to an aberrant sample (a type II error is the false rejection of a correct hypothesis for the same reasons). When results are said to confirm experimental hypotheses within a 5% confidence level, this means that there is a 5% risk of being wrong.

Specification of a confidence interval requires an assumption about the distribution of random errors around the means which are said to covary. It can be assumed that the quantity of electricity consumed by families living in similar homes in the same income class will be normally distributed around the mean or average consumption. The studies presented in chapter 5 show this to be a reasonable assumption.[31]

HAZARDS TO STATISTICAL CONCLUSION VALIDITY

Field experiments are susceptible to a number of hazards that degrade the statistical conclusion validity of any results. The following is a list of some common hazards:

i) Low statistical power: With small samples and high confidence intervals (say 95% or 99%) the chance of finding a false negative (incorrect rejection of a hypothesis supported by an actual weak covariate relationship hidden by a large variation - type II error) is increased. Caution in choosing appropriate sample sizes and looking in a range of confidence levels corresponding to the statistical power of the sample size guards against this hazard.

ii) Stability of measures: If measures of effects (dependent variables) are unstable or unreliable, this adds to the standard errors of observations and, hence, impairs the ablity to make valid inferences from resulting data. The use of experimental groups with similar characteristics improves reliability in this regard. This technique, called 'blocking', is discussed in Section 4.3.

iii) Administration of treatment: Like ii) above, if the treatment is administered by different people in different settings, the standard error of observations can also be

[31] All studies that presented disaggregate data (consumption statistics for each household) found that if the experimental groups are 'blocked' appropriately (members of each group shared characteristics that affect electricity consumption: type of home and appliances, number of family members, and income level), the individual quantities of electricity consumed over time are distributed approximately normally around a mean.

inflated.[32] Standardized implementation procedures or guidelines for administering the treatments can minimize this effect on standard error.

iv) Effects due to setting: Scores on the observed variable can be affected by feelings of exclusiveness, competition, resentment, demoralization, etc. These effects are peculiar to field experiments done in small communities or neighborhoods and derive from the very inequities the experiment must inflict on respondents in different groups. Interaction effects can be accounted for if observed and introduced into the statistical analysis. Nonetheless, it is the rare exception to find an experimental design that anticipates demoralization or diffusion of the treatment explicitly enough to gather appropriate data for introduction into the statistical analysis. For example, of the experiments reported in Chapter 5 that used questionnaires, none of the studies sent them to control group members as well as to those who received treatment.

## INTERNAL VALIDITY

After tests of statistical conclusion validity have shown that there is a statistically significant covariate relationship between two experimental variables, the next task is to ascertain the direction of causality.

Strict causality exists only in logical worlds of symbolic languages such as mathematics and does not obtain in the social sciences (nor in the physical sciences). The essence of scientific inquiry through experimentation is the attempt to

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[32] For example, if daily feedback on electricity consumption were delivered to some households by a cheerful research assistant who congratulated the family for reducing electricity demand, and another research assistant with a sour disposition delivered the same information to other households, the effect may be strong enough to result in consumption statistics varying around two separate means.

rule out implausible alternative hypotheses in favor of the most plausible hypothesis to explain an observed phenomenon. Questions about the internal validity of experimentally demonstrated causal relationships form the core of the scientific method to advance understanding.

In electricity conservation studies, a question of internal validity arises in response to the claim that information "A" <u>causes</u> conservation "B". Some alternative hypotheses are that direct information feedback "A" causes some other change,"C", such as a shift in values toward conservation, an attitude change, or a heightened awareness of the operating costs of each appliance, that in turn causes "B". If one of these alternative hypotheses is actually the case,

"A" ==> "C" ==> "B",

(Read "A" yields "C" yields "B"), then the results of an experiment that support the inference of causal relationship, "A" ==> "B", would lead to a false positive confirmation (type I error).

Moreover, if "A" and "B" are positively correlated while "B" and "C" are negatively correlated,

"A" + => "C" - => "B",

the relationships between the variables could offset each other and lead to false negatives (type II error).

Returning to the example above, this kind of situation may apply if information feedback heightened an awareness of operating costs, "A" + => "C", but since the cost of electricity is low relative to its value to the consumer, more electricity is used.

"C" - => "B" or "C" ==> -"B".

Here,"-B" means a negative conservation effect, or an increase in consumption. Indeed, this result has been realized in one experiment: Bittle, Valesano, and Thaler (1979).

To counter alternative hypotheses, good experimental design will include measures of many variables that could have a causal role in the phenomenon under investigation. Nonetheless, the judgement of the reasearcher is critical in determining which variables may be important <u>before the experiment is carried out</u> since higher costs usually accompany more measurements. Some of the more common hazards to internal validity are listed in the next section.

## HAZARDS TO INTERNAL VALIDITY

i) <u>History</u>: In a field experiment, events occur during the treatment period that are not part of the experimental treatment. These may affect the observed dependent variables. For events common to all experimental groups, such as a change in the price of oil, a no-treatment control group can be used to account for any non-treatment induced changes in observed variables. However, if the event is local and asymetric, i.e. it is not experienced equally by all groups, such as a community meeting, its potentially disproportionate effects will be much harder to guard against in the experimental design. This possibility of <u>local</u> history effects has led to experimental designs that draw all participants from one neighborhood or community.[33]

ii) <u>Diffusion or imitation of treatments</u>: If information is part of the treatment and groups can communicate or are clustered in one residential area, the treatment may affect the control group, thereby invalidating the experiment. This could be a particularly pernicious confound if the information has an

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[33] Each of the nine studies reported in Chapter 5 were conducted in a housing development, a community, or an apartment building.

economic value associated with it, such as continuous in-home electricity information display, because it could be perceived as desirable to be shared among neighbors.

iii) Demoralization of respondents receiving less desirable treatments: The inequity in treatment vs. control conditions when treatment groups receive something regarded as valuable may seed resentment or demoralization in control groups and change control group members' observed behavior. This type of change could lead to a measured difference between treatment and control groups that is not due to effects of the treatment, but rather, to demoralization of the control group. A opposite of demoralization is compensatory rivalry[34] which occurs if the control group sees fit to compete for scarce resources because they fear being put at a disadvantage relative to treatment groups. These changes in the observed variables of control groups are hazards to internal validity because they are in response to the inequities between groups that are inflicted by the experiment itself and are not effects of the treatment. Demoralization and compensatory rivalry were not observed in any of the field studies in Chapter 5.

iv) Learning: When an experimental design calls for multiple treatments (treatment, removal, and treatment), the familiarilty that the respondents gain with experimental operations is a form of learning that can confound results when this particular effect is not what is under test.

v) Maturation: In time-series studies which gather data over years, the effects on observed variables from attitude shifts and other changes in behavior as respondents mature (not in response to the treatment) are difficult to assess.

vi) Mortality and Attrition: If individuals drop out of the experiment while it is underway, the pretest and posttest

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[34] Saretsky (1972) has called this the "John Henry Effect" in honor of the steel driver who worked so hard that he died of overexertion when he learned that his output was to be compared to that of a steam-powered drill.

groups are not the same. There is no purely statistical method for data analysis that can account for errors due to treatment-related attrition during a field study.

vii) Selection: It is common for field experiments to have non-equivalent groups for comparison. This fact has led to the development of a substantial literature on quasi-experimental methods and design.[35] Quasi-experimental methods are used when samples cannot or are not selected at random from the entire population of interest. These methods allow restricted and cautious comparisons to be made between groups of dissimilar people. Some basic experimental designs for field research are discussed in Chapter 5.1. The quasi-experimental methods implicit in these designs provide a fallback option to 'true' randomized experiments.

CONSTRUCT VALIDITY

Before listing some of the principal threats to construct validity in field settings, it is important to be explicit about just what "constructs" of experimental operations are. As noted in Chapter 4.1, constructs are labels used to denote particular treatments, measured or unmeasured effects, and other parameters of the experiment. As labels, constructs incur all the difficulties inherent in the logic of symbolic representation, inference, and linguistics. Philosophers have dealt with these problems since antiquity.

Here, construct validity is treated as an analytic subdivision of external validity. It is concerned with the notion of confounding and the ability to generalize across cause and effect constructs, i.e., generalizing the particular exemplars of relationships found in one experiment to hold in more than just the experimental setting. Confounding of

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[35] This chapter is essentially a summary of the key points in the most recent comprehensive overview of quasi-experimental methods: Cook & Campbell, op cit.

constructs refers to the possibility of an experimental relationship characterized by a particular cause-effect construct being construed in terms of other plausible constructs. For instance, the construct relationship of "information" ==> "conservation" which characterizes the experimental constructs of most studies reviewed in chapter 5, could be alternatively construed as "researcher expectations" ==> "conservation", "information" ==> "hypothesis guessing", or even "researcher expectations" ==> "hypothesis guessing".

## HAZARDS TO CONSTRUCT VALIDITY

All of the hazards to construct validity listed below, derive from the following: the experimental design 1) fails to incorporate all dimensions of the construct of interest and/or 2) contains dimensions irrelevent to the target construct.

i) Inadequate definition of constructs before experimentation: It is very important to define, or at least explicate, constructs such as attitudes, values, feedback, and information as an integral part of the experimental design so that interpretation of results are intelligible within the working definitions of operational constructs. Inadequate definition can lead to fuzzy statements subject to serious alternative hypotheses. Most of the experiments in Chapter 5 did not present definitions of the constructs that were used as labels for particular experimental operations.

ii) Single operation bias: Experiments using one treatment or measuring only one effect can contain irrelevancies that could affect results. Moreover, since they do not utilize other instances of treatments which fall under the same construct nor collect data on alternate measures, the construct validity of single operation experiments is suspect. Using various types of treatment (for example, different forms of information feedback) and collecting data with alternate measures (kWh consumption/hr and /day) can reduce this bias.

iii) Single method bias: Using various types of treatment does not assure that all irrelevancies have been accounted for. "When all the manipulations are presented in the same way, or all the measures use the same means of recording responses, then the method is itself an irrelevancy whose influence cannot be dissociated from the influence of the target construct [treatment]".[36] All but one of the studies in Chapter 5, Winett, Neale, and Grier (1979), used only one method to deliver feedback.

iv) Evaluation apprehension: Most people being evaluated by experts in values assessment or psychology, will attempt to present themselves as competent and aware. For instance, when asked how one's own attempts to conserve relate to the energy crisis or national security[37], respondents tend to favor appearing concerned and responsible instead of careless and wasteful. In addition to the inherent difficulties of getting an accurate measure of attitude through surveys or interviews, participants in a conservation experiment will tend to be sensitized by their very participation and may watch

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[36] Cook & Campbell op cit., p. 66. Single operation bias in studies of electricity conservation due to information feedback can be minimized by testing the effects of different forms of feedback: daily vs. continuous; with or without social prompts or target reductions; or cost information vs. energy use. Single method bias, concerned with the method of feedback, can be minimized by delivering it in different ways: hand delivery, through the mail, in-home display, or having the respondent read her/his own meter. Nonetheless, caution is advised in multi-method or multi-operation experimental design. Not only would it be prohibitively expensive to administer the "definitive" field test with all possible operations and methods investigated, but it would also probably yield less compelling results than would many small experiments with different sample population characteristics, in varied settings, and at different times.

[37] See Seligman, C., et al [1979] and Becker, L. J., et al [1981].

consumption more closely during the experiment in hopes of a favorable or above average evaluation. The desire to be evaluated favorably is rarely a construct around which experiments are designed or data gathered.[38] For this reason, evaluation apprehension and the desire to get a favorable score from the expert is a possible confound.

v) Hypothesis guessing: Actions caused by a desire to please the researcher presuppose that respondents have tried to guess experimental hypotheses. Confounding of results due to a change in behavior to please the researcher is commonly called the "Hawthorne Effect".[39] If a compelling charge is made that this effect has been operating in a particular setting, this could seriously challenge the validity of experimental results. Nonetheless, "there is neither widespread evidence of the Hawthorne effect in field experiments, nor is there evidence of similar orientation in laboratory contexts. However, we still lack a sophisticated and empirically corroborated theory of the conditions under which hypothesis guessing (a) occurs, (b) is treatment specific, and (c) is translated into behavior that (d) could lead to erroneous conclusions about the natural setting".[40]

Experiments can be designed to minimize the Hawthorne effect by making actual hypotheses hard to guess, deliberately giving false hypotheses or randomly distributing different

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[38] An exception to this is found in Battalio, R. C., et al, 1979. In this study of residential electricity use in a small community in Texas, changes in consumption of the no-treatment control group is compared to that of the main feeder for the community. Since no significant differences were found, the authors concluded that voluntary participation in the experiment (and hence, sensitization due to experimental operations) had no noticeable effect on observed outcomes.

[39] Named after a classic set of industrial workplace experiments done by Hawthorne, reported by Roethlisberger and Dickson (1939).

[40] Cook & Campbell, op cit., p. 66.

hypotheses among respondents, and by choosing participants such that communication in and between groups is limited. Experimental designs for measuring response to information feedback that employ values surveys or group meetings of experimental groups should attempt to account explicitly for the Hawthorne effect. Such an attempt is made in the proposed design in Chapter 6 by recommending that participants be informed that the reason for installing the electricity meter is to test it for accuracy. While accuracy is <u>not</u> the hypothesis of interest, it is <u>not</u> untrue.

vi) <u>Experimenter expectations</u>: Closely related to the Hawthorne effect and evaluation apprehension are confounds resulting from overt expectations of the researchers that are made explicit before or during the experiment. By employing intermediaries who have no expectations about the results, to administer treatments and contact participants, the experimenters can guard against this hazard to construct validity.

vii) <u>Interaction of different treatments</u>: If several treatments are administered at once, it is not possible to unconfound the effects of each treatment from that of the others. What is needed if the effects of several treatments are to be studied, is a factorial design in which seperate groups receive either one unique treatment or a unique combination of treatments. This problem is central to the design presented in Chapter 6 because the feedback from the in-home display can take many distinct forms and combinations.

viii) <u>Interaction of testing and repeated treatment</u>: One design commonly used to get around the need for a large number of experimental groups, each receiving a unique treatment, is to stagger implementation of treatments. Results are analysed by using the unchanged experimental groups as control at each application of a new treatment to evaluate effects of the change in treatment.[41] A potential problem in any time series design that uses more than one treatment on the same group is confounding due to sensitization or preconditioning to receive the treatment. An appropriate tradeoff between potential confounding due to sensitization and costs for more single- treatment experimental groups must be made in the experimental design. Though early work suggested that sensitization is rare[42], caution must be exercised for this potential confound, especially in an experiment designed to investigate the difference in effectiveness of several forms or methods of delivering feedback and information.

ix) Confounding constructs with levels of constructs: If a statistically insignificant degree of covariation between two variables, "A" and "B" is found, the conclusion that "A" does not affect "B" could be a false negative. It could be the case that while the tested level of "A" does not affect "B", three times this level of "A" may well have an effect on "B". Parametric studies (using various levels of treatments) are the best remedy for this hazard. Parametric studies have been used quite advantageously to study the effects of price changes and the setting of reduction goals on energy conservation.[43]

## EXTERNAL VALIDITY

The external validity of experimental populations sets limits on the researcher's ability to generalize causal relationships to and across other populations. Four distinctions between population types are instrumental in

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[41] See Hayes and Cone [1977] for a complicated design of this sort.

[42] Lana, [1969].

[43] See Battalio, et al [1979], Winett, et al [1977], Hayes and Cone [1977], and Becker [1978], in Chapter 5.

analyzing experiments for external validity[44]: (1) target populations; (2) formally representative samples that correspond to known populations; (3) samples actually used in field research; and (4) achieved populations. Generalizing to target populations is logically distinct from generalizing across populations. The former is used in ascertaining whether the samples used in research (3) adequately represent the specified population (1) or some other population (4). The latter is used in ascertaining which subpopulations (fixed income vs. particular income levels, couples vs. families with children, etc.) have been affected by the treatment for assessing how far the results can be generalized.

HAZARDS TO EXTERNAL VALIDTY

The degree to which causal relationships found in field experiments can be generalized across various populations, in different settings, and at other times are subject to the following constraints on external validity:

i) Interaction of selection and treatment: The goal of randomly recruiting participants for field studies is to obtain a sample that is representative of the target population, within the limitations of sampling error. As participation in experimental treatments is almost always voluntary, results may be applicable only to the subset of people in the target population who commonly volunteer or, at least, don't object to being studied, those who offer income information, or those who have plenty of free time, etc. A review of the literature on field studies of information feedback and electricity conservation turned up only one experiment[45] that did not rely

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[44] Cook & Campbell, op cit., p. 71.

[45] McClelland and Cook [1979]. This study reports obtaining electricity data directly from Carolina Power and Light for homes with and without continuous display meters.

strictly on volunteers as participants. To ensure that selection factors do not place severe limits on the representativeness of actual samples, it is recommended that participation in the experiment be made as convenient as possible.

ii) Interaction of setting and treatment: Can findings from research done on campus populations or in a particular small town in Texas be applied to the general population? To the extent that students on campus or the residents of a small town are representative of the general population, the results can be generalized. This is usually not a major consideration in the design of individual studies, since particular causal relationships are extended to general populations only after the experiment is replicated and similar results are found in various settings with different people. This process of experimental replication and confirmation of results is the very method in the (social) sciences through which hypotheses that most elegantly explain the data come to be accepted.

In this light, the experiment proposed in Chapter 6 is designed to add substantively to the information feedback literature. Consistent with the (social) scientific method of hypothesis confirmation, it is hoped that its implementation would contribute to the results of other small field studies. It is proposed to develop a better understanding of the conditions under which information feedback can effectively induce energy conservation in the home. As the experiment is designed to administer feedback in the home, it would be generalizable to home settings only, not factory or office settings.

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Whether homeowner permission was required for release of data is not stated. In a number of states, the utility is not required by law to obtain permission for release of consumption data if all personal information (name, address, lot #, etc.) is deleted from the file.

iii) Interaction of history and treatment: Does the causal relationship hold over time? This question is important for energy conservation studies, given the range of uncertainty in long term oil prices. The logic of inductive inference prohibits strict extrapolation of present relationships to the future with 100% certainty. Even for predictions as mundane as the sun's rising, no number of previous observations confirming that the sun does rise after a few hours of darkness can conclusively predict that it will rise tomorrow.[46] Nonetheless, if an experiment is performed at different times (consecutive replication) and the literature is examined to ensure that no previous evidence refutes the causal relationship, reasonably guarded statements can be made about the validity of experimental results in the short term.

## TRADEOFFS BETWEEN VALIDITY TYPES AND CAVEATS

Tradeoffs between types of validity in the experimental design are inevitable. For instance, randomized experiments are best for internal validity, but access to communities or organizations that will welcome or allow these are probably less representative than those with members that will not yield their privacy to random selection. An experiment that rigidly controls exogenous stimuli increases statistical conclusion validity at the cost of reducing both external and construct validity. Indeed, almost any measure designed to enhance one particular kind of validity will result in a decrease in at least one other type of validity.

The previous discussion points out that randomization does not control for all threats to internal validity. Nonetheless, it is the best single means of increasing confidence in causal

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[46] See David Hume's, An Inquiry Concerning Human Understanding, originally published in 1748.

inferences. Some other means are discussed in the next section.

Constructs are hypothetical entities not corporeally represented by operations. In other words, the constructs "feedback", "prompting", and "goal setting" only name the experimental operations and are not identical with them. Since propositions that are tested by experimental operations are phrased in general terms (constructs), how can it be said that "A" is causally related to "B" when experimental results can only show relationships between experimental operations and measured variables? Causal claims supported by experimental results should be made cautiously in light of the problems of inferential logic mentioned above.

The significance of the general problem of imputing causality to constructs should not be written off as just another philosophical curiosity consigned to the cogitations of thinkers in antiquity. In recent work, different forms, implementation methods, and intensities of experimental operations have all been cloaked under the same construct: "feedback". Implications for policy or theory can be decidedly different over a range of effects resulting from a range of operations denoted by one label. To ensure the relevance of results to research goals and choice of policy, care must be taken to design research operations that adequately represent target constructs.

Though the emphasis in this chapter is on scientific rigor, the number of hazards which good design must account for makes qualitative contextual information very useful in choosing hypotheses which best explain the data.

## 4.3 METHODS FOR REDUCING EXPERIMENTAL ERROR

In the presentation of methods for reducing experimental error in field research, it is useful to distinguish between random error and error due to bias. Random error arises from variation between respondents because of individual differences. Errors due to bias occur when all respondents in a particular experimental group are affected alike by some event or condition which is not the treatment.

The most common techniques used in experimental design to reduce error due to bias is through the use of blocking and randomization in the selection of participants and assignment to experimental groups. The size of experimental groups and the use of control groups are critical in reducing random error.

## BLOCKING

Blocking takes its name from the experimental procedures used in agricultural research. R.A. Fisher developed this technique from 1919 to 1930 in planning agricultural field experiments in England.[47] Several immediately adjacent "blocks" of land were used to test the effects of different farming methods and seed strains in an environment that was otherwise nearly identical for all the plots.

If the researcher knows that the response to treatment will vary widely across respondents, it is desirable to obtain some measure, correlated to expected response, for each participant before assignment to experimental groups. For energy conservation studies, such a measure might be obtained from scores on a test for awareness of ways to conserve, the ratio of average monthly electricity cost to monthly income, or family size and type of home. Since all respondents within a block share common characteristics that are hypothetically correlated to expected response, the blocking metaphor from

[47] Cochran, William G., "Experimental Design", Encyclopedia of the Social Sciences, Vol 1, p. 248, 1983.

agricultural experimentation seems appropriate.[48] Indeed, some of the studies presented in Chapter 5 did use blocking to increase the precision of experimental results.[49]

RANDOMIZATION

In addition to blocking in experimental design, randomization serves as one of the most powerful tools for reducing experimental error due to bias. Random selection can be used to draw representative samples from target populations, while random assignment to experimental groups can be used to draw samples that are comparable (equivalent) within the limits of sampling error.[50]

It is recommended that randomization be carried out by using a table of random numbers.[51] Consider an experiment with 100 respondents, four types of treatment, and a control. Each respondent is numbered 1 through 100. The first 20 numbers selected from a two digit column of random numbers identifies members of a group to receive one treatment. In like fashion, the next 20 receive another experimental condition. The 20 respondents left after the fourth group has been selected receives the remaining experimental condition. The probability

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[48] "Blocking" of similar plots in the "field" to minimize environmental differences is the metaphor used to describe this method of "blocking" by similar traits in sample populations drawn in "field" experiments to minimize the variance of individual differences. Though peripheral to this study, analysis of metaphors used in the social sciences can unearth the "roots" of its methodology in the physical and biological sciences.

[49] High, medium, and low levels of average electricity consumption were used as blocks in Bittle, Valesano, and Thaler, 1979; McClelland and Cook, 1980; and Winett, et al.; 1978.

[50] Cook & Campbell, op cit., p. 341

[51] Cochran, William G., op cit., p. 248.

that the 20 participants most responsive to the treatment will be assigned to any one experimental group is only 1 in $5^{20}$.

"Unlike blocking, which attempts to eliminate the effects of an extraneous source of variation, randomization merely ensures that each treatment has an equal chance of being favored or handicapped by the extraneous source. Whenever possible, blocking should be used for all major sources of variation, randomization being confined to the minor sources".[52]

## IMPLEMENTING RANDOMIZED EXPERIMENTS

Though randomization is a powerful tool in reducing experimental error, it is not a panacea. Some of the more serious problems with implementing randomized procedures in field experiments are listed below.[53]

i) Withholding the treatment from control groups: If the treatment, such as information feedback, is generally perceived as desirable, resentment may arise in the no treatment control group causing them to change their behavior. Moreover, with information as treatment, interaction between members of different groups could easily transmit the treatment. This possibility, called the "contamination problem", is a serious concern when designing experiments to be conducted in communities or neighborhoods.

ii) Treatment related refusal to participate in the experiment: The problem with using randomization to draw participants from a target population or to assign treatments to groups, is that the researcher cannot rely on the acceptance of all those selected. In analyzing this problem, Riecken and Boruch have explicated three distinct phases in an experiment at which randomization could occur.

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[52] Cochran, op cit., p. 248.

[53] Cook & Campbell, op cit, p. 347-371.

1) Once a list of eligible units is achieved, random assignment could follow.
2) Once potential respondents have agreed to cooperate in the measurement activities which are to be shared by the experimental and control groups alike, random assignment could then follow. Note that this would be assignment from among persons who have agreed to cooperate with measurement but have not had the treatments described to them.
3) Once potential respondents have agreed to accept assignment to either the experimental or control treatments, random assignment could then follow. Note that this would be assignment from among persons who have had all the treatments described to them and would be willing to accept any of them, including those that are less desirable.[54]

Later stages of random assignment will experience less treatment related refusals. Nonetheless, randomizing at later stages, after those who refuse to accept the conditions of the experiment have been eliminated from consideration, reduces external validity. The later the randomization is done, the more suspect the attempt to generalize results to any population other than volunteers. Because of this problem, it is recommended that participation be made as convenient as possible.

iii) Treatment related attrition: There is no purely statistical method of correcting for treatment related attrition. If a similar proportion of respondents from each group leave the experiment (to take vacations, etc.), the attrition does not violate randomization. However, if the attrition is differential and was caused by the treatment, the grounds for making tests of statistical significance (equivalence of groups formed by random assignment) is violated.

The best solution for this problem is for the researcher to anticipate possible structural reasons for attrition and

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[54] Riecken and Boruch, et al., Social Experimentation: A Method for Planning and Evaluating Social Innovations, Academic Press, New York, 1974.

change the structural defects, if possible. The pilot study for the electricity display presented in Chapter 3 showed electrical interference with television and radio signals. If used as a feedback device in the field experiment proposed in Chapter 6, this is a structural defect that would cause some respondents to shut it off (thereby leaving the treatment).

Randomization has great value in experimental design for enabling valid causal inferences. Nonetheless, it is only one part of the experimental design which is only one part of the overall research design. It has nothing to do with asking relevant research questions nor with the choice of treatments and dependent variables. In short, randomization is not a panacea for field research, though it plays a vital role in reducing the number of the assumptions that have to be accepted for causal inference.

## SIZE OF EXPERIMENTAL GROUPS

There are two common approaches to finding the minimum number of respondents in each experimental group for statistically analyzable results. "One approach is to specify that the observed difference between the treatment means be correct to within some amount $\pm d$. The other approach is to specify the power of the test of significance of this difference".[55] Both approaches result in the same minimum sample size. The difference lies merely in how the required sensitivity of the test is specified.

Individual electricity consumption per unit time is measured on a continuous scale, e.g. kWh/day. Since data from previous studies show an expected difference in mean consumption of treatment and control groups as well as the

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[55] Cochran, op cit., p. 249.

standard deviation, $\tilde{o}$, in experimental groups[56], the first method of finding the minimum experimental group size, n, is both appropriate and convenient.

Assuming the standard deviation per unit of each experimental group is identical, $\tilde{o}_t = \tilde{o}_c = \tilde{o}$, the standard error of the observed difference between two treatment means is

eq. 4.1 $$SE = \tilde{o}\ (1/n_c + 1/n_t)^{1/2},$$

for $n_c$ = number of respondents in the control group and $n_t$ = number in the treatment group. If the number of respondents in both treatment and control groups is identical, $n_c = n_t = n$,

eq. 4.2 $$SE = (2)^{1/2}\ \tilde{o}\ /\ (n)^{1/2}.$$

In the case of electricity consumption, it is commonly assumed that individual quantities consumed each month in a well selected group are approximately <u>normally distributed</u> around a mean monthly figure in each rate class.[57] If the difference between experimental group consumption means, $\underline{X}_c - \underline{X}_t$, is assumed to be approximately normally distributed, then the probability that this difference is in error by more than

eq. 4.3 $$d = T \times SE, \text{ is } a\%,$$

for "T" and "a"% found in a table of normal distribution. The number "T" is a normalized measure of what percentage of a normal distribution falls in an area bounded by $\pm T$ away from the mean. Therefore, the larger T, the higher the probability or confidence level in percent, (1 - a)%, that the observed difference between means is <u>not</u> in error.

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[56] See Seligman & Darley (1977); and Winett, Neale, and Grier (1979) in Chapter 5.

[57] The primary classifications for rate structures are industrial, commercial, and residential. Each class has divisions and subdivisions for billing purposes. While the distribution of individual monthly quantities consumed within each classification may not be normal, when experimental groups are carefully formed by matching characteristics that correlate with electricity demand (household size, home type, income class, etc.), the sample can approach normal distribution.

Table 4.1 is excerpted from a normal table in a standard statistics text for some common confidence level values.[58]

TABLE 4.1

NORMAL DISTRIBUTION CONFIDENCE INTERVALS: TWO TAILED

| T | a | (1-a) |
|---|---|---|
| 1.65 | .10 | 90% |
| 1.96 | .05 | 95% |
| 2.58 | .01 | 99% |

Noting that the boundary condition of eq. 4.3 is at the minimum difference between observed means that the experiment is sensitive to, $\underline{X}_c - \underline{X}_t = d$, a minimum experimental group size can be derived for a specified per unit standard deviation of experimental groups, expected difference between means, and confidence interval. Substituting eq. 4.2 into eq. 4.3 and rearranging, the minimum group size required for statistically significant results is,

eq.4.4 $$n_{min} = 2T^2 \tilde{o}^2 / (\underline{X}_t - \underline{X}_c)^2 \text{ , for } \tilde{o}_c = \tilde{o}_t = \tilde{o} \text{ and } n_c = n_t = n.$$

Using eq. 4.4 and Table 4.1 it is possible to compute the minimum sample size needed to ensure with (1-a)% confidence that differences between group means are not due to random error. Application of eq. 4.4 can give a rough estimate of the minimum sample size necessary for sound causal inference from the results. Nonetheless, caution must be exercised since it is a simplified version of a more complicated general equation. Equation 4.4 holds only when all experimental groups are the same size, the standard deviation within each group is similar, and the experiment has a simple design. Calculations

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[58] Lindgren B.W., McElrath G.W., and Berry D.A., ntroduction to Probability and Statistics, Macmillan, New York, 1978, p. 318.

of minimum sample size in Chapter 6 apply equation 4.4 to the data from previous experiments reported in Chapter 5.

## CONTROL GROUPS

The use of no-treatment control groups for comparison to treatment groups strengthens internal validity of any experimental design. Almost all of the experiments reported in Chapter 5 used a control group to remove the effects of external events from experimental results. The concept of control as a check (verification) is not new, as Chapter 4.1 points out. It is this sense of "control" that is developed in the Experimental Design Archetypes section of Chapter 5.1. The use of control groups for comparison with treatment groups of sufficient size is the principal design means for strengthening the internal validity of an experiment and reducing random errors.

# CHAPTER 5 ELECTRICITY CONSERVATION FIELD STUDIES

From 1975 to 1978 a number of field experiments were conducted to better inform energy conservation policy. Interest in conservation in the U.S. was generated largely by OPEC's oil price hike in 1973. Federal government policy to reduce dependence on foreign oil and the oil price increase led to negative growth in domestic electricity demand in 1973 and 1974. Five years of government sponsored research on various strategies not based on price changes to encourage conservation followed.[59]

In this chapter, the methods and findings of information feedback and price change field studies done during the mid 1970's in the residential energy sector are presented. In Chapter 5.1, the strengths and weaknesses of basic experimental designs are discussed. In light of these, three pioneering studies done from January to August 1975 are reported in Chapter 5.2 . Each of these experiments measured the change in kWh consumed in response to monetary rebates (marginal price changes), feedback, and government pamphlets on how to conserve energy. Finally, in Chapter 5.3, six field studies conducted from July 1975 to May 1978 are presented. These studies investigated residential response (measured by change in kWh consumed) to electricity reduction goal-setting, social

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[59] Conservation policy included government pamphlets delineating dozens of ways to conserve, television and newspaper ads equating driving slowly at 55 MPH and lowering the thermostat in winter to good citizenship, rent credits for energy saving home improvements, subsidies for alternative energy conversion processes, and raising the federal tax on gasoline and fuel oil. A comparative analysis of Canadian and U.S. conservation policy is presented in Dunbar, W.S., "Designing Energy Conservation Information Programs: What the U.S. Can Learn From Canada", Massachusetts Institute of Technology, 1979. The feedback studies reported here were part of this ambitious program to effect policy that might reduce this nation's energy dependence in light of the economic and political implications of the OPEC action.

prompts, and various forms of feedback (written, continuous, of cost vs. kWh consumtion data).

Each of the field studies presented in this chapter subscribe to the social science paradigm of quantified empirical research. These experiments form the framework on which any results from an experiment following the design proposed in Chapter 6 would be judged. This presentation highlights where the literature might be strengthened by yet another quantitative field study that also incorporates qualitative research to illuminate the context of the causal connections between feedback and electricity reductions.

## 5.1 EXPERIMENTAL DESIGN ARCHETYPES

Quasi-experimental design is intended for studies conducted in everyday settings that offer little control over external events or random selection of participants. Design of social experiments should include the validity considerations that arise when planned random selection and assignment procedures breakdown or otherwise fail to achieve statistically representative samples of target populations. Generic quasi-experimental designs are presented below as building blocks for robust designs that can serve as fallbacks to randomized designs.

Experimental groups labelled "non-equivalent" are those that have not been formed by random assignment, and so, are not directly comparable in a strict sense. The responses of such groups to experimental treatments are potentially not equivalent since characteristics of the members of each group have not been rendered heterogeneous by random assignment.

There are two basic types of Quasi-experiments:

i) non-equivalent control group designs in which the difference between dependent variables of treatment vs. control groups is measured before and after the test, and

ii) <u>interrupted time-series designs</u> in which the short and long-term effect of treatment is observed.

The distinction between these two design types is not sharp, but merely convenient for purposes of analysis and presentation. Actual field experiments commonly contain elements of both design types.

The following notation for design structure is adopted from Cook & Campbell [1979]:

$O_i$ denotes an observation or measurement of a dependent variable at time i;

$X_j$ denotes an application of treatment $X_j$ ;

$X_j{}^*$ denotes removal of treatment $X_j$ ;

- - - - a dashed line separating experimental groups denotes that they were not formed randomly or for other reasons should be considered to be <u>non-equivalent</u>.

NO-TREATMENT CONTROL GROUP DESIGN

The most elementary quasi-experimental design uses a single observation of dependent variables for each group before and after the independent variable (treatment condition) is introduced.

| | | | |
|---|---|---|---|
| Treatment group: | $O_1$ | X | $O_2$ |
| Control group: | $O_1$ | | $O_2$ |

This design controls for most threats to internal validity, with maturation and local history (when outside events are not identical for each experimental group) as two notable exceptions.

A variation of this design which adds one or more pretest observations can account to some extent for errors due to maturation.

| | | | |
|---|---|---|---|
| $O_1$ | $O_2$ | X | $O_3$ |
| $O_1$ | $O_2$ | | $O_3$ |

This variation shows the rate of change in any group's dependent variable measure relative to other groups in the pretest phase. Nonetheless, this design is still problematic. If a small number of samples are taken in a relatively short pretest phase, the resulting growth rates are susceptible to measurement error. Moreover, to use this pretest information, the researcher usually must assume that the observed relative rate of change between $O_1$ and $O_2$ will continue until $O_3$. Nonetheless, the assistance obtained in interpreting possible causal relationships is usually well worth the small cost of adding another pretest observation.

REMOVED TREATMENT DESIGN

It is possible to obtain meaningful results without a control group if effects are observed after the treatment is removed.

| | | | | |
|---|---|---|---|---|
| $O_1$ | X | $O_2$ | $X^*$ | $O_3$ |

If a treatment has <u>no</u> long term effect on the dependent variable, this design is subject to confounding. The short-term effect of treatment can be confounded with the dissipation of effects resulting from removal of the treatment. This confounding is less likely the greater the change in the dependent variable upon removal.

A variation on this design uses repeated treatments to replicate effects and, thereby, minimize the possibility of errors due to exogenous events occurring simultaneously with either application or removal of the treatment.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $O_1$ | X | $O_2$ | $O_3$ | X* | $O_4$ | $O_5$ | X | $O_6$ |

Nonetheless, the repeated treatment design is subject to the hazards of cyclical maturation (due to boredom and sensitization to the treatment), learning, and hypothesis guessing. This basic design would be strengthened by the addition of a control group to enable measurement of these effects.

While there are many other types of basic non-equivalent group designs, these two are sufficient for analyzing the feedback experiments reported in Chapter 5.2.

INTERRUPTED TIME-SERIES DESIGNS

When the experimental situation allows many observations over an extended period of time, two designs can be used to obtain more powerful results than those possible from simple non-equivalent control group designs:

i) In a factorial design, levels of more than one treatment factor are applied across experimental groups to investigate the effects of various mixes of treatments.

ii) The parametric design allows study of the effects of various levels or intensities of each treatment by successively applying various treatment levels in a different sequence to each group.

TAXONOMY OF EFFECTS

The results of time-series experiments display some logically distinct types of effects.[60]

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[60] This analysis of different types of effects is succinctly presented in Cook & Campbell [1979], p. 208.

i) A sharp discontinuity in the dependent variable mean at the time the treatment is applied is called a change in level.

ii) A change in slope of the dependent variable is called a drift or trend.

iii) Effects can show up as a change in variance around the mean after application of the treatment.

iv) There is a daily, weekly, and annual pattern of seasonality in electricity consumption that should not be confounded with experimental effects.

v) The effects can be instantaneous or delayed.

vi) Effects of experimental treatments may be continuous (does not decay over time), long-term (decays slowly over time), or short-term (decays quickly over time).

Analyses of results from time-series studies should be sensitive to the type of effect, its lag time, and its permanence. At least 50 observations are recommended for a good statistical estimation of the error correlated with the mean value of dependent variables over time.[61]

INTERRUPTED TIME SERIES: BASIC DESIGN

The basic time series design, first implemented by the British Industrial Fatigue Research Board, was extended and refined by Hawthorne in his study of rest and productivity.[62]

$$O_1 \quad O_2 \quad O_3 \quad O_4 \quad X \quad O_5 \quad O_6 \quad O_7 \quad O_8$$

This method can assess maturation before treatment and seasonal trends if carried out long enough. Nonetheless, without some

[61] Cook & Campbell [1979], p. 225.

[62] ibid., p. 209.

control group for comparison, treatment induced change from the population at large (the effect) is very difficult to measure. Treatment caused attrition, history, and seasonal variation all pose serious threats to the validity of imputed relationships shown by simple interrupted time-series studies.

## INTERRUPTED TIME SERIES DESIGN WITH NON-EQUIVALENT, NO-TREATMENT CONTROL

By adding a no treatment control group to the simple time-series design, the integrity of experimental results can be greatly enhanced.

| | | | | | | |
|---|---|---|---|---|---|---|
| $O_1$ | $O_2$ | $O_3$ | X | $O_4$ | $O_5$ | $O_6$ |
| $O_1$ | $O_2$ | $O_3$ | | $O_4$ | $O_5$ | $O_6$ |

The major strength of this design is that it minimizes the possibility of results being biased by exogenous historical events. Confounding effects with seasonal variation is also minimized in this design. Moreover, the use of non-treatment control groups is indispensable in making inferences about the delay and duration of any treatment effect. Nonetheless, if the non-equivalent groups have been selected from different populations, such as two different neighborhoods in the same city, events unique to only one group which are concurrent with the onset of treatment can still pose a problem of interpretation.

## INTERRUPTED TIME-SERIES DESIGN WITH NON-EQUIVALENT DEPENDENT VARIABLES

Monitoring different dependent variables throughout the experiment may strengthen construct validity.

| | | | | | | |
|---|---|---|---|---|---|---|
| $O_{A1}$ | $O_{A2}$ | $O_{A3}$ | X | $O_{A4}$ | $O_{A5}$ | $O_{A6}$ |
| $O_{B1}$ | $O_{B2}$ | $O_{B3}$ | X | $O_{B4}$ | $O_{B5}$ | $O_{B6}$ |

In the design diagrammed above, "a" and "b" stand for measures of a separate dependent variable. The experimental groups have no dashed line between them because they are identical: the dependent variables "a" and "b" are DIFFERENT measures of the same group. This design can strengthen construct validity by gathering data relevant to explicit research hypotheses of the form: treatment "X" will have more effect on "a" than on "b".

Consider the hypothesis that continuous in-home electricity information feedback will be most effective in motivating conservation of discretionary electricity consumption, e.g., lighting, television, and cooking loads as opposed to heating, refrigeration, and hot water loads that are usually controlled automatically. Separate monitoring during times of day when respondents are at home and when they are not would enable a test of this hypothesis. This method strengthens construct validity because the constructs "discretionary" and "hidden electricity consumption" may correspond more closely to actual effects of feedback than does the construct "(daily) consumption".

This design would be strengthened in the same way as the simple interrupted time-series design was by introducing a no treatment control group.

## INTERRUPTED TIME SERIES DESIGN WITH TREATMENT REMOVAL

An extension of the simple removed treatment design into a time-series format can reduce threats to internal validity posed by exogenous events (history). For events other than the treatment to confound results of this design, two different countervailing events would need occur <u>simultaneously</u> with the application and removal of the treatment. Also, selection errors due to treatment related attrition are minimized since two different kinds of attrition would be required at different times to confound the results.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $O_1$ | $O_2$ | $O_3$ | X | $O_4$ | $O_5$ | $X^*$ | $O_6$ | $O_7$ | $O_8$ |

One of the possible hazards to internal validity of results from this design is demoralization or resentment at having the treatment removed.

INTERRUPTED TIME-SERIES DESIGN
WITH SWITCHING REPLICATIONS (CROSSOVER)

In this design, commonly called a crossover design, one group serves first as control, and then as a treatment while the other is the control.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $O_1$ | $O_2$ | $O_3$ | X | $O_4$ | $O_5$ | $O_6$ | | $O_7$ | $O_8$ | $O_9$ |
| $O_1$ | $O_2$ | $O_3$ | | $O_4$ | $O_5$ | $O_6$ | X | $O_7$ | $O_8$ | $O_9$ |

This design controls for most threats to internal validity and extends both external and construct validity. External validity is enhanced because the effect can be demonstrated with two populations at two settings at two points in time. Possible hazards due to differences in local history between the experimental groups can be minimized by random assignment.

## 5.2 RESPONSE TO PRICE, FEEDBACK, & INFORMATION

### HAYES & CONE, 1977

Setting: This study was conducted from January to May 1975 in an 80-unit married student housing complex at West Virginia University.[63] All units were identical unfurnished apartments heated by gas and all occupants had at least one child. Each of the four units that volunteered for the study were given a combination of treatments detailed below.

Procedure: After two weeks of covert electrical consumption observation, 5 families were approached and asked to volunteer for "a study of energy consumption and ways to reduce it". Four of the five volunteered. All contact during the study was through the mail. After one additional week of overt daily consumption observations, a complicated factorial and parametric design of treatments lasting about one week each was initiated as diagrammed below.

Rebates (lump sum awards) were calculated by the percent weekly reduction in kWh from the amount consumed during the covert baseline weeks. Payments were delivered in the mail at the end of the week. There were five different levels of payments administered: the full 100% payment condition received $15 for a 50% reduction from the covert baseline level while a 10% reduction earned $3. This high rebate level amounts to an average price reduction in electricity on the order of 750 to 1000% (@ 3¢/kwh and 12-15 kwh/day). Written feedback was delivered daily containing (a) the cost of electricity consumed the previous day, (b) the cumulative cost of electricity consumed so far for the week, (c) a forecast of the week's

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[63] Hayes, S. C., & Cone J. D. Reducing Residential Electrical Energy Use: Payments, Information, and Feedback. Journal of Applied Behavior Analysis, 1977, 10, 425-435.

electricity cost at this rate, and (d) the percent above or below the covert baseline level that "c" represented. <u>Information</u> consisted of a poster that described ways to reduce electricity consumption and listed the average amount of electricity consumed each year for most common household appliances.

<u>Design</u>:

$R_a$ = 100% rebate condition $R_b$ = 83% rebate condition

$R_c$ = 50% rebate condition $R_d$ = 25% rebate condition

$R_e$ = 10% rebate F = daily feedback I = Information

Daily observations taken for 13 weeks.

| n | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | $O_1$ | $O_2$ | $O_3$ | $R_a$ | $O_4$ | | $O_5$ | $O_6$ | I | $O_7$ | $I^*$ | $O_8$ | $R_a{}^*$ | $O_9$ |
| 1 | $O_1$ | $O_2$ | $O_3$ | $R_a$ | $O_4$ | $R_a{}^*$ | $O_5$ | $O_6$ | I | $O_7$ | $R_a$ | $O_8$ | $R_a{}^*$ | $O_9$ |
| 1 | $O_1$ | $O_2$ | $O_3$ | $R_a$ | $O_4$ | | $O_5$ | $O_6$ | | $O_7$ | F | $O_8$ | $F^*$ | $O_9$ |
| 1 | $O_1$ | $O_2$ | $O_3$ | $R_a$ | $O_4$ | $R_a{}^*$ | $O_5$ | $O_6$ | F | $O_7$ | $R_a$ | $O_8$ | $R_a{}^*$ | $O_9$ |
| 80 | $O_1$ | $O_2$ | $O_3$ | | $O_4$ | | $O_5$ | $O_6$ | | $O_7$ | | $O_8$ | | $O_9$ |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $O_9$ | $R_c$ | $O_{10}$ | $R_d$ | $O_{11}$ | F | $O_{12}$ | $F^* R_d{}^*$ | $O_{13}$ |
| $O_9$ | $I^*$ | $O_{10}$ | $R_d$ | $O_{11}$ | F | $O_{12}$ | $F^* R_d{}^*$ | $O_{13}$ |
| $O_9$ | $R_b$ | $O_{10}$ | | $O_{11}$ | $R_c$ | $O_{12}$ | $R_c{}^*$ | $O_{13}$ |
| $O_9$ | $F^*$ | $O_{10}$ | $R_d$ | $O_{11}$ | $R_e$ | $O_{12}$ | $R_e{}^*$ | $O_{13}$ |
| $O_9$ | | $O_{10}$ | | $O_{11}$ | | $O_{12}$ | | $O_{13}$ |

<u>Results</u>: Reductions in daily electricity consumption for each participating household during the study was computed as the percent change from the average daily consumption during the covert baseline period. The 80 member "control" group which included the four experimental households was not appropriate for comparison in that it was an aggregate electricity demand record for the entire apartment complex including outdoor lighting, laundry, and offices. Nonetheless, the resulting data led the researchers to conclude that "<u>payments produced</u>

immediate and substantial reductions in consumption in all units, even when the magnitude of the payments was reduced considerably. Feedback also produced [less significant] reductions, but information about ways to conserve and about the cost of using various appliances did not. ...in general, payments combined with either information or feedback produced no greater effect than payments alone."[64]

Discussion: Though this study implemented a rather advanced parametric and factorial design, it was subject to a number of serious difficulties for the validity of the results. However, this was a pilot study, designed to bring out such problems to define questions for further research. The statistically insignificant sample of four participants were all students and volunteers. No income or budget share information was obtained and the price of all utilities were included in the rent. As the researchers discuss the difficulties inherent in "removing" the information condition, learning probably did occur. Because so many types of treatment were applied to each household, sensitization to the treatment, maturation, and hypothesis guessing was likely. Moreover, because the respondents knew they were participating in a conservation study, evaluation apprehension, evaluator expectations, and interactions of testing and repeated treatments may easily have confounded the results. Finally, feedback was only applied after rebates had been given. It could be argued that the rebates sensitized the participating households, thereby making them more receptive to subsequent (feedback) treatments.

WINETT, KAISER, & HABERKORN, 1976

Setting: This study was done from March to May, 1975 in a

[64] ibid, p.425.

thirty unit apartment complex in Lexington, Virginia.[65] Of 18 apartments that were solicited, 7 volunteered and 5 more agreed to have their meters read. All were occupied by students and recent college graduates. The purpose of the study was to investigate the effect of daily feedback when electricity was used for air conditioning (heating and cooling loads) as well as for appliances and lighting.

Procedure: Volunteers were solicited through a letter which detailed the purpose of the study and included general information on how to conserve electricity. After a monitoring baseline period of one week, each of the six treatment apartments were placed on a high rebate system rewarding electricity reductions relative to daily average consumption in the baseline and to the consumption of control units during the treatment period. Full rebates ranged from $2 for a 5 - 9% reduction to $7 for reductions in excess of 30%. This amounted to an average price reduction in electricity of between 300 to 400% (@ 3¢/kWh and 180kWh/wk). During the second week of treatment, one treatment group was placed on a 1/2 rebate scheme while the other treatment group received feedback only. The feedback condition consisted of a daily feedback note indicating the apartment's change in demand relative to their baseline and the demand of the control group. In the final three weeks of the study, both treatment groups received daily feedback only.

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[65] Winett, R.A., Kaiser, S., & Haberkorn, G. The Effects of Monetary Rebates and Daily Feedback on Electricity Conservation. Journal of Environmental Systems, 1976-77, 6(4), 329-341.

Design:

$R_1$ = 100% rebate condition    $R_2$ = 50% rebate condition
F = daily feedback

Daily observations for two treatment groups and one control

| n | | | | | | | |
|---|---|---|---|---|---|---|---|
| 3 | $O_1 \ldots O_7$ | $R_1$ | $O_8 \ldots O_{14}$ | $R_2$ | $O_{15} \ldots O_{21}$ | F | $O_{22} \ldots O_{29} \ldots O_{36} \ldots O_{42}$ |
| 3 | $O_1 \ldots O_7$ | $R_1$ | $O_8 \ldots O_{14}$ | F | $O_{15} \ldots O_{21}$ | | $O_{22} \ldots O_{29} \ldots O_{36} \ldots O_{42}$ |
| 6 | $O_1 \ldots O_7$ | | $O_8 \ldots O_{14}$ | | $O_{15} \ldots O_{21}$ | | $O_{22} \ldots O_{29} \ldots O_{36} \ldots O_{42}$ |

Results: Because of the small sample size, n, the data were not subjected to formal statistical analysis. Nonetheless, graphical analysis indicated an average reduction of 10 - 15% in an apartment setting due to feedback preceded by rebates. "Relative to the control apartments, the full rebate system yielded a 30% reduction in electricity use while the half rebate and feedback systems yielded 15%".[66] Feedback was less effective on hot days when air-conditioning dominated apartment electricity demand. As air-conditioning demand represents a major component of total summer loads in many part of the US, the researchers concluded that there is a need to investigate other forms of feedback more explicitly tied to air-conditioning.

Discussion: As with the Hayes & Cone study, this experiment did not use statistically significant samples (n = 3) nor random assignment. Moreover, the data showed high variability of response and two units (one each from treatment and control groups) had to be removed from the analysis for the generalizations above to be possible. Again, college students who all volunteered for the study were used. Self-selection and the limited sample originally contacted constrain any

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[66] ibid, p.329.

generalization of results to: college students who volunteer. Moreover, all participants, treatment and control group members alike, were given information on how to reduce electricity consumption, further removing the sample from comparability to any meaningful population.

The study period was brief (5 weeks) with no follow-up to determine the permanence of the feedback effect nor the effect of removing feedback. As the study was conducted in one apartment complex among neighbors, it is likely that the treatment could have spread into the control group, especially after the size of the first week's rebates became known. This could have resulted in an underestimation of the effects due to rebates and feedback.

After the experiment each treatment group participant was interviewed to learn how electricity was conserved. The response varied from significant changes in thermostat setting and less TV viewing to little change at all after the rebates ended.

BATTALIO, KAGEL, WINKLER, & WINETT, 1979

Setting: A random sample of 496 residential customers who had paid electricity bills at the same residence for at least one year in College Station, Texas were sent letters of invitation to the study.[67] The letter explained that the purpose of the study was to determine if energy use was affected by price reductions. Participants were promised either a price reduction plan and/or a package of energy conservation

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[67] Winett, R.A., Kagel, J.H., Battalio, R.C., and Winkler, R.C. "Effects of Monetary Rebates, Feedback, and Information on Residential Electricity Conservation", Journal of Applied Psychology, 1978, 63(1), 73-80. The same field experiment is reported in Battalio, et al., "Residential Electricity Demand: An Experimental Study", The Review of Economics and Statistics, 1979, 61(2), 180-189. All data and statistical analyses are taken from the latter, while information on selection and recruitment are taken from the former.

material. After two attempts were made over the phone to contact non-respondents, 129 households were enrolled in the study.

Participants were required to attend an initial meeting, allow their meters to be read weekly for 13 weeks, authorize the utility to release past records to the researchers, and return a postcard each week indicating the number of days the house had been unoccupied. Those planning a vacation during the study period or those whose residential structure had been altered in the past year were excluded. "About 90% of the participants were married, the age range of participants was 21-76 years (median = 42) and the median net income was between $12,000 and $15,000. Nearly 80% owned their residences. About 70% of the households had central air conditioning".[68]

Procedure: Before the respondents were assigned to experimental groups, meters were monitored during a two week baseline period. For the next four weeks, respondents were randomly assigned to one of five experimental conditions. This was followed by a six week period in which experimental conditions were changed (crossed) as needed to clarify results from the initial period. The procedure is diagrammed in the schematic below.

High Price Rebate Group: Members of this group received 30¢ for each 1% reduction in weekly kWh demand over their average weekly demand the past summer. A bonus of $10 was awarded to the top 50% of those in the group with the largest percentage reductions. Payments were mailed only after the end of the fourth week. Weekly meter readings along with a calculation of the amount of payment to which they were entitled for that week were left each week by the meter

[68] Battalio, et al, op cit, p. 181.

readers. In addition, members of this group received two government prepared information booklets giving tips on how to reduce household energy consumption and instructions on how to compute their electric utility bill.

Low Price Rebate Group: Members of the low price rebate group received 1.3¢ per kWh reduction below their average weekly demand the past summer. A bonus of $2 was awarded to the 50% who reduced the most over last summer. This group also received the same type of feedback and information as the high price rebate group.

At the time of the experiment, the marginal cost of electricity was 2.6¢ per kWh. Hence, the low price rebate amounted to a 50% increase in the marginal cost of electricity. At the mean use level of 493 kWh/wk, the high price rebate amounted to a marginal cost increase of about 235%.

Feedback Group: Members received all of the weekly feedback of the two rebate groups and the conservation information, but did not receive any rebates.

Information Group: Members of this group were given the government prepared conservation pamphlets and instructions on how to compute their electric bill.

Control Group: Members of this group were not mailed anything during the initial four weeks.

Design:

H = High Price Rebate L = Low Price Rebate

F = Weekly Feedback I = Conservation Information only

Weekly Observations and Changes in Treatment Conditions

| n | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 17 | $O_1$ | $O_2$ H | $O_3 \ldots O_6$ | | $O_7$ | $O_8$ | $O_9$ | $O_{10}$ | H* $O_{11}$ | $O_{12}$ |
| 20 | $O_1$ | $O_2$ L | $O_3 \ldots O_6$ | | $O_7$ | $O_8$ | $O_9$ | $O_{10}$ | L* $O_{11}$ | $O_{12}$ |
| 24 | $O_1$ | $O_2$ F | $O_3 \ldots O_6$ | | $O_7$ | $O_8$ | $O_9$ | $O_{10}$ | $O_{11}$ | $O_{12}$ |
| 20 | $O_1$ | $O_2$ I | $O_3 \ldots O_6$ | I* | $O_7$ | $O_8$ H | $O_9$ | $O_{10}$ | $O_{11}$ | $O_{12}$ |
| 26 | $O_1$ | $O_2$ | $O_3 \ldots O_6$ | I | $O_7$ | $O_8$ | $O_9$ | $O_{10}$ | $O_{11}$ | $O_{12}$ |

Results: This field experiment, unlike the two previous studies presented above, was designed and executed for statistically significant results (n > 15, random assignment, and psuedo-random selection). Analysis of changes in electricity use for each group relative to its own aggregate baseline level were presented for the initial and follow-up periods. Group consumption during baseline was chosen as the standard, rather than consumption during the previous summer, to provide "much more updated information on household energy use, correcting for changes in household composition and energy using appliances, thereby reducing spurious between subject differences".[69] The internal changes in consumption for each group are then compared across groups with tests of statistical significance. Table 5.1 presents the mean changes in electricity use from baseline levels within each experimental group during the initial treatment period.[70]

Table 5.1 Mean Changes in Electricity Use by Treatment Groups during Initial Four Week Experimental Period (percent change in mean kWh demand relative to baseline)

| Group: | High (H) | Low (L) | Feedback | Info | Control |
|---|---|---|---|---|---|
| Mean Change | -3.48 | -4.56 | +1.72 | +7.25 | -0.93 |
| Number | 17 | 20 | 24 | 20 | 26 |

The mean differences in Table 5.1 show some unexpected results. Namely, the information group increased electricity use the most, while the low rebate group realized greater reductions than the high rebate group. The difference between the reductions in both rebate groups and the increase in the information group was statistically significant at the 5%

[69] ibid, p. 184.

[70] ibid., p. 185.

level.[71] Moreover, the difference between the information group and the control group was significant at the 10% level. No other significant differences between groups were found.

The second phase of this experiment was designed to allow for crossover application of treatments to various groups for comparison. Given the unexpected results of the initial period, it was wise to allow enough flexibility to check if the relations still held when treatments were applied to different groups.

As shown in the schematic of the design, the control group was first given the information condition in week 6 to check of they would display the same order of increase as did the original information group. After a two week delay for the information effect to dissipate[72], the information group was placed on a modified high rebate scheme. Finally, the rebates were discontinued from the original rebate groups two weeks before the study ended. During phase II, the feedback group was left unchanged to serve as reference for evaluating the changes in the other experimental groups. The mean changes during phase II from consumption under the initial conditions is presented in Table 5.2.

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[71] We can be 95% confident that the observed differences between group mean % shifts is actually due to a difference between the shift in means and not a chance error.

[72] The increase in consumption displayed by the information group did not wear off during these two weeks. Recall the conceptual difficulty with removing information mentioned in the presentation of Hayes & Cone, 1977.

Table 5.2 Mean Changes in Electricity Use Within Experimental Groups During Weeks 6 Through 12 (percent change in mean kWh demand relative to weeks 1 - 4)

| Initial Condition: | High (H) | | Low (L) | | Info | Control |
|---|---|---|---|---|---|---|
| New Cond: | Payment | H* | Payment | L* | H | I |
| Mean Change | -8.29 | -3.24 | +1.44 | -2.75 | -7.56 | +0.95 |
| Number in Group | 17 | | 20 | | 20 | 26 |

Results from phase II indicate that 1) the receipt of payment after the initial 4 weeks coincided with a marked reduction in the high rebate group (significant at the 2.5% level), 2) the modified (weakened) high rebate scheme applied to the information group coincided with most significant reductions (significant @ the 1% level), and 3) information did not bring about the same order effect on the control group as initially displayed by the information group (insignificant at the 10% level).

These results temper the initial findings of significant differences between rebate and information groups and indicate the robustness of the high rebate scheme for reducing electricity consumption. <u>The 12% reduction in electricity demand (relative to baseline demand) by the high rebate group</u> after receipt of the payment for the first four weeks until the end of the study <u>was the only significant reduction in electricity use over the length of the study</u>.

Removing the rebates from the initial rebate groups did <u>not</u> result in increased electricity use relative to the initial period. Though the study ended two weeks after this withdrawal, the researchers attribute the continued lower levels of consumption to persistence in maintaining energy saving habits.

<u>Discussion</u>: The researchers offer one plausible hypothesis for why the information condition corresponds to an <u>increase</u> in electricity consumption.

> "Since the available evidence suggests that (at the time) most consumers didn't know the detailed costs of electricity using behaviors and/or severely overestimated these costs, the information given may well have resulted in a downward revision of the estimated costs of a number of activities, thereby promoting their use. While the exact relationship between cost information and energy use required further study, all of the available data suggest that although educational materials by themselves may lead to better informed consumers and more favorable attitudes towards energy consumption, it is not likely in the short term to lead to reduced use."[73]

However, another possible confounding effect could be due to resentful demoralization of the information group because they figured they would not be getting any of the desirable rebates during the length of the study for which they had volunteered.

The results show that the weekly feedback group did not show any significant reductions even though they were also given conservation materials and information on how to calculate their bill. It is possible that the effects of weekly feedback and actual cost information offset each other in a countervailing fashion, thereby confounding the effect of weekly feedback.

No information is presented on attrition from the experimental groups. In the Journal of Applied Psychology article[74], the researchers report sample sizes 15% larger than those cited above. Most of the attrition (16 of 129) was from the low rebate and information groups. This asymmetric attrition, if related to the treatment conditions, violates randomness and cannot be corrected statistically. Moreover, a self-selection bias may have operated against randomness during the selection process. The analysis does not show how representative of the general College Station, Texas population the experimental sample was (70% married and 80% homeowners). The researchers did, however, note that there were no

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[73] ibid, p. 188.

[74] Winett, et al., op cit., p. 75.

significant differences between the changes in demand serviced by a major residential feeder line for College Station and the changes in the control group. This is cited in support of the claim that volunteering had little to no effect on the results. Nonetheless, no data was gathered for the participants and the community for comparison before the study. A compelling case cannot be made for no significant differences between volunteers and the general public without data on consumption levels before the study, changes at the onset of the study, and cross-sectional data of the participants for comparison with the community as a whole. The authors also cite the finding of Hayes & Cone of no significant difference between readings taken covertly before their study and those taken during the overt observation period. However, as the Hayes & Cone study was more impressionistic than statistically significant, these observations cannot be relied upon to reasonably reduce the threat to external validity from samples drawn from volunteers. The problem of relying on volunteers is common to almost all of the field studies presented here.[75]

Finally, it could be charged that the participants anticipated the payments figured on reductions from baseline use (hypothesis guessing) and, therefore, increased consumption during that period to maximize their rebates. The same behavior might result from the desire to please the researcher by being able to make large reductions. Again, no measurement of consumption before the study was done to test these hypotheses.

Overall, this exemplary study highlights the particular problems that crop up in field experiments. No matter how carefully the experiment is designed and data gathered to test alternative hypotheses, tradeoffs between the different kinds of experimental validity are inevitable.

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[75] The exception is McClelland & Cook, 1979.

In the next section, 5.3, studies of different forms of feedback and goal setting are presented. Though these are treated as distinct from the studies of marginal price changes and feedback presented in 5.2, the distinction is merely for convenience.

Demand management studies from a macro perspective have focused on price elasticities of demand for electricity in the various end use sectors. The implicit hypothesis is at the root of neo-classical economics: price increases reduce demand. This approach leads to the policy recommendation that peak load pricing is a most effective way to encourage conservation. The behavioral science studies of feedback and social prompting investigate a different, though not mutually exclusive, path to conservation policy. The implicit hypothesis is: if consumers have better information about how much electricity is consumed by each activity and, thereby, feel they have more control over their energy consuming patterns, they will adjust demand accordingly. The six experiments presented in the next section investigate this hypothesis.

## 5.3 RESPONSE TO FEEDBACK, GOALS, & PROMPTS

### SELIGMAN & DARLEY, 1977

Setting: Forty homeowners from physically identical homes were recruited (how selection was done is not reported) for the study from a 3000 home development in central New Jersey.[76] Each home had central air conditioning. In each home,

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[76] Seligman, C., & Darley, J.M. "Feedback as a Means of Decreasing Residential Energy Consumption", Journal of Applied Psychology, 1977, 62(4), 363-368. The study was carried out in this setting because variance in energy consumption between physically identical homes is almost entirely due to variance in the energy consumption habits of the occupants.

electricity was used for air conditioning, lighting, refrigeration, and other appliances, while natural gas was used for hot water, the range, and the clothes dryer.

The experiment, carried out from July to September, 1975, focused on feedback designed to reduce electricity used for air conditioning. In these homes the air conditioning system consumes about 70% of the total summer electricity demand and a 1°F increase in summer thermostat setting could save about 8% of the summer total demand. The researchers designed the feedback to explore this potential for conservation.

Procedure: The forty respondents were randomly assigned to either a feedback or control condition. After a four week observation period, all respondents received a letter informing them that they were in an energy study[77], that air conditioning was the largest user of electricity, and that the researchers "hoped they would reduce their air conditioning usage".[78]

Daily information about electricity consumption in each home of the feedback group was displayed by a research assistant in a Lucite display attached outside the kitchen window in the evening. The number displayed was the ratio of actual daily demand to a demand predicted by an energy consumption model tied to outside temperature. Hence, a display of 115% would mean that the household had consumed 115% of the amount predicted for that day by an electricity demand regression based on a 4 week pre-feedback period during which data was collected on daily electricity demand vs. outside temperature. Members of the feedback group were given an explanation of the display values in the letter delivered on the first day of feedback. The treatment condition lasted for

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[77] Apparently, daily household electricity consumption was monitored covertly for the first four weeks of the study.

[78] ibid, p. 365.

four weeks, after which feedback and observations were discontinued.

Design:

F = feedback condition I = received letter only

Weeks of Daily Observations and/or Feedback Postings

| n | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 15 | $O_1$ | $O_2$ | $O_3$ | $O_4$ | F | $O_5$ | $O_6$ | $O_7$ | $O_8$ |
| 14 | $O_1$ | $O_2$ | $O_3$ | $O_4$ | I | $O_5$ | $O_6$ | $O_7$ | $O_8$ |

Results: The average daily consumption during observation and treatment periods for each group is presented in Table 5.3.

Table 5.3

Mean Electricity Consumption Before and After Daily Feedback

| Experimental Group | | Pre-treatment | Post-treatment |
|---|---|---|---|
| Feedback (n=15) | Mean (kWh/day)<br>Std. Dev. | 68.33<br>(10.45) | 48.56<br>(7.94) |
| Control (n=14) | Mean (kWh/day)<br>Std. Dev. | 69.14<br>(11.04) | 54.25<br>(5.12) |

The two groups did not differ significantly in average electricity demand during the four week observation period. After feedback was initiated, however, the feedback group used about 10.5% less electricity than the control group, with only a 4% chance that the difference was due to random error. Further statistical analysis of respondents in the feedback group by rank in electricity demand during the pre-treatment period, showed that a household's initial consumption level was not related to the size of its reduction. This led the researchers to conclude that "energy conservation campaigns need not be aimed solely at the relatively higher energy consumers; lower users are also capable of further conservation".[79]

Discussion: As the Battalio, Kagel, Winkler, and Winett, 1979 study showed, the difference between feedback groups and those who are given written encouragement to conserve may be mostly due to changes in the "control" group rather than to changes in the feedback group. Since the "control" group in this study was "treated" by being encouraged to reduce electricity consumption, the effect of feedback relative to an untreated group is not clear. Moreover, the effects of researcher expectations, made explicit in the letter, are inextricably confounded with the effects of daily feedback relative to the "control" group. This is so because of the possibility of two effects that would tend to exaggerate the differences: 1) members of feedback group may have developed loyalties to the researchers, whose representative visited each day to display desirable information, and caused them to reduce consumption to please the researchers; and 2) members of the "control" group may have resented being studied, especially if not contacted before the letter arrived, and not heeded the wishes of the researchers to reduce air conditioning demand.

No information on income, budget share for electricity, electricity price, or family size is reported. Methods used to select the participants is not reported but for the technical grounds of similar physical house characteristics. The study included no follow up observation period after treatment removal nor did it use a survey to illuminate the actions of members of each group.

While the data show a statistically significant relationship between the two groups, it is not at all clear what the relationship is due to. Nonetheless, the results do show the feedback group consumed 10% less electricity than the

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[79] ibid, p. 367.

"control" during treatment when ostensibly the only difference between the groups was the treatment condition.

McLELLAND & COOK, 1979

Setting: Twenty-five of the 101 homes in the Polk's Landing Development, Carrboro, North Carolina were equipped with Fitch energy monitors during construction.[80] All homes were single family dwellings with all-electric with identical energy conservation construction packages. Homes with the energy meters were the last to be occupied and were scattered throughout the construction project. Residents had no knowledge of or choice in obtaining monitors at the time of purchase. The units were first occupied between fall 1975 and December of 1976 by singles (13%), couples (63%), and families with children (24%). This study compared electricity consumption of occupants with energy meters to those without between September 1976 and July 1977.

Procedure: No pretest was possible in this experiment as the treatment began as soon as the homes equipped with energy monitors were occupied. Monthly electricity consumption data was obtained from Carolina Power and Light by lot number for the 11 month study. No interaction occurred between the researchers and the homeowners during the study.

Continuous feedback was displayed by LEDs on a small panel inside the home. The Fitch energy meter displayed the cost of electricity in the form of ¢ per hour at a cost per kWh set manually on the device.

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[80] McClelland, L., & Cook, S.W. "Energy Conservation Effects of Continuous In-Home Feedback in All-Electric Homes", Journal of Environmental Systems, 1979-80, 9(2), 169-173.

Design:

X = homes with Fitch Energy meter

Observations of Monthly Kwh Demand

| n | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24 | X | $O_1$ | $O_2$ | $O_3$ | $O_4$ | $O_5$ | $O_6$ | $O_7$ | $O_8$ | $O_9$ | $O_{10}$ | $O_{11}$ |
| 69 | | $O_1$ | $O_2$ | $O_3$ | $O_4$ | $O_5$ | $O_6$ | $O_7$ | $O_8$ | $O_9$ | $O_{10}$ | $O_{11}$ |

Results: The homes with the energy monitors were significantly larger than those without (131 vs 121 $m^2$) and were occupied by slightly larger families. The effects on energy consumption of these two confounds were removed statistically with multiple regression analyses. KWh consumption was regressed on family size, $m^2$, and presence-absence of monitors for each of the eleven months.

"Monitors are associated with lower consumption in all eleven months. The differences neither increase nor decrease over time, averaging about 12 %, but do tend to be larger in lower consumption months. This suggests that the conservation actions taken by households with monitors primarily affected energy uses other than heating and cooling. [As distinct from other forms of feedback commonly studied], the monitors may have served more to teach residents what activities consume the most energy than simply to draw attention to the cost of energy".[81]

Discussion: This study approaches a "true" experiment with random assignment and no interaction between researcher and respondents. Nonetheless, the results could have been strengthened significantly if a survey was conducted to discover what the occupants of the homes with monitors had done to reduce energy consumption. A design change that, in

[81] ibid, p. 171.

retrospect, would have greatly enhanced the results would have been to use a monitor that could store time-of-day data to find if periods when the occupants were generally at home (evenings) showed the most marked reductions or not. Moreover, if the households were blocked by different income levels and average electricity consumption in the data analysis, instead of removing these parameters by regression, differential effects of continuous display may have been found.

The most striking result from these data is the evidence that the effects of continuous feedback may differ from those of daily feedback which seem to be more effective at promoting reductions in heating and cooling. Indeed, if the device is used to learn what each appliance consumes, it would encourage reduced lighting, a warmer refrigerator setting, and less use of the range, clothes dryer and other small house loads. This is the only study in the literature that investigated the effect on electricity consumption of continuous feedback.

BECKER, 1978

Setting: The study was conducted in the summer of 1976[82] in the same 3000 unit townhouse development in central New Jersey in which Seligman and Darley did their work in 1975. Families were called at random from a list of 317 identical three-bedroom townhouses. One hundred and seventy-five families had to be contacted to find 100 willing to participate. Median annual family income in the sample was $20,000 - $25000.

Procedure: Monthly consumption data was collected for all participating households for the two months preceding the study. Families were randomly assigned to 5 groups of 20

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[82] Becker, L.J., "Joint Effect of Feedback and Goal Setting on Performance: A Field Study of Residential Energy Conservation" Journal of Applied Psaychology, 1978, 63(4), 428-433.

each for a three week treatment period during August of 1976. All participants received a letter during an in-home interview by one of four research assistants that explained the purpose of the study, the goals (for treatment groups only), and a list of appliances showing energy consumption relative to the demand of an air conditioner run for one hour.

Control: The letter explained to the control group that "it was their regular everyday consumption patterns that were of interest, and they were asked just to continue using electricity as they normally would."[83]

Goals: Two of the four treatment groups were asked to achieve a hard goal of 20% electricity reduction, while the other two groups were asked to set an easy reduction goal of 2%.

Feedback: One of the groups assigned to each goal was given feedback 3 times weekly. The feedback consisted of a percent ratio showing how close to their target reduction each household was. This ratio was derived from each household's cumulative electricity consumption from the beginning of the treatment period as compared to an estimate predicted by baseline data for that household and consumption of the control group during the treatment period. Feedback was displayed in a plastic pocket outside the patio window by a research assistant on Monday, Wednesday, and Friday during the 3 week treatment period. After the three week study was complete, observations were discontinued and all feedback devices were removed.

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[83] ibid, p. 430.

Design:

F = feedback updated three times weekly
H = hard reduction goal of 20
E = easy 2% reduction goal
$O_M$ = observations of monthly consumption (June & July)
$O_i$ = daily observations of consumption during week i

Experiment Design: Daily Observations for Three Weeks

| n | | | | | | | |
|---|---|---|---|---|---|---|---|
| 20 | $O_{M1}$ | $O_{M2}$ | H F | $O_3$ | $O_4$ | $O_5$ | $H^* F^*$ |
| 20 | $O_{M1}$ | $O_{M2}$ | H | $O_3$ | $O_4$ | $O_5$ | $H^*$ |
| 20 | $O_{M1}$ | $O_{M2}$ | E F | $O_3$ | $O_4$ | $O_5$ | $E^* F^*$ |
| 20 | $O_{M1}$ | $O_{M2}$ | E | $O_3$ | $O_4$ | $O_5$ | $E^*$ |
| 20 | $O_{M1}$ | $O_{M2}$ | | $O_3$ | $O_4$ | $O_5$ | |

Results: The only statistically significant effect this study showed was that the group with the 20% reduction goal and feedback reduced electricity consumption by 13% relative to the control group (at the 5% level). A high degree of variance in the results for all other groups made any effects other than this statistically indistinguishable.

Discussion: These results support the hypothesis of this study that "the motivational effect previously attributed to either feedback or to goal setting is actually due to their joint effect".[84] This is an alternative hypothesis that previous studies had not gathered data to refute or support. The construct validity of these results, therefore, is stronger than previous results that confounded the two effects. Nonetheless, this experiment tested only one exemplar of each possible form of feedback and goal setting in support of the claim above. The results say nothing about the efficacy of other forms of feedback (daily, continuous, and those not tied

[84] ibid, p. 432.

to target reductions) or the interaction between these other forms and goal setting.

WINETT, NEALE, WILLIAMS, YOKLEY, & KAUDER, 1978

Setting: This study was conducted from late April to early September of 1977 in Greenbelt, Maryland.[85] During this time major increases in electricity use were primarily attributable to air conditioning. Participants were drawn from three separate areas with distinct home types. Participants from area "A" all lived in two storey, two bedroom townhouses, had an average income from $15,000 to $20,000, and consumed an average of 10.7 kWh / day. Participants from area "B" lived in three storey, three bedroom townhouses, had incomes from $20,000 to $25,000, and consumed an average of 20.8 kWh / day. Participants from area "C" lived in three or four storey, four bedroom, free standing homes, had incomes from $30,000 to $35,000, and consumed an average of 29.7 kWh / day during the baseline period. Homes in areas "B" and "C" had central air conditioning while those in are "A" had at least one window unit.

Procedure: All participants were recruited using a personal door-to-door approach. Volunteers were assigned to either feedback or comparison groups by clusters of homes in order to "1) potentially enhance feedback's effectiveness through social comparison by neughbors, 2) use group feedback in definable areas and limit the types of feedback to one location, and 3)

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[85] Winett, R.A., Neale, M.S., Williams, K., Yokley, J., and Kauder, H., "The Effects of Feedback on Residential Electricity Consumption: Three Replications", Journal of Environmental Systems, 8(3), 1978-79, 217-233.

reduce logistical problems in distributing feedback forms.[86] At separate outdoor meetings for feedback and control group members, a thorough explanation of the procedures was given and participants in the feedback groups selected a reduction goal which averaged around 5%. Seventy-three percent of the households originally contacted agreed to participate in the project. While assignment was not random, "both feedback and comparison groups from each area were composed of residences that were virtually identical in physical and demographic characteristics and average kWh used."[87]

Feedback: Written feedback was delivered daily to the doorstep of each household in the feedback groups. The forms indicated kWh used the previous day and the percent increase or decrease relative to the consumption of the control group from that area. Moreover, the forms were color coded with an ascending series of smiles and frowns to indicate how well the feedback groups were conserving electricity and a gold star was affixed when the household had met its reduction goal. Three types of feedback were given: 1) information on the individual household's consumption relative to the control group, only, 2) information on the feedback group average consumption relative to the control group, and 3) information on both the individual household's performance and that of the group relative to the control group.

A three to four week baseline observation period was followed by five to six weeks of feedback. The treatment was then removed and observations were continued for another seven weeks.

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[86] ibid, p. 220.

[87] ibid, p.222.

Design:

I = individual daily feedback only
G = group daily feedback only
IG = Both individual and group daily feedback

| n | Group | Daily Observations for 18 Weeks | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 21 | | $O_1$ | $O_2$ | $O_3$ | I | $O_4$ | $O_5$........$O_{10}$ | I* | $O_{11}$........$O_{18}$ |
| 14 | A | $O_1$ | $O_2$ | $O_3$ | G | $O_4$ | $O_5$........$O_{10}$ | G* | $O_{11}$........$O_{18}$ |
| 22 | | $O_1$ | $O_2$ | $O_3$ | | $O_4$ | $O_5$........$O_{10}$ | | $O_{11}$........$O_{18}$ |
| 11 | B | $O_1$ | $O_2$ | $O_3$ | $O_4$ | IG | $O_5$........$O_{10}$ | IG* | $O_{11}$........$O_{18}$ |
| 10 | | $O_1$ | $O_2$ | $O_3$ | $O_4$ | | $O_5$........$O_{10}$ | | $O_{11}$........$O_{18}$ |
| 16 | | $O_1$ | $O_2$ | $O_3$ | I | $O_4$ | $O_5$........$O_{10}$ | I* | $O_{11}$........$O_{18}$ |
| 13 | C | $O_1$ | $O_2$ | $O_3$ | IG | $O_4$ | $O_5$........$O_{10}$ | IG* | $O_{11}$........$O_{18}$ |
| 14 | | $O_1$ | $O_2$ | $O_3$ | | $O_4$ | $O_5$........$O_{10}$ | | $O_{11}$........$O_{18}$ |

Results: No statistically significant reductions were realized in the group with group feedback only. A 7% reduction for low users and a 20% reduction for high users was realized in groups using individual feedback, only. The two groups receiving both individual and group feedback in moderate and high consumption areas "B" and "C" realized 20% reductions, each. Some maintenance of these effects were witnessed in the follow-up period in areas "B" and "C", only.

The greatest percentage reductions were obtained for the higher users during the warmest weather. Post-study questionnaires indicated that "virtually all participants who reduced their electricity consumption relative to their comparison group attributed their savings to less use of air conditioning".[88] This effect and response led the researchers to recommend that "the high user should be the target for conservation efforts [and that] intensive conservation programs

[88] ibid, p. 230.

would best be mounted during the summer cooling and winter heating seasons".[89]

Discussion: The policy implications drawn from these results are not surprising given that the study was conducted in the summer and respondents were encouraged to reduce air conditioning demand as it constitutes the largest single load in the summer. Larger consumers with central air conditioning will naturally have more of a margin to reduce air connditioning energy demand than smaller consumers with only a window unit.

This design which used group feedback and social prompts to obtain effects may have been more subject to resentful demoralization among control groups than those that do not use group meetings and social comparison by neighbors. Nonetheless, the use of a follow-up observation period and blocking by income level and amount of electricity consumed is a marked improvement over previous designs.

BITTLE, VALESANO, & THALER, 1979

Setting: This study was conducted in a rural Southern Illinois community during the summer of 1977.[90] Participants were solicited door-to-door. Families were asked for permission to read their electricity meters and to be furnished with daily information on their energy consumption. Of the 376 families who volunteered to be in the study, 23 were later excluded because they took vacations or added energy saving home improvements during the study.

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[89] ibid, p. 231.

[90] Bittle, R.G., Valesano, R.M., and Thaler, G.M., "The Effects of Daily Feedback on Residential Electricity Usage as a Function of Usage Level and Type of Feedback Information", Journal of Environmental Systems, 9(3), 1979-80, 275-287.

<u>Procedure</u>: Participants were randomly assigned to one of four types of feedback. Every fourth household in each treatment condition was assigned to a delay group that was not to receive the treatment until 10 days after the rest of the group. This delay group was to serve as a control group during the delayed treatment period. After a 17 day observation period, beginning on June 15, 1977, the feedback groups began receiving daily feedback on small cards delivered to their doorstep by the meter readers. Meter readers were unaware of the experimental hypotheses and were told to direct all questions from the participants to the research team. The delayed members began receiving the same at day at day 28. All feedback was discontinued after day 52 and a one week observation period followed.

<u>Feedback</u>: The feedback consisted of one of four types: 1) daily kWh consumed, 2) cumulative kWh consumed since the first of the month, 3) $ cost of the day's electricity, or 4) $ cost of the cumulative consumption since the first of the month.

<u>Design</u>:

Feedback notation:

$X_1$ = energy (kWh) used during the previous day
$X_2$ = cumulative kWh used since the first of the month
$X_3$ = cost ($) of electricity consumed the previous day
$X_4$ = cumulative cost of electricity used since the first of the month

Daily Observations and Written Feedback

| n | | | | | |
|---|---|---|---|---|---|
| 69 | $O_1 \ldots O_{17}$ | $X_1$ | $O_{18} \ldots O_{52}$ | $X_1^*$ | $O_{53} \ldots O_{59}$ |
| 66 | $O_1 \ldots O_{17}$ | $X_2$ | $O_{18} \ldots O_{52}$ | $X_2^*$ | $O_{53} \ldots O_{59}$ |
| 66 | $O_1 \ldots O_{17}$ | $X_3$ | $O_{18} \ldots O_{52}$ | $X_3^*$ | $O_{53} \ldots O_{59}$ |
| 66 | $O_1 \ldots O_{17}$ | $X_4$ | $O_{18} \ldots O_{52}$ | $X_4^*$ | $O_{53} \ldots O_{59}$ |
| 22 | $O_1 \ldots O_{28}$ | $X_1$ | $O_{29} \ldots O_{52}$ | $X_1^*$ | $O_{53} \ldots O_{59}$ |
| 24 | $O_1 \ldots O_{28}$ | $X_2$ | $O_{29} \ldots O_{52}$ | $X_2^*$ | $O_{53} \ldots O_{59}$ |
| 22 | $O_1 \ldots O_{28}$ | $X_3$ | $O_{29} \ldots O_{52}$ | $X_3^*$ | $O_{53} \ldots O_{59}$ |
| 18 | $O_1 \ldots O_{28}$ | $X_4$ | $O_{29} \ldots O_{52}$ | $X_4^*$ | $O_{53} \ldots O_{59}$ |

Results: Because of the experimental design and a weather change during the study, the results were highly variable and difficult to interpret. Without a control group against which to compare the effects of treatment and removal, some unusual results occurred, despite the significant sample size. To decrease the variation in the results, the researchers analyzed the data in three groups by size of mean consumption. Nonetheless, when this was done, the size of the delay groups used for control during the application of feedback at day 18 fell to an average of 7 (smallest = 3, largest = 10).

Despite these structural problems, the researchers concluded that cumulative data was more effective than daily data for encouraging conservation. Moreover, the results indicate that daily feedback was effective for high consumers, but may correspond to an actual increase in consumption among the lowest consumers.

Discussion: An experimental design without a significant control group is to be avoided. The control comparisons in this study were limited to the 10 day delay time. No information was collected on income or budget share of electricity costs. Without data on consumption of a control group that did not experience any treatment, the research team was left with making some intergroup comparisons to baseline consumption, only. While the results do indicate that daily feedback of cumulative information may be more effective than feedback of daily information, no survey was done to find out why this may be the case or what the respondents did to reduce consumption.

WINETT, NEALE, & GRIER, 1979

Setting: This study was conducted in a suburban Maryland townhouse community near Washington, D.C. during the winter of

1978.[91] Participants were drawn from an upper-middle class neighborhood living in almost identical all-electric townhouses that consumed on average 170 kWh/day for a monthly electricty bill of over $200. The median income of the participants was about $40,000 annually.

Procedure: All participants were recruited using the same door-to-door procedure as in the previous summer study in the same community.[92] Sixty percent of the households initially contacted consented to participate in the study. The 45 participating households were randomly assigned to feedback, self-monitoring, or "volunteer comparison" conditions. It was possible to read the meters of 29 households that had declined to participate in the treatments. This group was compared against the volunteer comparison group that received no experimental treatment to ascertain the effects of volunteer status on energy consumption.

A three week observation period was followed by four weeks of treatment. After the treatment was removed, observations continued for ten weeks to view the characteristic maintenance in the effects of the two methods of feedback.

Feedback: Both feedback and self-monitoring groups attended separate meetings at which the rationale for the study was explained and information emphasizing thermostat control as a means to conserve energy was distributed. During the four week treatment period, written color-coded sheets were delivered to the door of each member of the feedback group. "Each day's sheet indicated the household's prior day's kWh consumption, its percentage increase or decrease from baseline with a correction for weather, the relationship of the decrease

[91] Winett, R.A., Neale, M.S., and Greir, H.C., "Effects of Self-Monitoring and Feedback on Residential Electricity Consumption", Journal of Applied Behavior Analysis, 1979, 12, 173-184.

[92] See Winett, et al, [1978].

to a reduction goal chosen by the household in the meeting, and an estimate of the household's monthly electricity bill in dollars, based on its prior day's use".[93]

Self-monitoring: At the meeting of the self-monitoring group, participants were taught to read their own electricity meters. One member of each household had to pass an exam of competency in taking the readings and calculating all of the parameters that were given to the feedback group as specified above. Members of this group were given graphs and charts to enable them to do these calculations during the four week treatment period. Each day during treatment the self-monitoring groups received a short note at their door indicating their expected use for that day estimated with a weather correction factor. Moreover, carbon copies of their calculations were picked up by the meter readers for the first three weeks of treatment.

Design:

F = written feedback with goal setting
S = self read meters with goal setting
V = volunteer comparison group
NV = non-volunteer control group

Daily Observations and Feedback over 18 Weeks

| n | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12 | | $O_1$ | $O_2$ | $O_3$ | F | $O_4$ | $O_5$ | $O_6$ | $O_7$ | F* | $O_8$ | ..............$O_{18}$ |
| 16 | | $O_1$ | $O_2$ | $O_3$ | S | $O_4$ | $O_5$ | $O_6$ | $O_7$ | S* | $O_8$ | ..............$O_{18}$ |
| 14 | V | $O_1$ | $O_2$ | $O_3$ | | $O_4$ | $O_5$ | $O_6$ | $O_7$ | | $O_8$ | ..............$O_{18}$ |
| 29 | NV | $O_1$ | $O_2$ | $O_3$ | | $O_4$ | $O_5$ | $O_6$ | $O_7$ | | $O_8$ | ..............$O_{18}$ |

Results: The Volunteer and non-volunteer groups were combined into one large control group after it was found that the

[93] ibid, p. 176.

consumption of the two groups did not significantly differ from each other. "During the intervention and follow-up periods, the feedback group and self-monitoring group reduced electricity consumption by about 13% and 7% respectively, based on the combined comparison group's use".[94]

Maintenance of the treatment effects did not show any signs of decay through the tenth week after removal. A follow-up questionnaire showed that most of the reductions could be attributed to changing the thermostat setting. As most participants kept their thermostats set at the lower temperature even after the treatment was removed, this is consistent with this result and its interpretation.

Discussion: The effect of volunteer status was analyzed and found to be insignificant. However, this conclusion is drawn by not treating a group of volunteers. Hence, the test for differences used here is that of differences between status quo consumption of volunteers vs. non-volunteers. The non-volunteers used more, but not significantly more, electricity than the volunteers during the baseline phase (183 kWh/day vs. 168 kWh/day, on average). Throughout the study, the changes in consumption of the volunteer group are not significantly different from the changes in consumption of the non-volunteer group. This expected result is used to support the researchers' claim that no significant differences exist between the two groups.

There is a possibility of a false negative type error here because of the data used to support the no-difference claim. It is desirable to know whether a difference exists between volunteers and non-volunteers with respect to their response to treatment conditions. What has been tested in this study is the response of volunteers to control conditions, not the response of non-volunteers to treatment conditions. Whether or

[94] ibid, p. 179.

not non-volunteers respond differently to feedback can only be surmised and the data of this study does not support or refute any claims on this matter.

The research was done in a very high use environment with respondents explicitly encouraged to reduce their thermostat settings. Given this, the resulting reductions due primarily to thermostat changes are not surprising. The introduction of another method of delivering feedback (self readings) is a novel contribution of this experiment. As the self-readers reduced electricity demand by 1/2 of the reductions realized by the feedback group, this very low cost method for conservation awareness may have more potential than a first reading of these results shows.

# CHAPTER SIX PROPOSED EXPERIMENTAL DESIGN

From the literature discussed in Chapter 5, it is evident that the effects on residential electricity consumption of various types of continuous in-home feedback have not been investigated. The digital electricity meter presented in Chapter 2, Chapter 3, and the Technical Appendices, has been designed as a research device for this purpose. In this chapter, an experimental design is proposed to show statistically significant effects (or lack of effects) from various forms of feedback using the continuous in-home display method of delivery. The reservations on terminology and definition of terms found in Chapter 4.1 will apply to this design.

Hypotheses:

I. The perceived degree of control over electricity consumption that people have at home will be enhanced by continuous display of electricity consumption data. A measurable reduction (or increase) in electricity demand will result from this method of feedback.

II. The effect of continuous in-home feedback (measured by a change in average monthly electricity demand) will vary according to: i) budget share for electricity (monthly cost of electricity / household monthly income); ii) quantity of monthly average electricity consumed (kWh/mo); and iii) type of end-use (discretionary vs automatic loads).

III. Simulated performance of a grid-connected photovoltaic array will result in further measurable changes in average household demand.

While it may be unworkable to test all five different hypothesized effects in one experiment within reasonable costs, it is important to note, up front, what hypotheses the proposed experiment is not designed to test. The proposed design is not intended to show effects on electricity consumption resulting from marginal electricity price changes, reduction goal-setting, continuous in-home display of ¢ / hour data, or feedback of cumulative versus daily data. Each of these effects have been investigated by the research presented in Chapter 5. Moreover, these previous studies have adequately examined the effects of different methods for delivering feedback (hand-delivery of written data, display of daily data, self-read meters, and continuous display). The proposed experiment is designed to investigate effects on residential electricity consumption of one method of delivering feedback (continuous in-home display) and two forms of information (electricity demand data and performance data from a simulated photovoltaic array).

The only other study of continuous in-home display, McClelland and Cook (1980), found that electricity reduction as a percentage of monthly demand was largest in non-heating or cooling months. Implicit in Hypothesis II.iii), is the notion that the percent reduction in discretionary demand (lighting, television, etc.) will be greater than the percent reduction in hidden demand (refrigeration, hot water, heat, etc.). The experiment is designed to investigate this hypothesis by gathering time-of-use data and asking the participants what conservation measures they undertook. In this way, it is an attempt to replicate and amplify the results of McClelland and Cook.

Size of Experimental Groups: If blocking is used to analyze effects of continuous in-home feedback in groups with different average daily quantities of electricity demand, each block should contain enough participants to derive statistically significant relationships for each of the two treatments.

Substituting data from Seligman and Darley (1977), for average daily electricity demand during the pre-treatment observation-only period, $\underline{X}$ = 68 kWh/day, difference between means during treatment, $\underline{X}_c$ - $\underline{X}_t$ ≅ 5.5 kWh/day, and standard deviation, õ ≅ 6.5 kWh/day, into equation 4.4 yields:

$$n_{min} = 2T^2 (6.5)^2 / (5.5)^2 = 2.8T^2.$$

From Table 4.1:

for a = .10, $n_{min}$ = 8,
for a = .05, $n_{min}$ = 11,
for a = .01, $n_{min}$ = 19.

The sample sizes in the Seligman and Darley study were 15 and 14.

From Winett, Neale, and Grier (1979), for pre-treatment average daily electricity demand of $\underline{X}$ = 171 kWh/day, and during treatment, $\underline{X}_c$ - $\underline{X}_t$ ≅ 34kWh/day and õ ≅ 36 kWh/day, equation 4.4 yields:

$$n_{min} = 2T^2 (36)^2 / (34)^2 = 2.24T^2.$$

From Table 4.1:

for a = .10, $n_{min}$ = 6,
for a = .05, $n_{min}$ = 9,
for a = .01, $n_{min}$ = 15.

The sample sizes in this study were not equal ($n_1$ = 12, $n_2$ = 16, $n_3$ = 14, $n_c$ = 29), nor were the standard deviations. Equation 4.4 is a simplified algorithm that assumes all sample sizes and standard deviations are equal. Nonetheless, the calculations above will suffice for a rough estimation of the minimum size required for experimental groups.

Recommendation: Each group to be used in analysis of data resulting from this experiment should contain at least 10 members.

Dependent measures: There are three dependent variables, two quantitative and one qualitative, to be measured in this design. Electricity consumption data stored in the meter memory during workday hours and nighttime and weekends are quantitative measures that will be used to show any discretionary vs. hidden changes in usage. Discretionary end uses of electricity are home appliances that will be displayed as an increase in power demand when they are turned on. Hidden end uses include air conditioning, electric heating, hot water, and refrigeration that do not draw electricity at the flip of a switch, but rather, are regulated to turn on and off automatically to maintain a set temperature.

As analysis of demand data by day and nighttime will not completely separate discretionary from hidden consumption, a qualitative dependent variable is proposed to strengthen causal inferences to these constructs. A pre-study questionnaire is recommended to explore each household's attitudes toward conserving electricity. A sample used in the prototype phase of this project is included in the Appendix. After the study is concluded, all participants should receive another brief survey asking what conservation measures they undertook. The results of this survey will assist in the interpretation of technical data in any attempt to make causal inferences about the effects on electricity consumption of each form of feedback delivered by continuous in-home feedback.

Hence, this attempt to disaggregate changes in electricity consumption patterns into discretionary and hidden end-uses will be shown by statistically significant covariation (or lack of covariation) of kWh consumed at different times of day and will be illuminated by personal reflections by the people participating in the experiment.

Setting: The cooperation of an electric utility will be necessary to obtain previous consumption data on participating households. As New England Electric Power Company has been supportive and instrumental in carrying out the prototype test of the digital display unit, it is recommended that the experiment be conducted in a community within their service area. The progressive management policies of NEEP that support conservation and renewable energy research fit well with the motivation of this project.

To guard against the local history hazard to internal validity, and to minimize implementation costs, it is recommended that the study be conducted in one community within an area of a few square miles. The most desirable setting would be in a neighborhood or development comprised of similar homes with residents having a sizable range of incomes and monthly electricity demand.

Ease of Participation: The digital display meter to be used as a feedback device in this experiment is a desirable commodity. To minimize selection bias arising from refusal to participate in the experiment, it is essential to make participation as convenient as possible. The use of amp clamps and a standardized installation procedure developed during the prototype testing phase of this project assures minimal installation time (4 hours) and little to no alteration of house wiring at the distribution panel. The radio frequency interference emitted by the microprocessor and data acquisition boards must be eliminated before implementing the experiment.

Selection: Since change in average kWh consumed during each hour of the day is the proposed dependent variable measure in this experiment, analysis of experimental results would be strengthened by blocking potential participants by average electricity demand before selection. If this is not practicable, random selection of participants can proceed. Random selection should be done according to the procedure for random assignment detailed in Chapter 4.2. Letters detailing the uses of the device and emphasizing that this study is intended to test the accuracy of the meter and its usefulness to homeowners (or renters) should be sent to those originally contacted. The letters should be followed up by a phone call and a personal visit by a member of the research team to reassure the homeowners that: 1) the meter line will be removed upon request; 2) no alterations will be made to the home; and 3) they need not invest any more time as a participant than is required to learn how to read the display. If hourly data is to be collected for assessing when changes in electricity usage occurs, a control group with data collection meters, but no display must be installed. In this case potential respondents should agree to accept any experimental condition before being assigned to groups.

If blocking is not done before selection, it should be done before random participants are assigned to treatment conditions. Random assignment within each block should follow the procedures in Chapter 4.2.

Length of Study: Most experiments relating electricity feedback to conservation have been carried out for at least one month but less than four. A week to a month is needed to assess effects of treatment and no evidence of significant delays in these effects have been found. However, Winett, Neale, and Grier (1979) found evidence of continuation of treatment related effects for at least a few weeks after the feedback was removed. Many of the previous studies targeted air-conditioning/heating reductions and found reduced effects toward the end of the summer/winter. Due to this, variation in seasonal demand can become confounded with removal of treatment effects.

To avoid this potential confounding, it is recommended that treatment be administered and removed during Spring or Fall, in a time that heating and cooling loads are not expected. Another way to avoid seasonal confounding would be to select only households that do not have electric heat or air conditioning. Nonetheless, this restriction may lead to participants with lower average daily electricity consumption who are less sensitive to feedback.

Given the lack of evidence showing a delay in effects of feedback, the replicated evidence of continued effect after removal, and the possibility of confounding due to seasonal changes in electricity demand, a seven month or 13 month design with removal of feedback at the end of a heating/cooling season is proposed. One month of observation both before feedback is initiated and after it is removed should give ample data for intergroup comparisons during the 5 (11) month treatment period and after removal. Because the microprocessor based electricity meters would be installed in the homes of all participants, it would be easy to extend the observations after treatment removal for more than one month if signifiant persistence of effect is found.

Design:

D = Continuous Display of House Electricity Demand, Only
S = Simulated Full PV Array

| n | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | $0_1$ | D | $0_2$ | $0_3$ | DS | $0_4$ | | $0_5$ | $0_6$ | DS* | $0_7$ |
| 15 | $0_1$ | D | $0_2$ | $0_3$ | | $0_4$ | DS | $0_5$ | $0_6$ | DS* | $0_7$ |
| 15 | $0_1$ | DS | $0_2$ | $0_3$ | | $0_4$ | | $0_5$ | $0_6$ | DS* | $0_7$ |
| 15 | $0_1$ | DS | $0_2$ | $0_3$ | DS* | $0_4$ | | $0_5$ | $0_6$ | | $0_7$ |
| 15 | $0_1$ | | $0_2$ | $0_3$ | | $0_4$ | | $0_5$ | $0_6$ | | $0_7$ |

Procedure: After all participants have been selected and informed as above, the microprocessor based electricity meter should be installed in all homes. Gathering time-of-day consumption data should begin for all groups at the same time. Random assignment could be done during installation. Memory chips with programs unique to each treatment could be placed in each generic meter to begin data gathering. One month later, the displays can be connected for the two feedback groups. After a few months, the array simulation feedback could be added to the electricity demand information-only group to test if the effect of the simulation is significant. At the end of the heating/cooling season, all displays should be removed. Data gathered in this follow-up phase will show an important parameter for setting conservation policy: The continuance or rate of decay of the feedback effects. After the one month of observation, participants (control included) should be asked how they reduced their electricity consumption in order to illuminate the qualitative content of the effects shown by quantitative data. The 5 month treatment period design is flexible enough to allow cross-over of treatments and treatment-removal-treatment variations.

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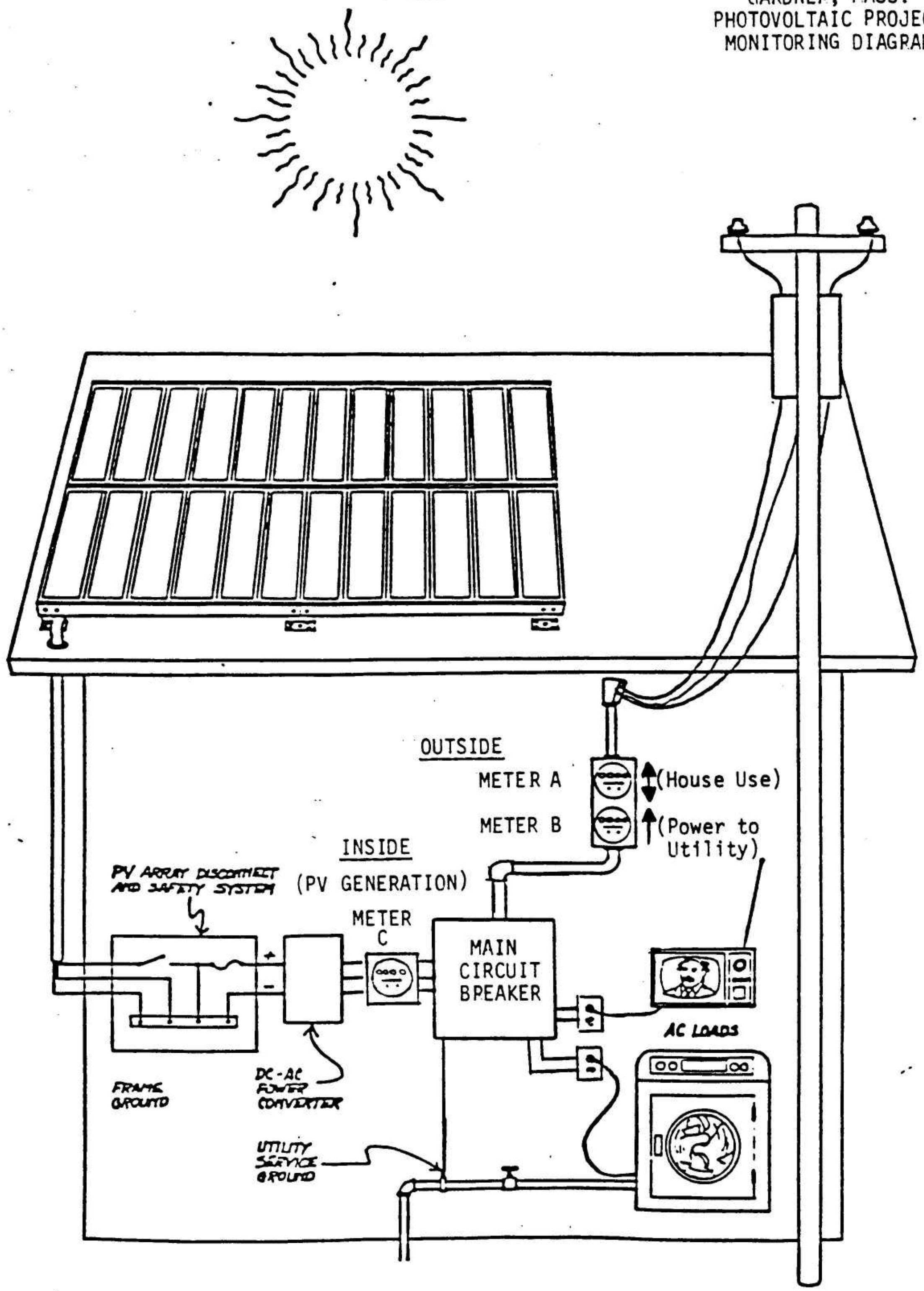
APPENDIX 1.1

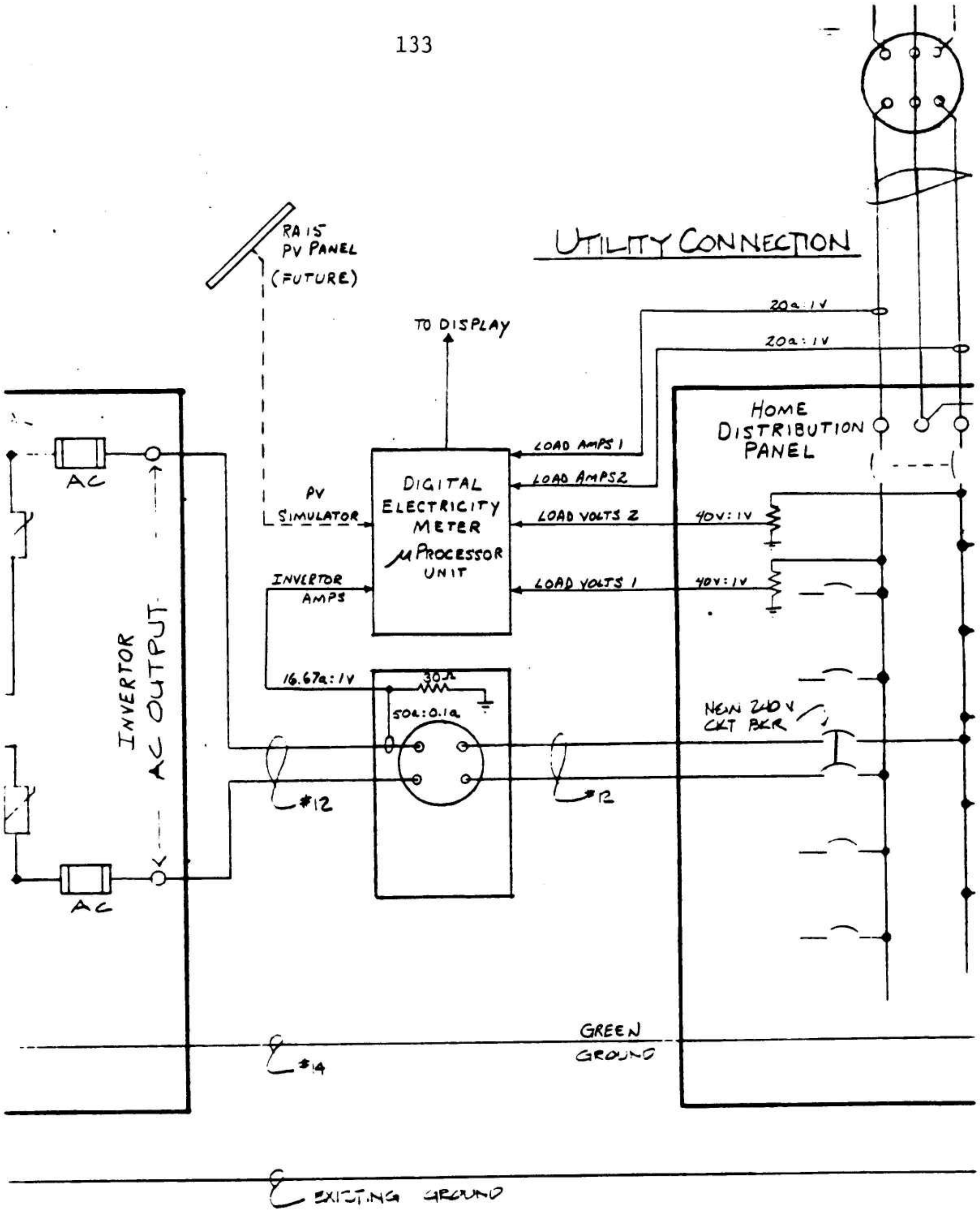
PHOTOVOLTAIC PROJECT MONITORING DIAGRAM

WIRING DIAGRAM

RA 15 TECHNICAL SPECIFICATIONS

GARDNER, MASS.
PHOTOVOLTAIC PROJECT
MONITORING DIAGRAM






WIRING DIAGRAM
Interactive Energy Meter/Display Prototype Test
in Gardner, MA Solar Home

# Ra15

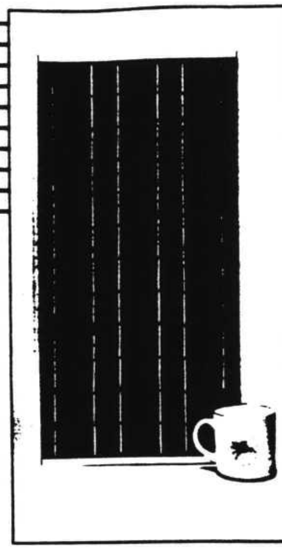
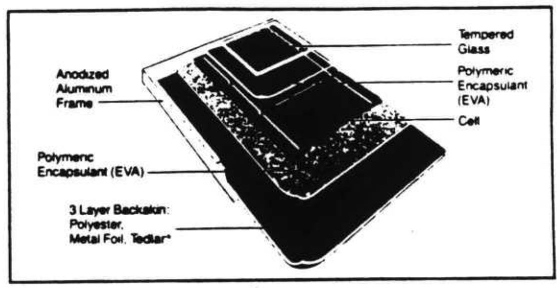


Figure 1:
Ra15 Module

The Ra15 is a 12 volt (nominal), 15 watt (peak), photovoltaic (PV) module designed primarily for low power applications. These applications include communications, telemetry, lighting, solar thermal circulator pumps, marine battery charging and navigational aids.

Rectangular solar cells, manufactured by Mobil Solar's Edge-defined, Film-fed Growth (EFG) technology, allow the highest packing density for maximum power output per unit area. The Ra15 is designed to exceed JPL (Jet Propulsion Laboratory) Block V performance criteria with rugged, maintenance-free construction.

Figure 2:
Module Cross Section




## MODULE FEATURES *(see FIGURE 1)*

- Dimensions — Millimeters (Inches):
  Thickness X Width X Length
  Unframed: 29.4* X 307.3 X 604.5 (1.156* X 12.1 X 23.8)
  Framed: 31.8 X 312.7 X 607.1 (1.25 X 12.3 X 23.9)
  *Thickness includes 25.4 (1.0) for termination studs
- Weight — Kilograms (Pounds):
  unframed: 3.1 (6.8)
  framed: 3.2 (7.1)
- One series string of 36 EFG ribbon cells
- Redundant interconnections between solar cells for increased reliability
- Module surface of tempered, low-iron glass; 4.0 millimeters (5/32 inch) thick
- Ethylene vinyl acetate (EVA) encapsulant cushions cells from thermal stress and produces a superior optical coupling between cells and glass
- A multi-layer module backskin provides the final barrier to moisture and weather extremes. (see FIGURE 2)
- A strong, four-piece frame constructed of anodized aluminum
- Tin-plated brass, threaded module termination posts for easy wiring of the module. Termination posts are protected by industrial plastic sleeves; screws in the termination posts are stainless steel. (See the Ra30 module brochure for complete "Ra" family characteristics)

## QUALITY ASSURANCE

All Mobil Solar modules are subjected to strict quality control throughout the manufacturing process. Before leaving the factory, each finished module is carefully inspected and tested to assure delivery of a superior product.

MSEC'S *LIMITED WARRANTY* guarantees power output of each module for a period of five (5) years from the date of shipment. See MSEC's full warranty for details.

## HOW TO ORDER A Ra15 MODULE

When ordering the 12 volt (nominal) Ra15 module, the notation *Ra15-12* should be used. An optional junction box with a selection of connectors is available at additional cost. A complete discussion of module options (JUNCTION BOX, WIRING AND CONNECTORS AND AMP® CONNECTOR) can be found in the Ra30 module brochure, available upon request from Mobil Solar Energy Corporation.

Affix one of the following suffixes to *Ra15-12* when ordering module options:

| | Suffix | Option Ordered |
|---|---|---|
| Ra15-12 | – H | Factory installed Junction Box with (2) HEYCO® strain relief fittings and one plug (should installation require only one fitting) |
| | – R* | Factory installed Junction Box with +/– SOLARLOK Receptacles |

*EXAMPLE*. Ra15-12-H defines a Ra15, 12 volt module complete with factory installed juction box, two HEYCO® fittings and one plug.

*With SOLARLOK receptacles, cable length of the mating harness must be specified.

**Mobil Solar Energy Corporation**
Subsidiary of Mobil Oil Corporation
*16 Hickory Drive, Waltham, Massachusetts 02254 (617) 890-1180 Telex 951272 MOBIL SOLAR WHA*



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## ELECTRICAL CHARACTERISTICS

### Figure 3: Electrical Outputs at Standard Test and Normal Operating Conditions

| Condition Air Mass 1.5 | $I_{SC}$ Typ (A) | $I_{NO}$@$V_{NO}$ Typ (A) | (V) | $V_{OC}$ Typ (V) | $P_{NO}$(W) Min | Typ |
|---|---|---|---|---|---|---|
| (Standard Test) $T_C$ = 25°C, 1000 W/m² | 1.1 | 0.97 | 15.5 | 18.9 | 13.5 | 15.0 |
| (Normal Operating) $T_A$ = 20°C, $T_C$ = 46°C, 800W/m² | 0.9 | 0.8 | 13.5 | 17.0 | 9.7 | 10.8 |

Temperature Coefficients
TC $I_{SC}$ = 1.6 mA/°C (0.9 mA/°F)
TC $V_{OC}$ = −78.5 mV/°C (−43.6 mV/°F)

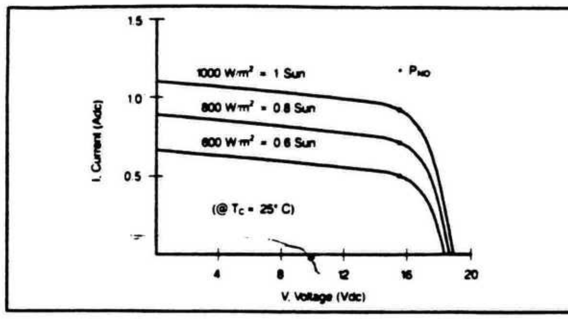
$I_{SC}$ = Short Circuit Current, Amps DC
$V_{OC}$ = Open Circuit Voltage, Volts DC
$V_{NO}$ = Nominal Operating Voltage, Volts DC, is the Reference Voltage Level at which the Modules are Designed to Provide Maximum Power Output at Specified Operating Conditions.
$I_{NO}$ = Current, Amps DC, Measured at $V_{NO}$
$P_{NO}$ = Power, Watts DC, Measured at $V_{NO}$
$T_A$ = Ambient Temperature, °C
$T_C$ = Cell Temperature, °C
$P_M$ = Maximum power, Watts DC, measured at any specified condition.

Environmental Operating Conditions
Temperature: −40°C to 90°C (−40°F to 195°F)
Humidity: 0 to 100%
Altitude: to 7620 meters (25000 ft.)
Wind Loading: Modules withstand sustained winds in excess of 200 km/h (125 mph) or 50 lbs/sq ft.

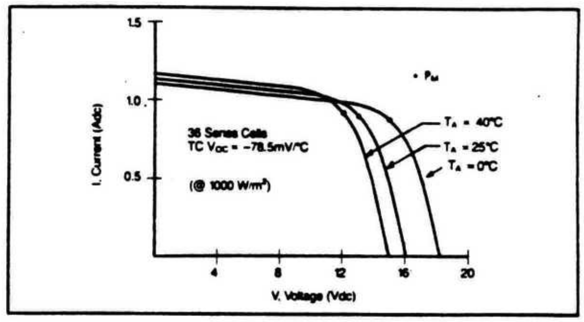
This document contains information on a new product. Mechanical and electrical information is subject to change without notice.

## I-V CURVES

### Figure 4: Ra15-12 Characteristics vs. Sunlight Intensity

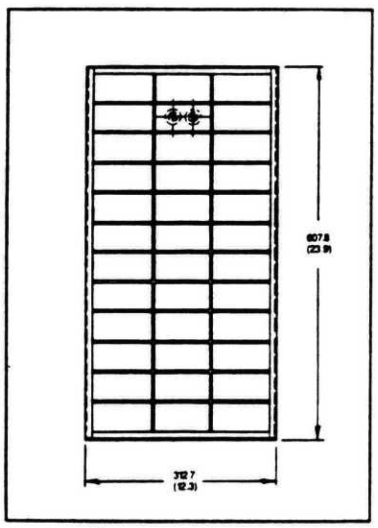



### Figure 5: Ra15-12 Characteristics vs. Temperature

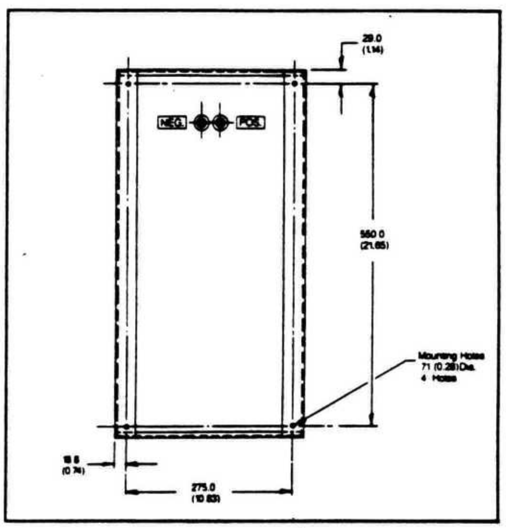



## MECHANICAL CHARACTERISTICS*

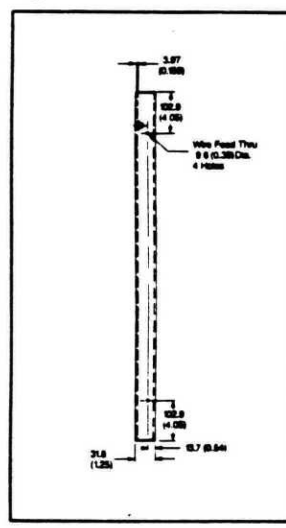
### Figure 6: Front View



### Figure 7: Back View




### Figure 8: Side View



***All dimensions in millimeters (inches)**

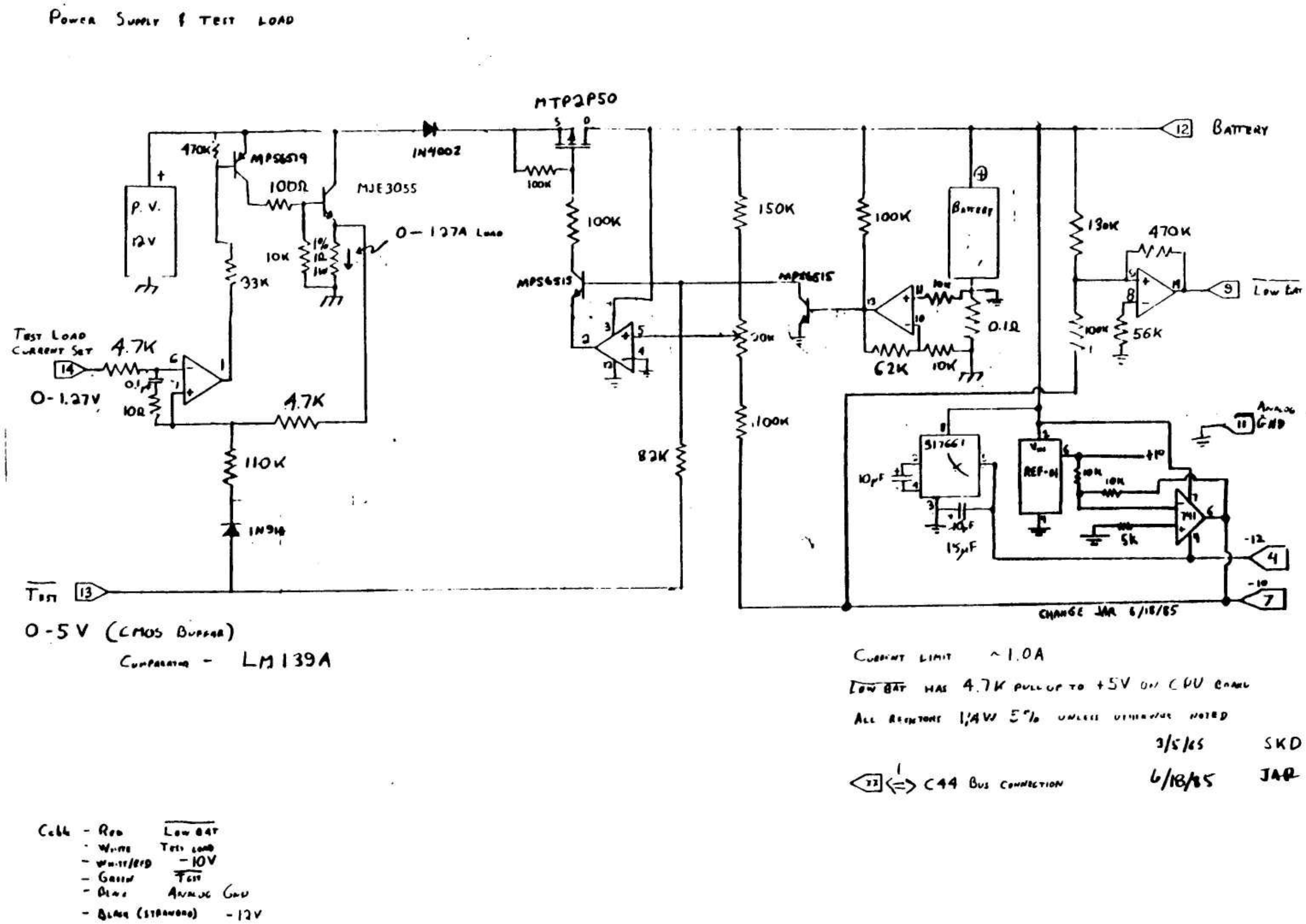


**For further information:**

APPENDIX 1.2

SCHEMATIC DIAGRAM
D/A PV Current Controller and Power Supply Board
Original Design: Unit I

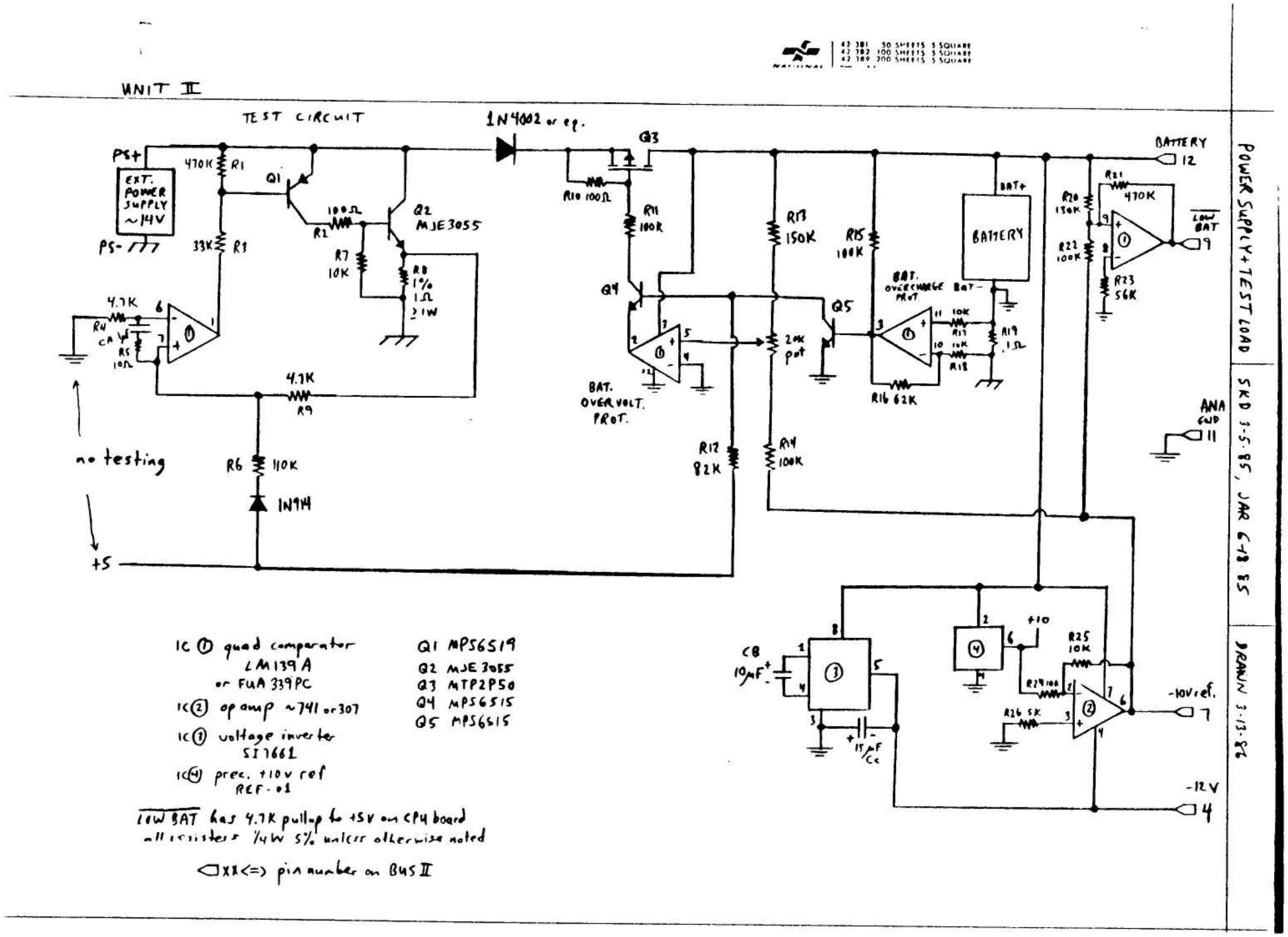
SCHEMATIC DIAGRAM
Power Supply Board as Revised for Prototype (Unit II)




SCHEMATIC DIAGRAM

D/A PV Current Controller and Power Supply Board

Original Design: Unit I




SCHEMATIC DIAGRAM

Power Supply Board as Revised for Prototype (Unit II)

APPENDIX 1.3

LABORATORY POWER READING DATA FOR INTERACTIVE ENERGY METER/DISPLAY

SCHEMATIC DIAGRAM
Original A/D Design Including D/A for PV Control

SCHEMATIC DIAGRAM
Modified A/D Board for Prototype (Unit II) w/o PV Simulator Capability

S/H INPUT
A/D INPUT

HOLD MODE BIAS ERROR
A/D CIRCUITRY LAG ERROR

## LABORATORY POWER READING DATA FOR INTERACTIVE ENERGY METER/DISPLAY

### A/D CONVERSION

| Analog MUX Input (Volts) | Analog A/D Input (Volts) |
|---|---|
| -5 | 0 |
| -4 | 0.99 |
| -3 | 1.99 |
| -2 | 2.97 |
| -1 | 3.99 |
| 0 | 5.00 |
| 1 | 6.02 |
| 2 | 7.06 |
| 3 | 8.10 |
| 4 | 9.13 |
| 5 | 10.16 |

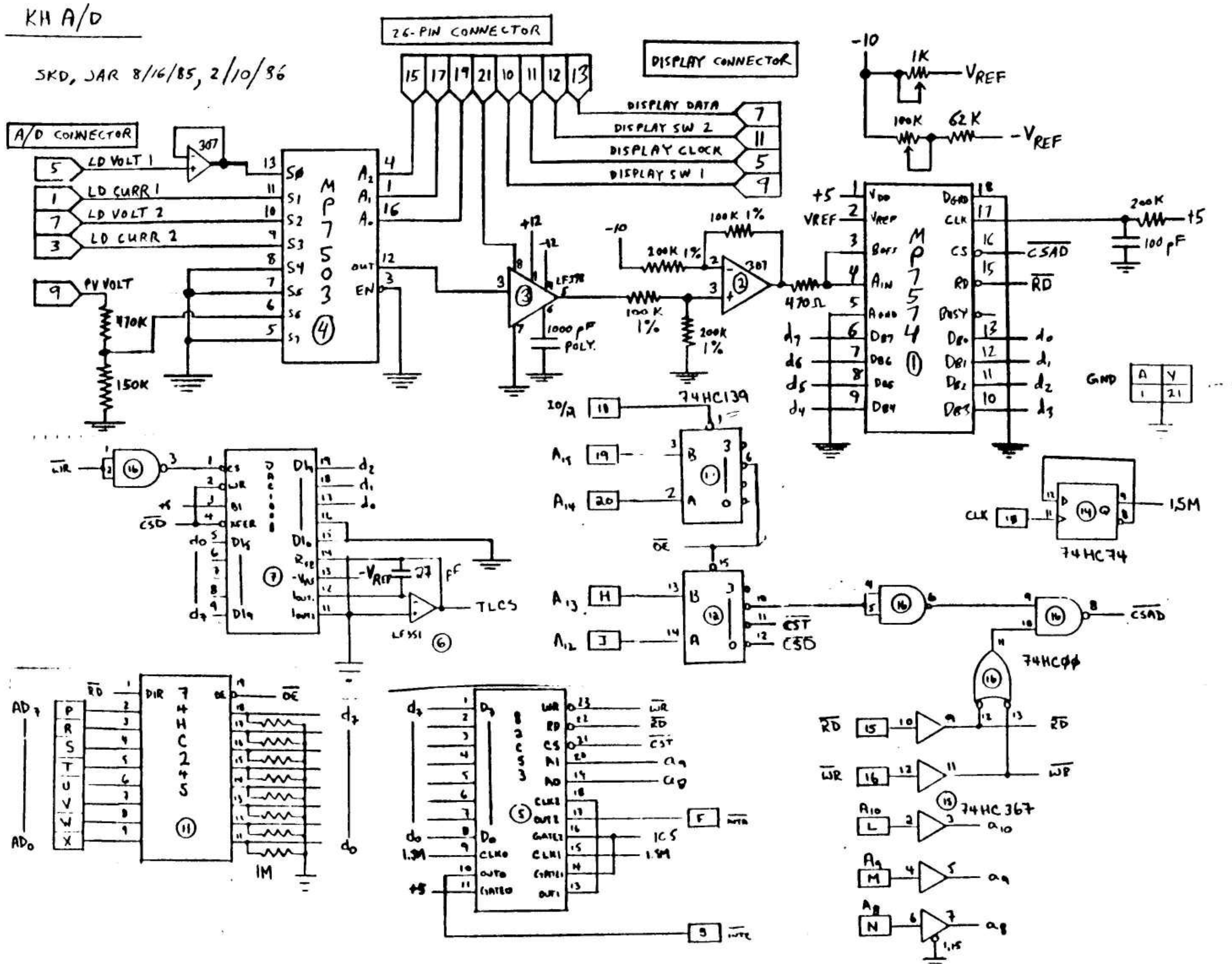
### DISPLAY POWERS ACTUAL VS. IDEAL

| *Load Signal Input (V) | Demand Display kW Actual (Ideal) | Array Display kW Actual (Ideal) |
|---|---|---|
| ± 0.5 | .40 ( .40) | .01 (.00) |
| ± 1.0 | 1.61 (1.60) | .02 (.00) |
| ± 1.5 | 3.62 (3.60) | .03 (.00) |
| ± 2.0 | 6.48 (6.40) | .04 (.00) |
| ± 2.5 | 10.05(10.00) | .05 (.00) |
| ± 3.0 | 14.47(14.40) | .06 (.00) |
| ± 4.0 | 25.70(25.60) | .11 (.00) |

* Positive Signals applied to both $v_1$ and $i_1$ inputs.

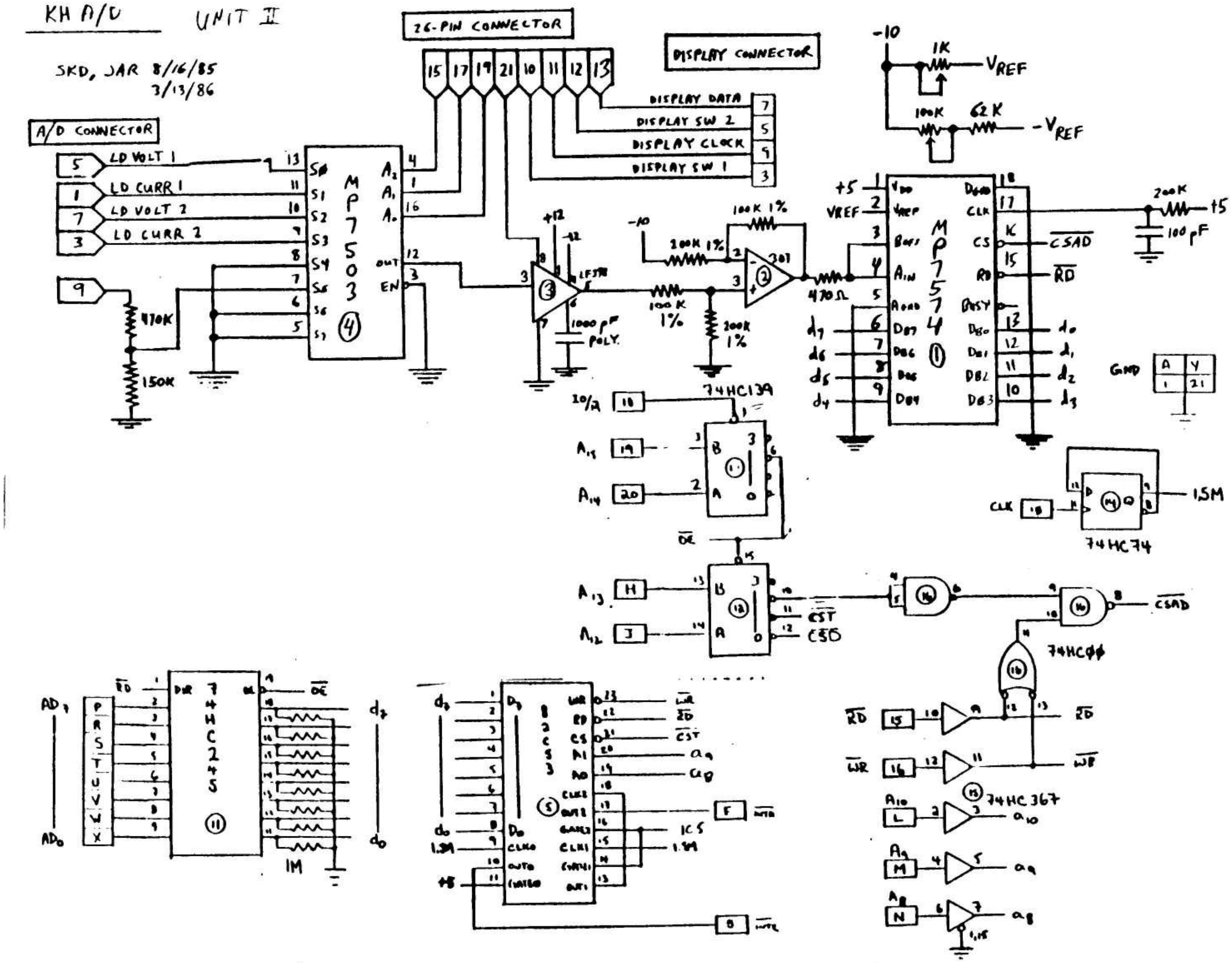
Negative signals applied to $v_2$ and $i_2$ inputs.

Array Invertor Channels Grounded.

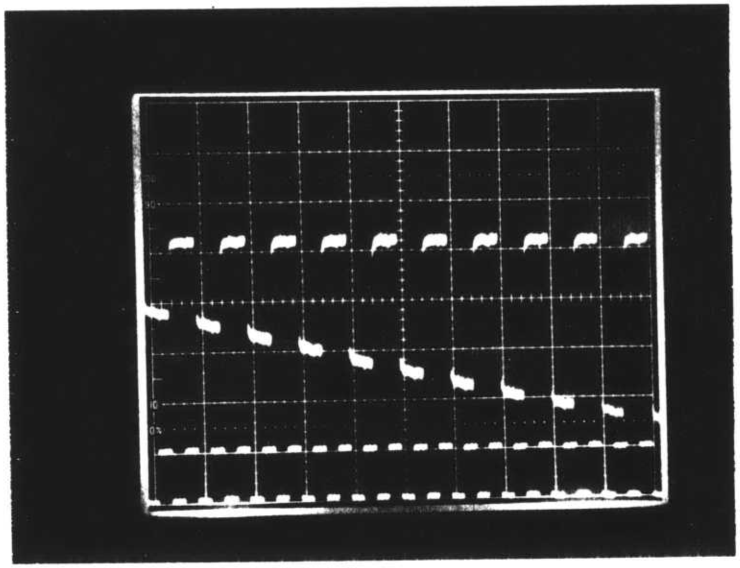



SCHEMATIC DIAGRAM

Original A/D Design Including D/A for PV Control

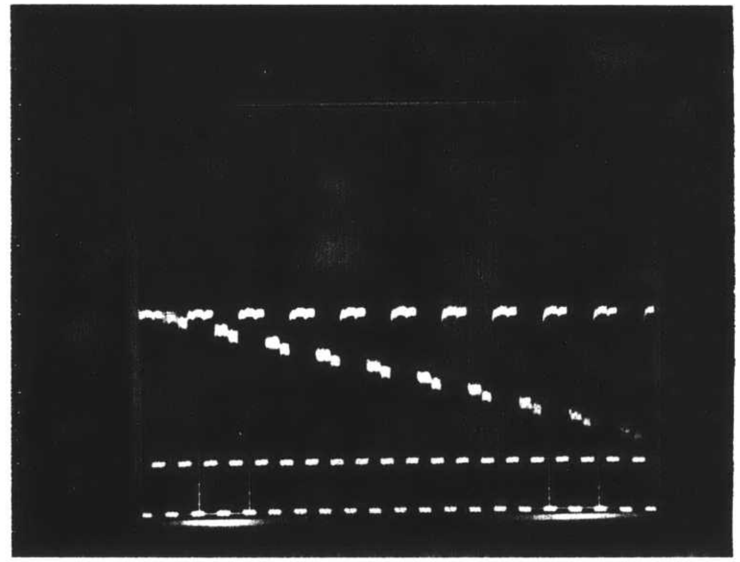



SCHEMATIC DIAGRAM
Modified A/D Board for Prototype (Unit II) w/o PV Simulator Capability



A: S/H Input (1v, .2msec/div)

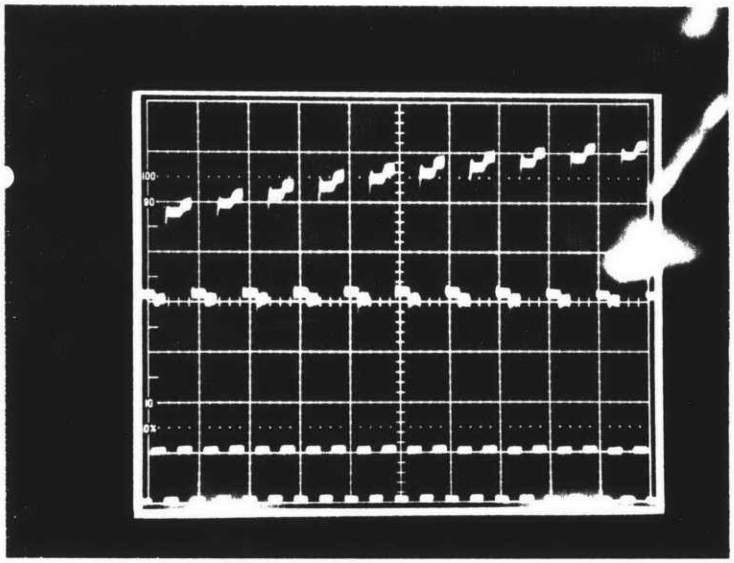
B: $\overline{\text{Hold}}$ Signal (5v/div)



A: A/D Input (2v, .2msec/div)

B: $\overline{\text{Hold}}$ Signal to S/H Chip (5v/div)

HOLDING WHEN $\overline{\text{HOLD}}$ SIGNAL LOW



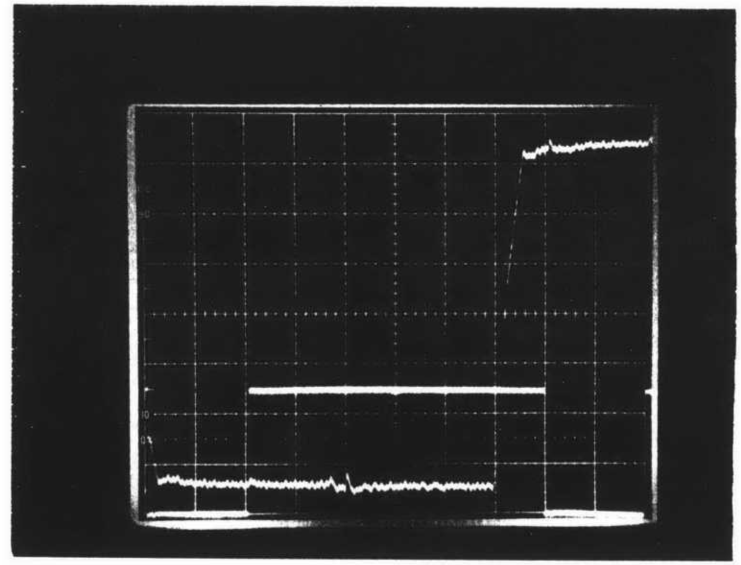
A: A/D Input with S/H Chip Placed

Immediately before A/D Input

(1v, .2msec/div)

B: Hold Signal (5v/div)

Note: Positive Bias Induced by S/H Chip During A/D Conversion of a Grounded Input



A: A/D Input during Read (A/D Conversion)

± 3.5v Input Signal (1v, 12.5 microsec/div)

B: Busy Signal of A/D Chip (2v/div)

(Low Signal Indicates A/D Conversion is Underway)

# APPENDIX 1.4

MEMORY ALLOCATION AND PORT ASSIGNMENT

MICROPROCESSOR BOARD SCHEMATIC

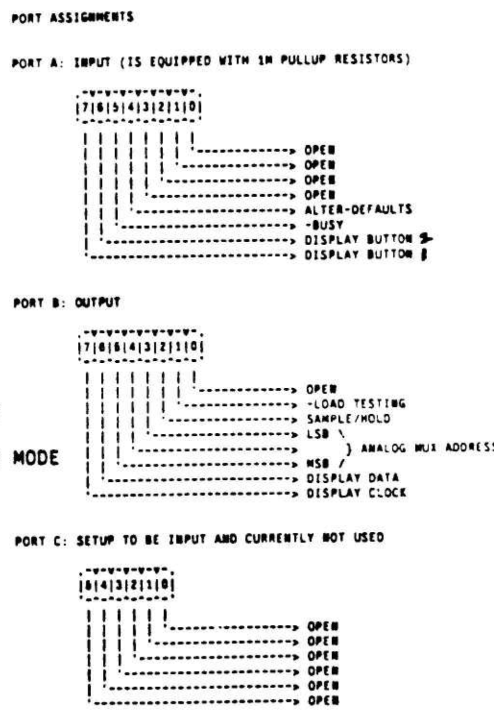
MICROPROCESSOR BOARD LAYOUT

MEMORY BOARD SCHEMATIC

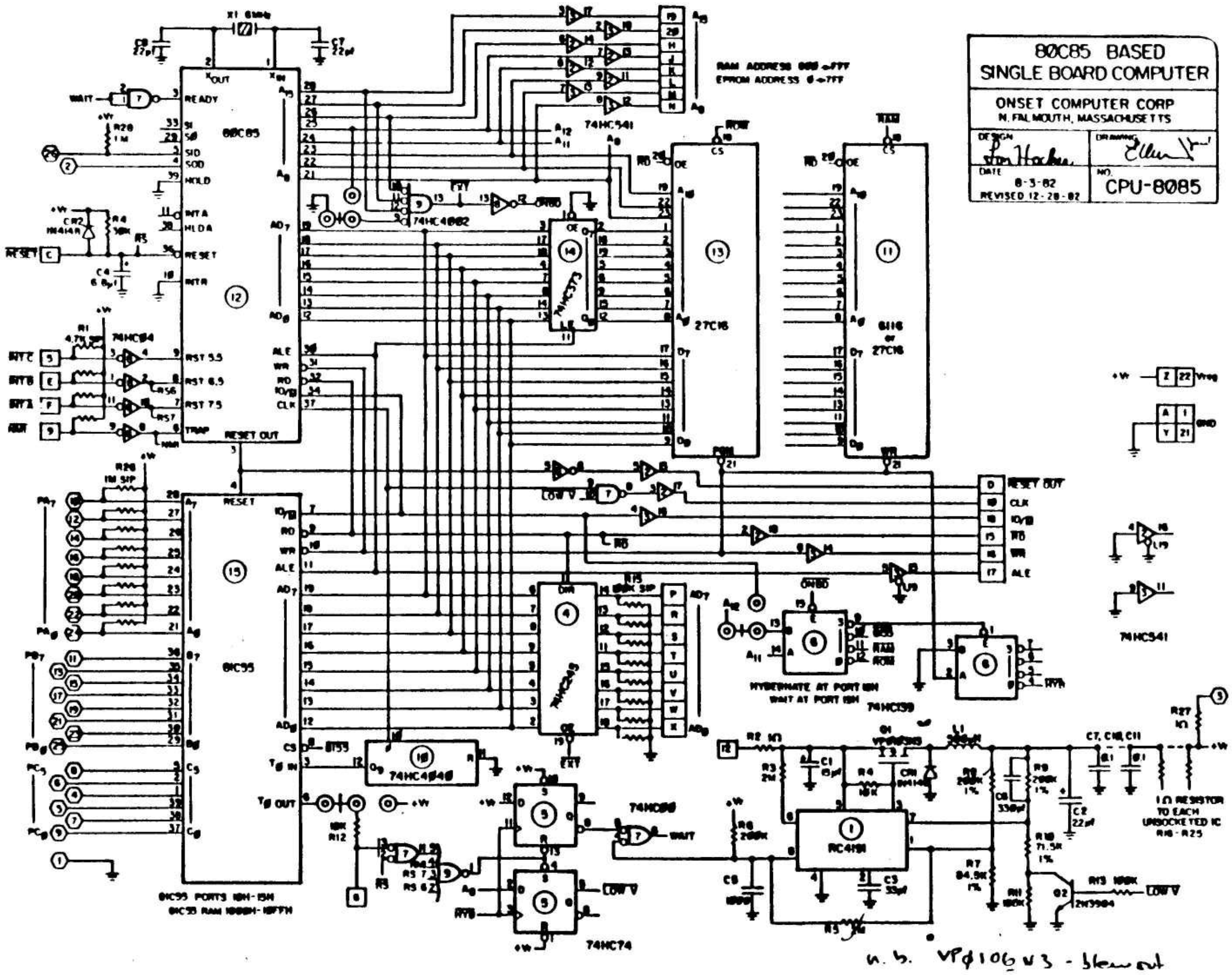
MEMORY BOARD LAYOUT

| Memory Address | |
|---|---|
| 0000-07FF | MONITOR PROGRAM |
| 0800-0FFF | EMPTY RAM OR EPROM |
| 1000-10C3 | OPEN RAM |
| 10C4-10C6 | NMI CALL ADDRESS |
| 10C7-10C9 | INTC CALL ADDRESS |
| 10CA-10CC | INTB CALL ADDRESS |
| 10CD-10CF | INTA CALL ADDRESS |
| 10D0-10FF | USED BY MONITOR PROGRAM |
| 1100-1FFF | NOT USED |
| 2000-2FFF | |
| 3000-3FFF | |
| 4000-4FFF | 4K PROGRAM : SEE CH. 2 |
| 5000-5FFF | 4K MEMORY |
| 6000-6FFF | NOT AVAILABLE |
| 7000-7FFF | NOT AVAILABLE |
| 8000-8FFF | D/A |
| 9000-9FFF | TIMER |
| A000-AFFF | A/D |
| B000-BFFF | READILY AVAILABLE |
| C000-CFFF | |
| D000-DFFF | |
| E000-EFFF | |
| F000-FFFF | |

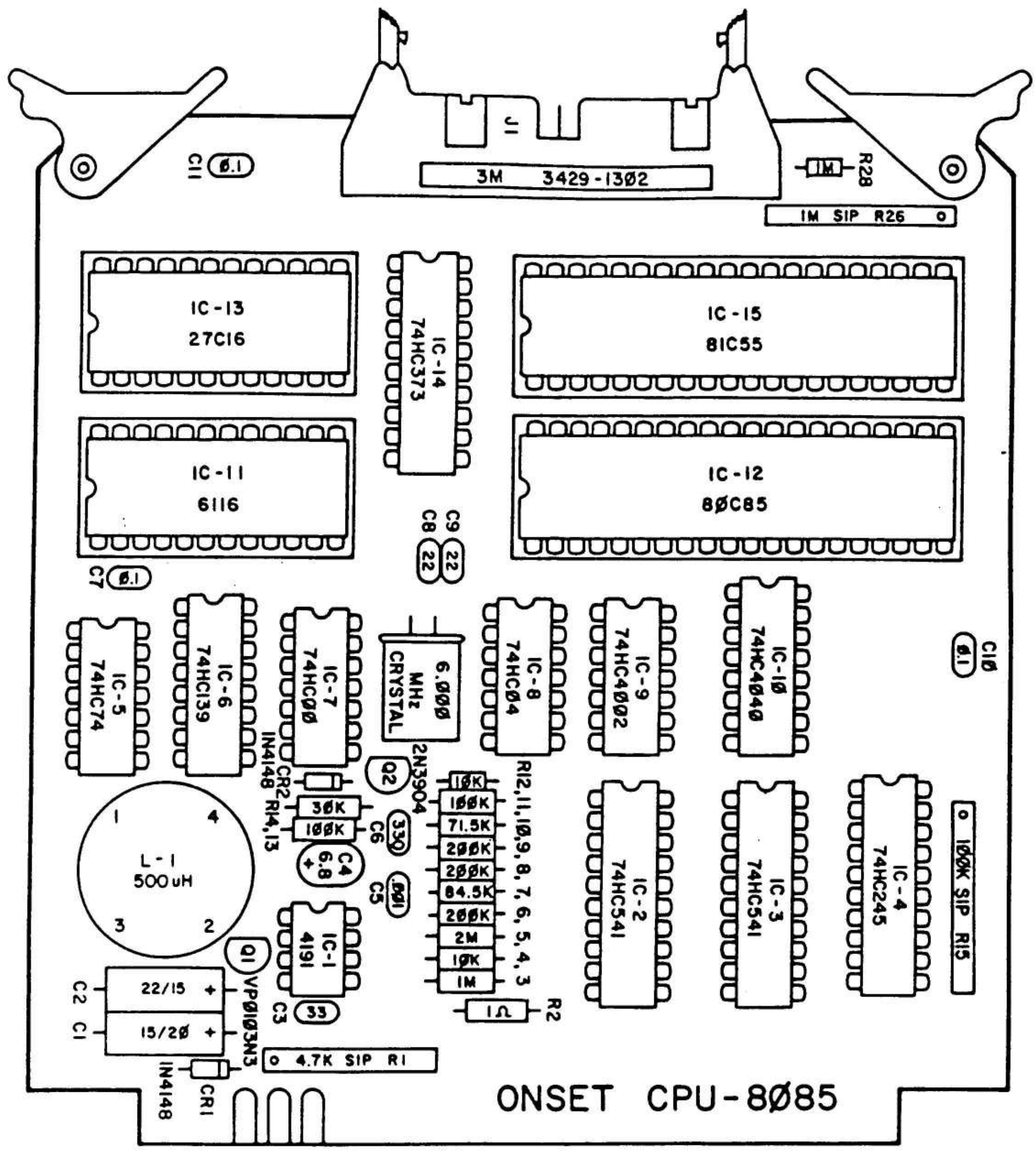
| PORT ADDRESS | |
|---|---|
| 00 | |
| 01 | |
| 02 | |
| 03 | |
| 04 | |
| 05 | |
| 06 | |
| 07 | |
| 08 | |
| 09 | |
| 0A | |
| 0B | |
| 0C | |
| 0D | |
| 0E | |
| 0F | |
| 10 | INTERVAL COMMAND/STATUS REGISTER |
| 11 | GENERAL PURPOSE I/O PORT A |
| 12 | GENERAL PURPOSE I/O PORT B |
| 13 | PORT C - GENERAL PURPOSE I/O OR CONTROL PORT |
| 14 | LOW ORDER BYTE OF TIMER COUNT |
| 15 | HIGH 6 BITS OF TIMER COUNT & 2 BITS OF TIMER MODE |
| 16 | |
| 17 | |
| 18 | HYBERNATE COMMAND |
| 19 | WAIT MODE COMMAND |
| 1A | |
| 1B | |
| 1C | |
| 1D | |
| 1E | |
| 1F | |



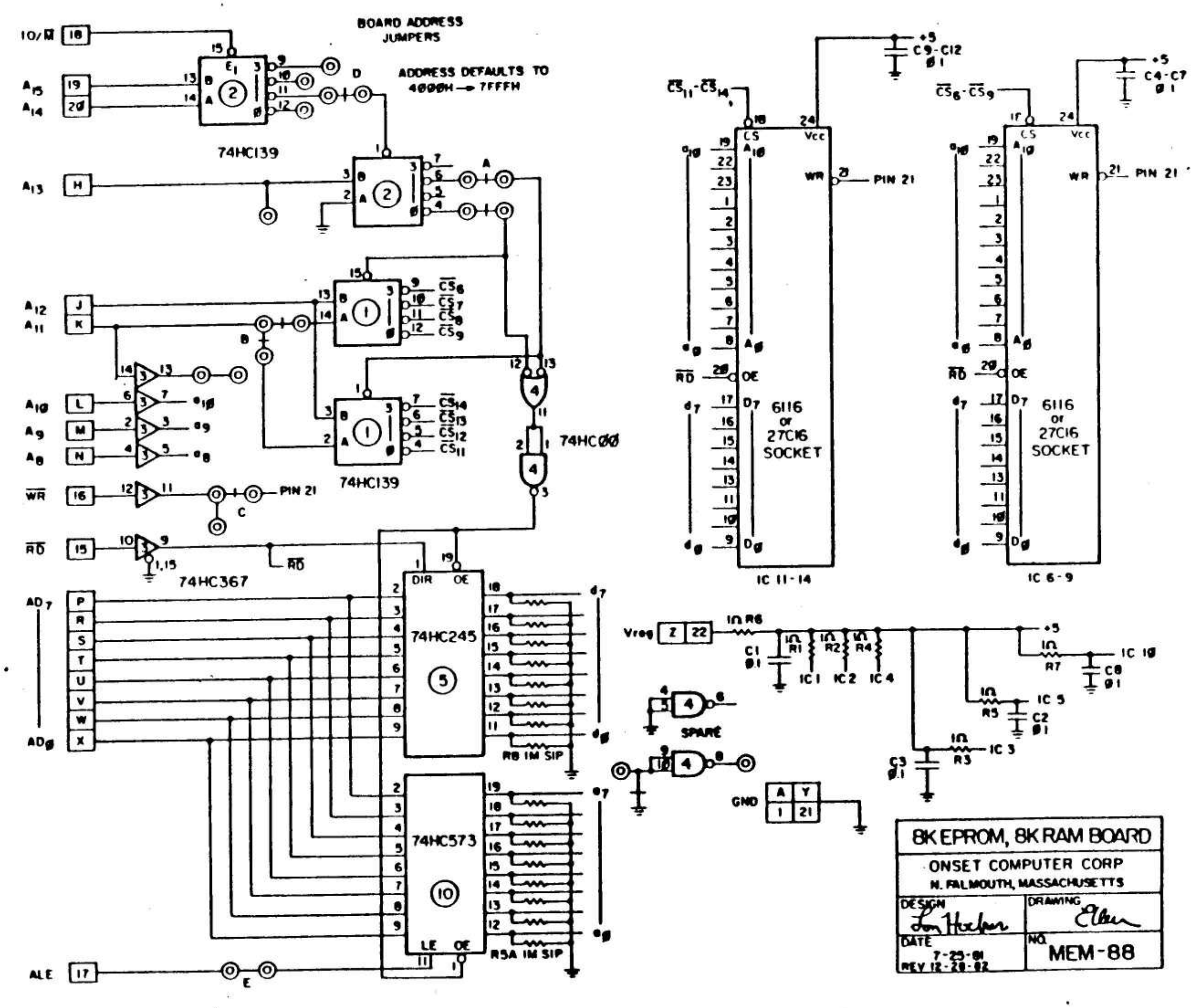

MEMORY ALLOCATION AND PORT ASSIGNMENT



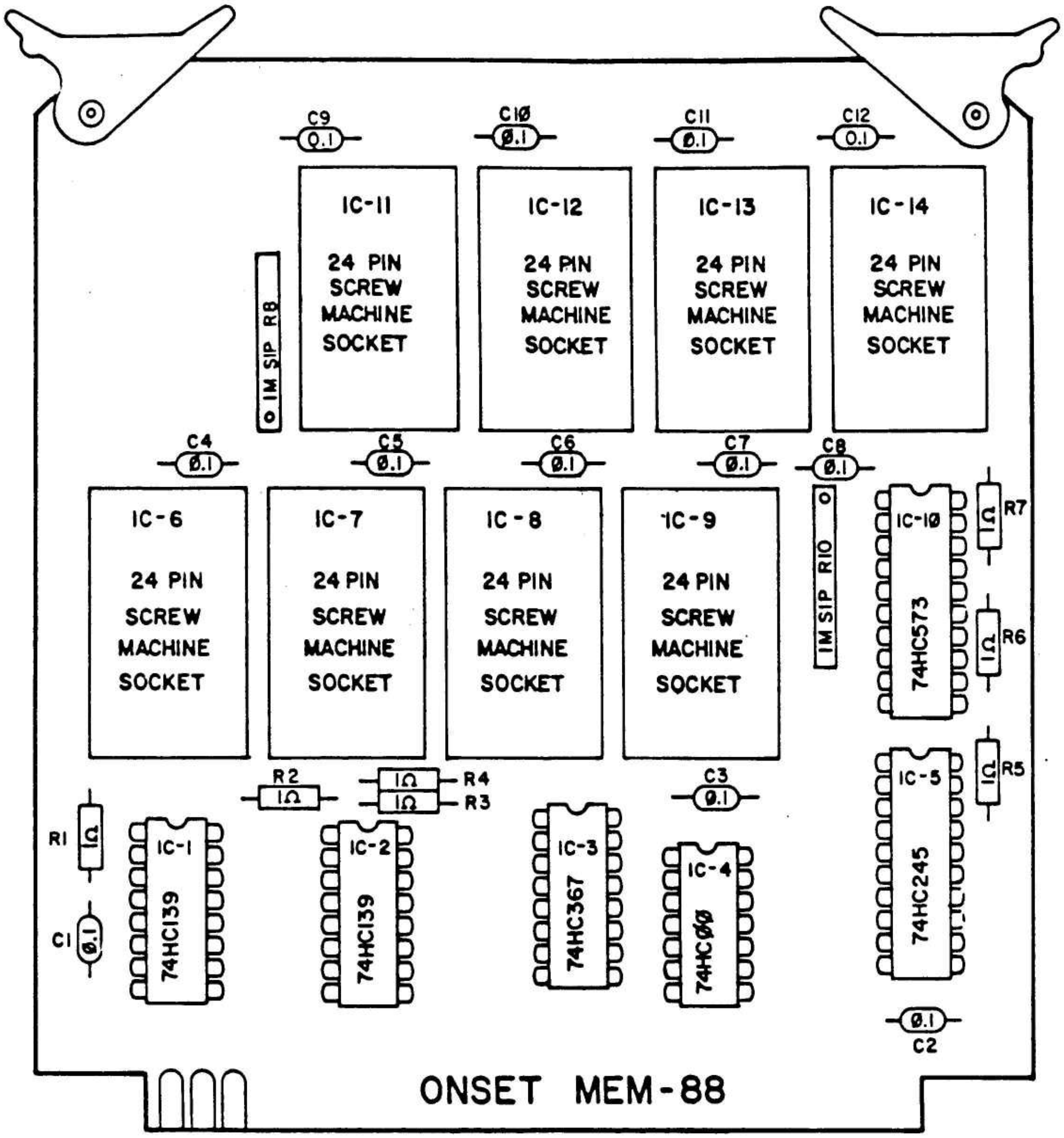

MICROPROCESSOR BOARD SCHEMATIC




MICROPROCESSOR BOARD LAYOUT




MEMORY BOARD SCHEMATIC




MEMORY BOARD LAYOUT

APPENDIX 1.5

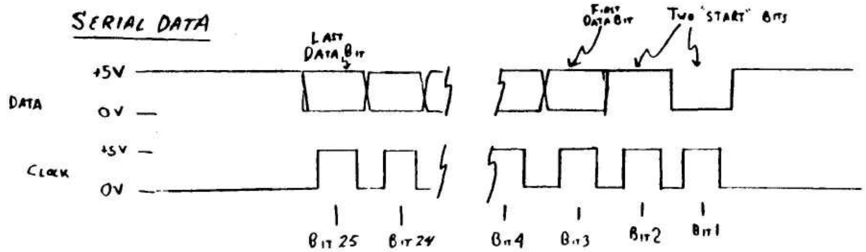
PROTOTYPE (UNIT II) DISPLAY

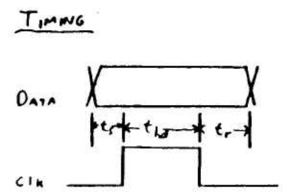
TIMING DIAGRAM FOR PROTOTYPE DISPLAY (UNIT II)

SCHEMATIC DIAGRAM UNIT II DISPLAY

SCHEMATIC DIAGRAM UNIT I DISPLAY

# INTERFACE SPECIFICATIONS: PROTOTYPE (UNIT II)

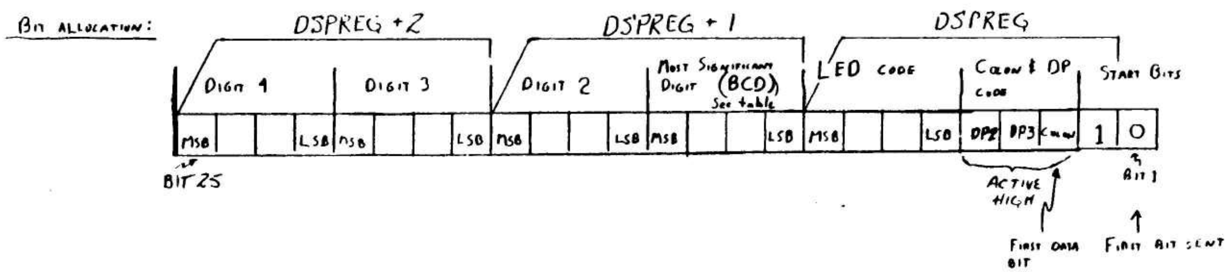



$t_s \geq 500\,nS$

$t_{hd} \geq 500\,nS$

$t_r = 0\,nS$



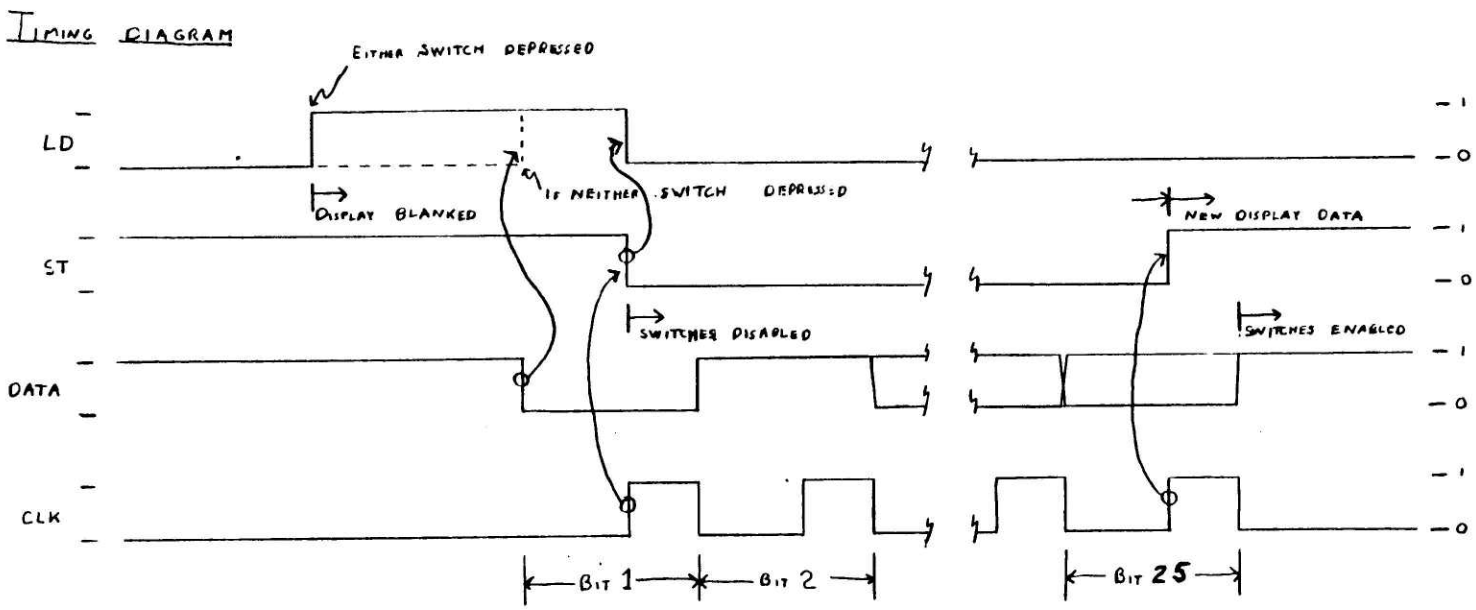

**DRIVER CODES FOR DIGITS**

| D (MSB) | C | B | A (LSB) | DISPLAY CHARACTER |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 1 | 1 |
| 0 | 0 | 1 | 0 | 2 |
| 0 | 0 | 1 | 1 | 3 |
| 0 | 1 | 0 | 0 | 4 |
| 0 | 1 | 0 | 1 | 5 |
| 0 | 1 | 1 | 0 | 6 |
| 0 | 1 | 1 | 1 | 7 |
| 1 | 0 | 0 | 0 | 8 |
| 1 | 0 | 0 | 1 | 9 |
| 1 | 0 | 1 | 0 | L |
| 1 | 0 | 1 | 1 | H |
| 1 | 1 | 0 | 0 | P |
| 1 | 1 | 0 | 1 | R |
| 1 | 1 | 1 | 0 | - (minus sign) |
| 1 | 1 | 1 | 1 | BLANK |

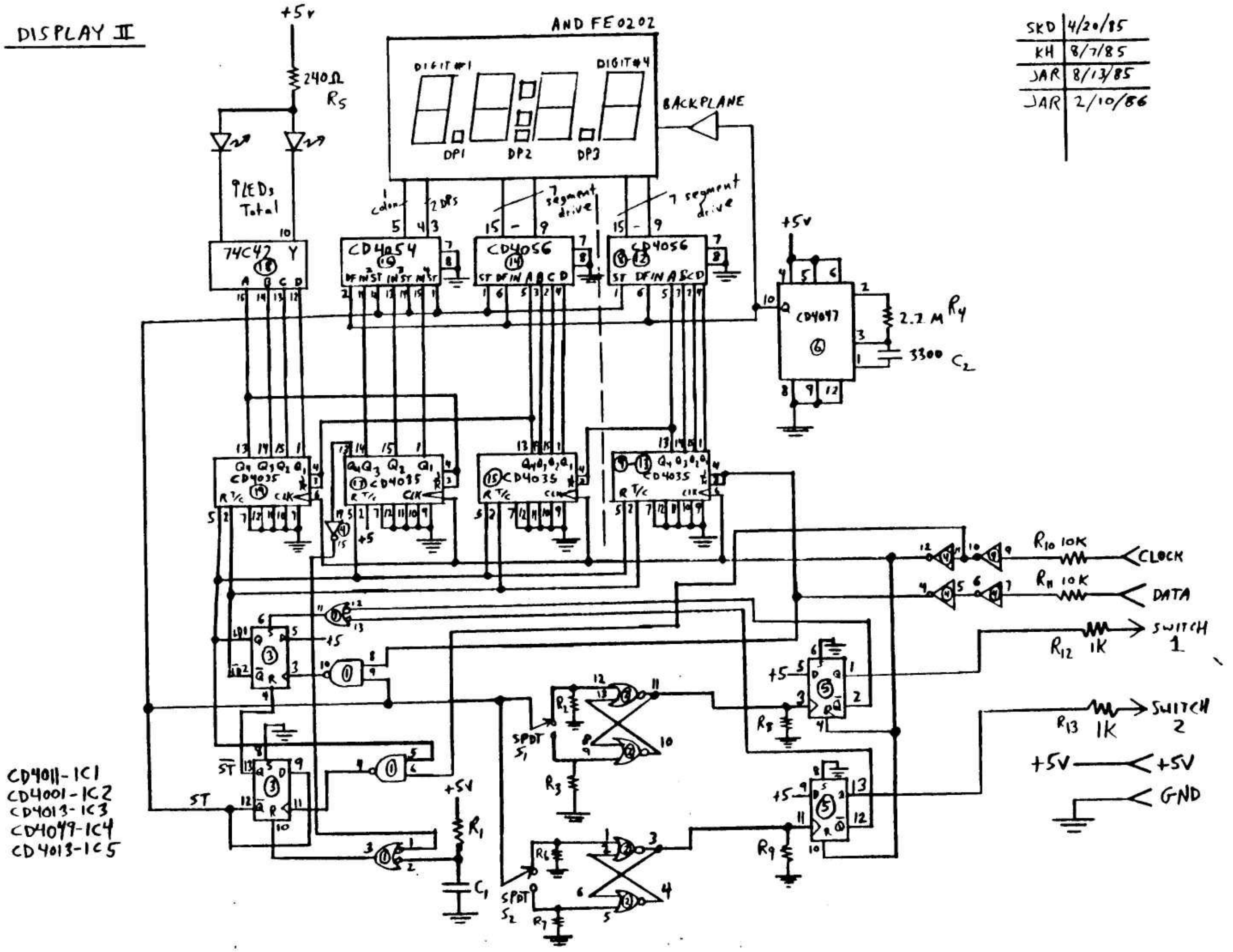
**LED CODES**

| MSB | | | LSB | LABEL |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | - BLANK - CLOCK |
| 0 | 0 | 0 | 1 | KW ARRAY SUPPLY |
| 0 | 0 | 1 | 0 | KW HOUSEHOLD DEMAND |
| 0 | 0 | 1 | 1 | $ NET BILL |
| 0 | 1 | 0 | 0 | $ NET BILL W/O ARRAY |
| 0 | 1 | 0 | 1 | KWH ARRAY SUPPLY |
| 0 | 1 | 1 | 0 | KWH HOUSEHOLD DEMAND |
| 0 | 1 | 1 | 1 | — |
| 1 | 0 | 0 | 0 | — (INVALID CODES) |
| 1 | 0 | 0 | 1 | — (INVALID CODES) |
| 1 | 0 | 1 | 0 | — (INVALID CODES) |
| 1 | 0 | 1 | 1 | — (INVALID CODES) |
| 1 | 1 | 0 | 0 | — (INVALID CODES) |
| 1 | 1 | 0 | 1 | — (INVALID CODES) |
| 1 | 1 | 1 | 0 | — (INVALID CODES) |
| 1 | 1 | 1 | 1 | — (INVALID CODES) |

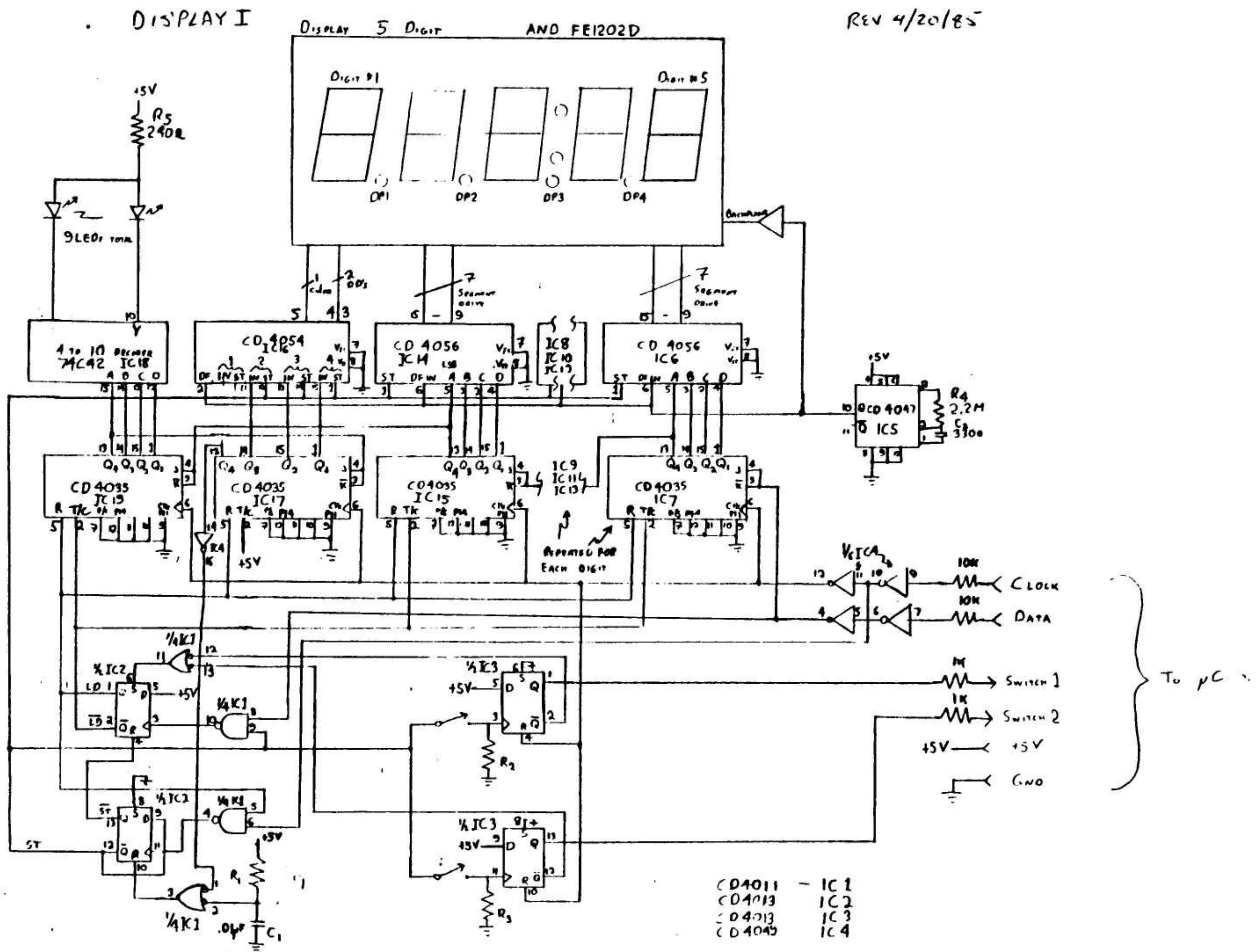
PROTOTYPE (UNIT II) DISPLAY




TIMING DIAGRAM FOR PROTOTYPE DISPLAY (UNIT II)

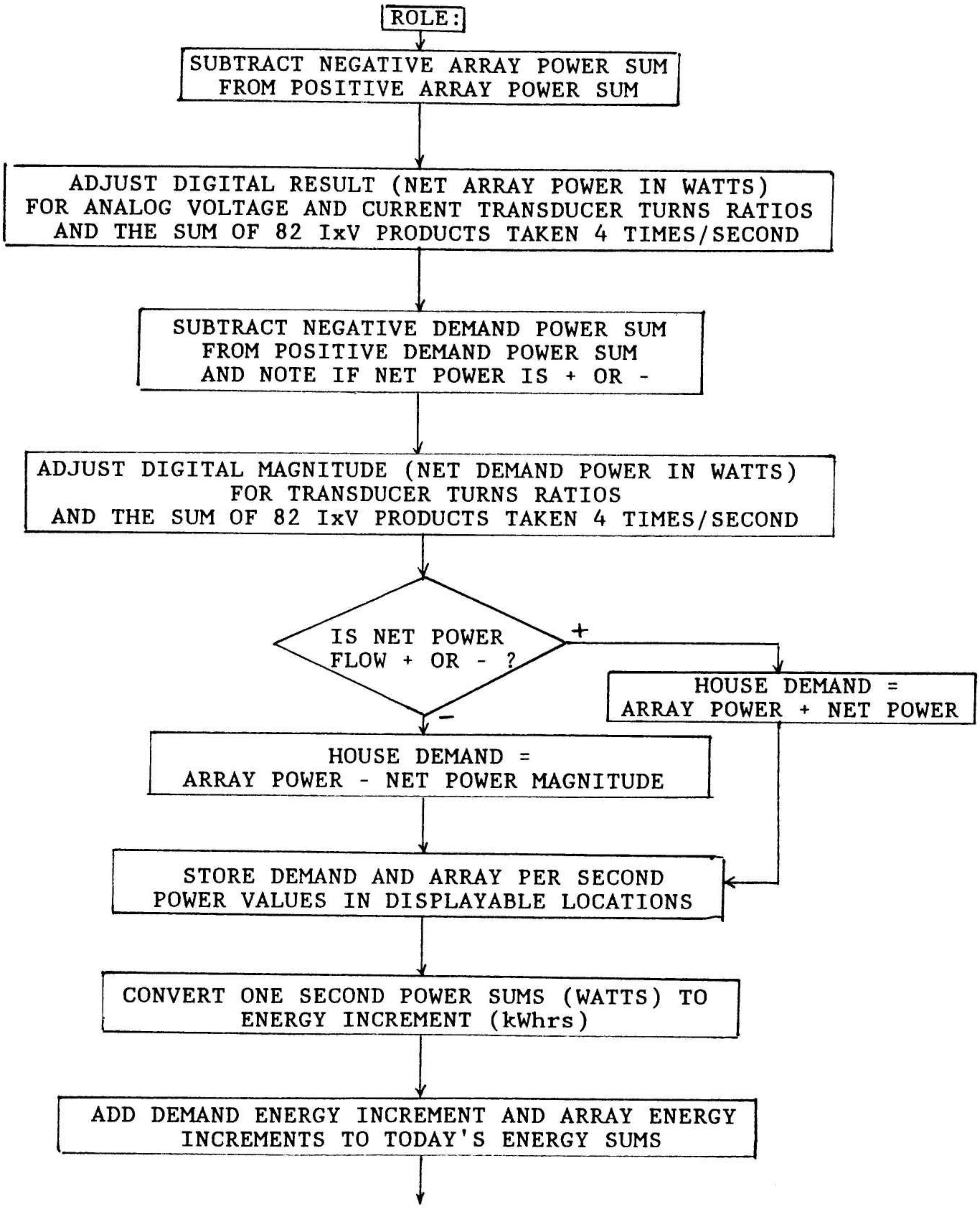


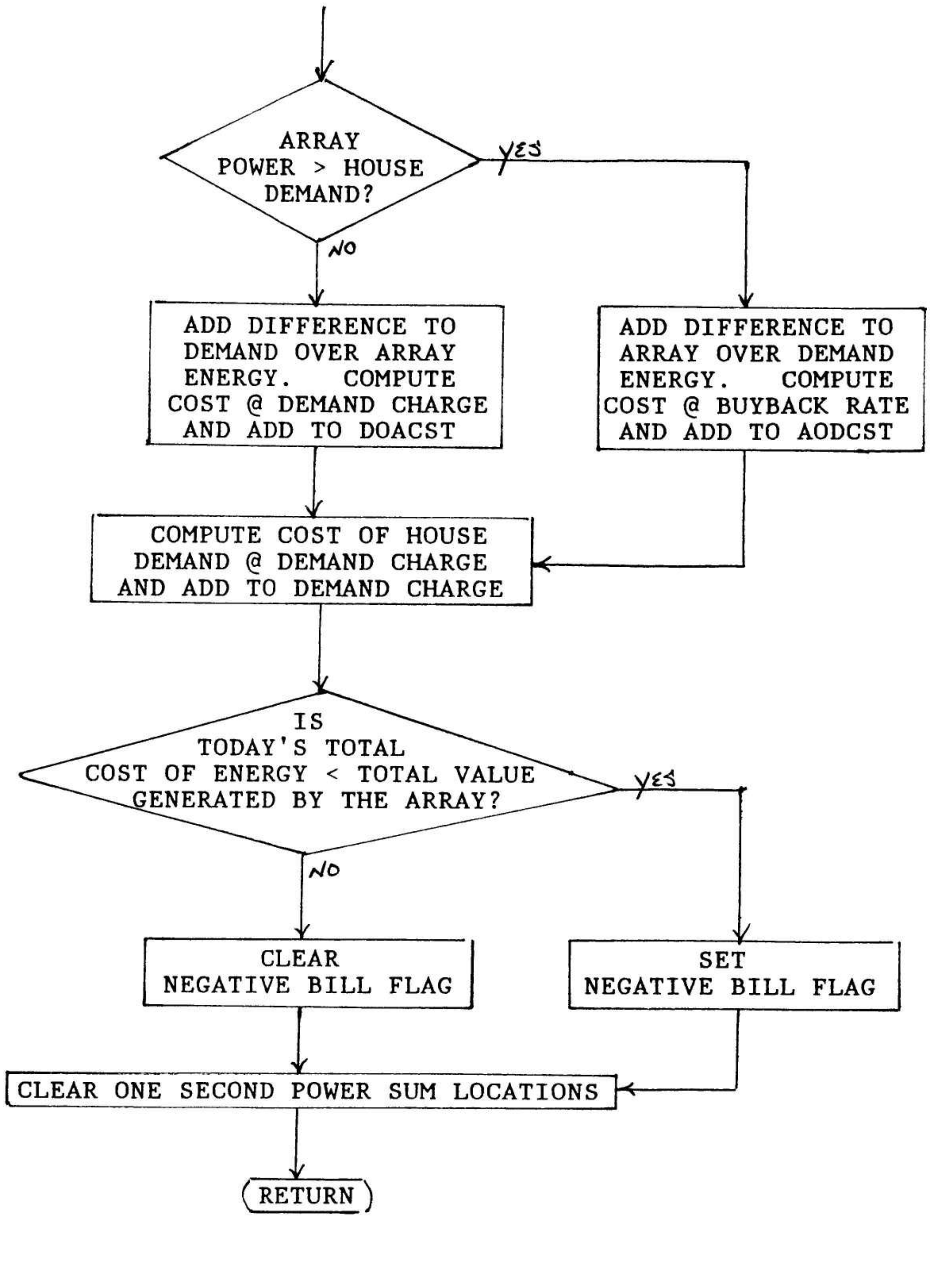

SCHEMATIC DIAGRAM UNIT II DISPLAY



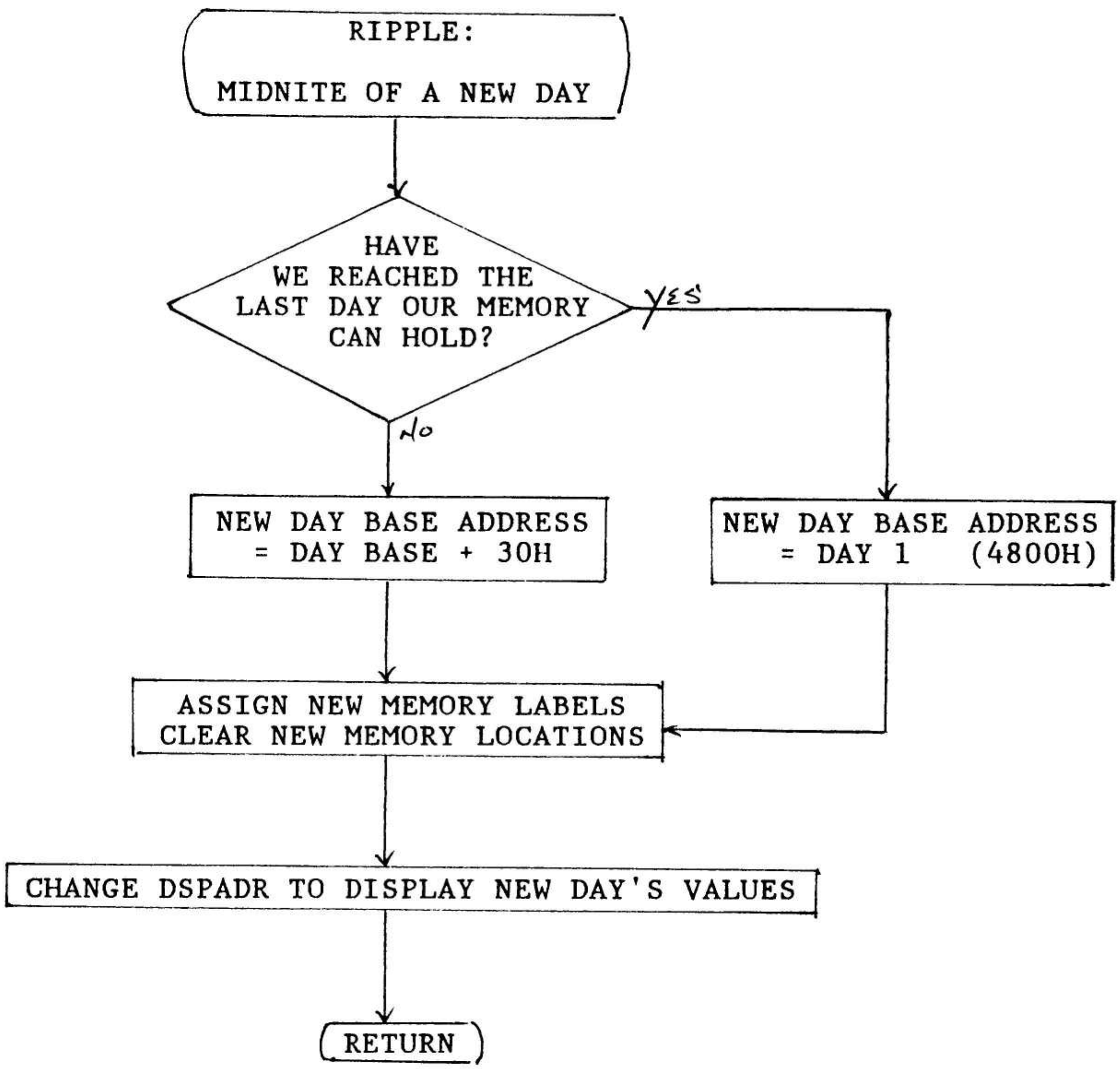

SCHEMATIC DIAGRAM UNIT I DISPLAY (Original)

# APPENDIX 2

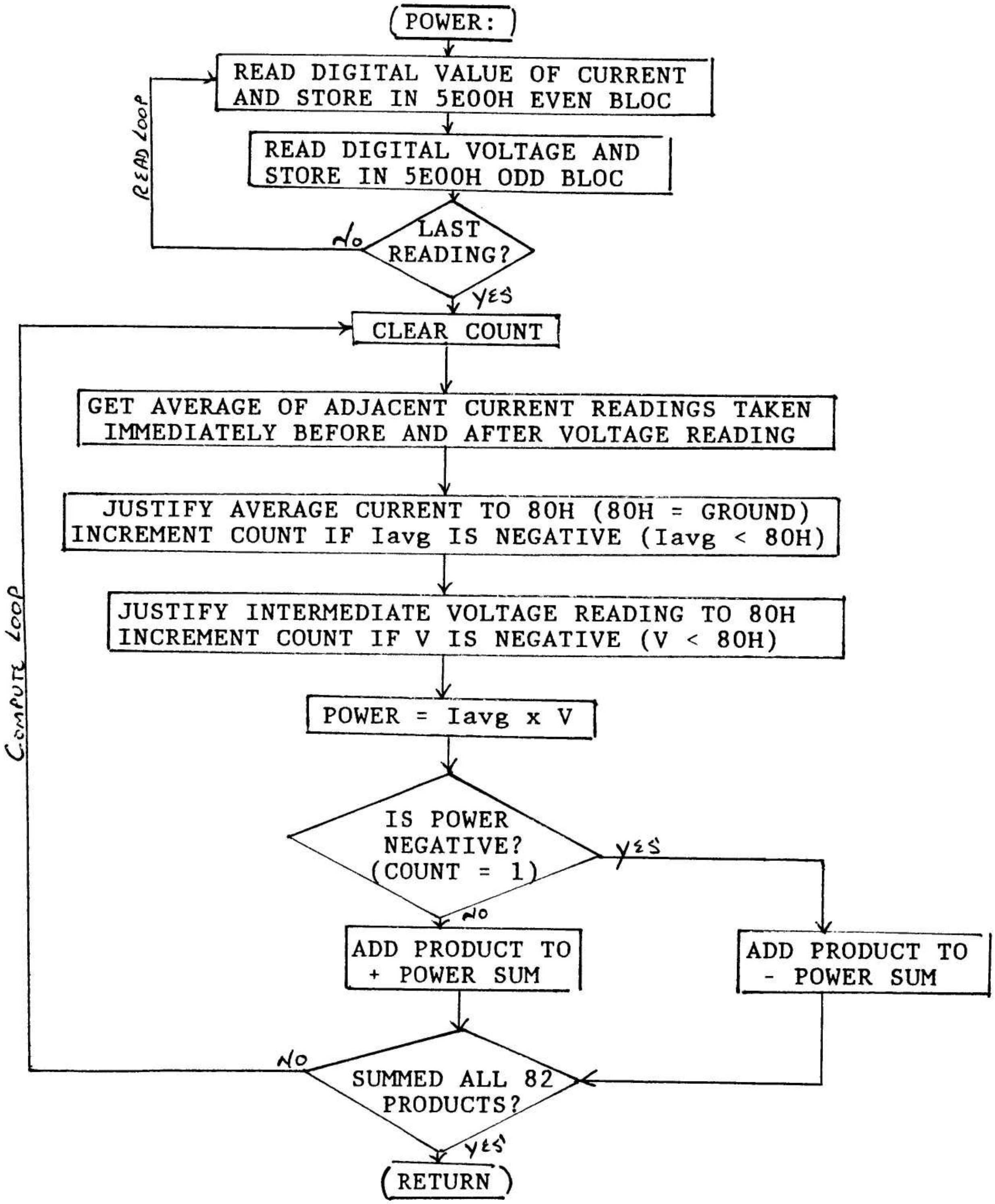

ROLE:
SUBTRACT NEGATIVE ARRAY POWER SUM FROM POSITIVE ARRAY POWER SUM
ADJUST DIGITAL RESULT (NET ARRAY POWER IN WATTS) FOR ANALOG VOLTAGE AND CURRENT TRANSDUCER TURNS RATIOS AND THE SUM OF 82 IxV PRODUCTS TAKEN 4 TIMES/SECOND
SUBTRACT NEGATIVE DEMAND POWER SUM FROM POSITIVE DEMAND POWER SUM AND NOTE IF NET POWER IS + OR -
ADJUST DIGITAL MAGNITUDE (NET DEMAND POWER IN WATTS) FOR TRANSDUCER TURNS RATIOS AND THE SUM OF 82 IxV PRODUCTS TAKEN 4 TIMES/SECOND
IS NET POWER FLOW + OR - ?
+
HOUSE DEMAND = ARRAY POWER + NET POWER
-
HOUSE DEMAND = ARRAY POWER - NET POWER MAGNITUDE
STORE DEMAND AND ARRAY PER SECOND POWER VALUES IN DISPLAYABLE LOCATIONS
CONVERT ONE SECOND POWER SUMS (WATTS) TO ENERGY INCREMENT (kWhrs)
ADD DEMAND ENERGY INCREMENT AND ARRAY ENERGY INCREMENTS TO TODAY'S ENERGY SUMS



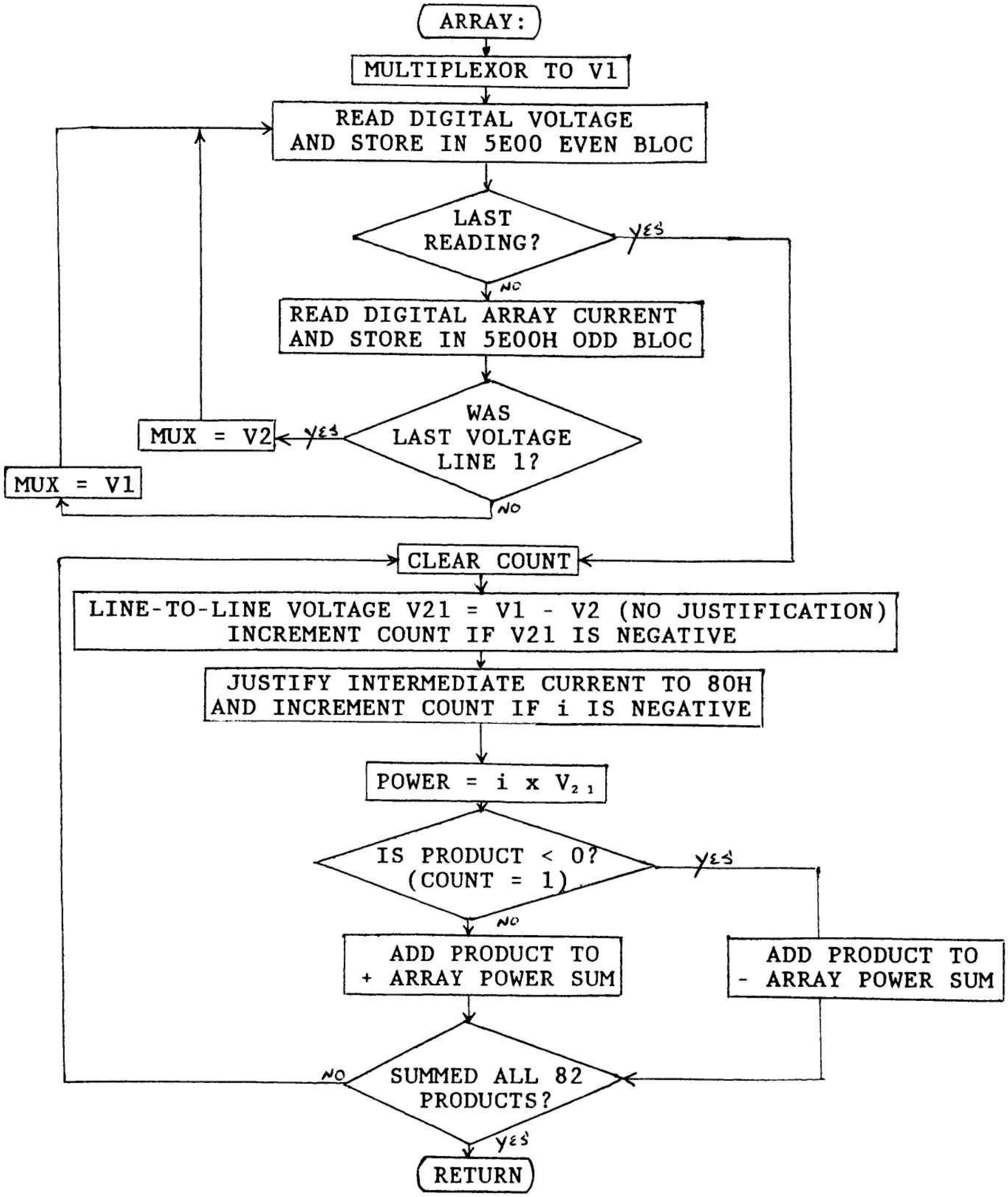

Flow Chart of Role Routine



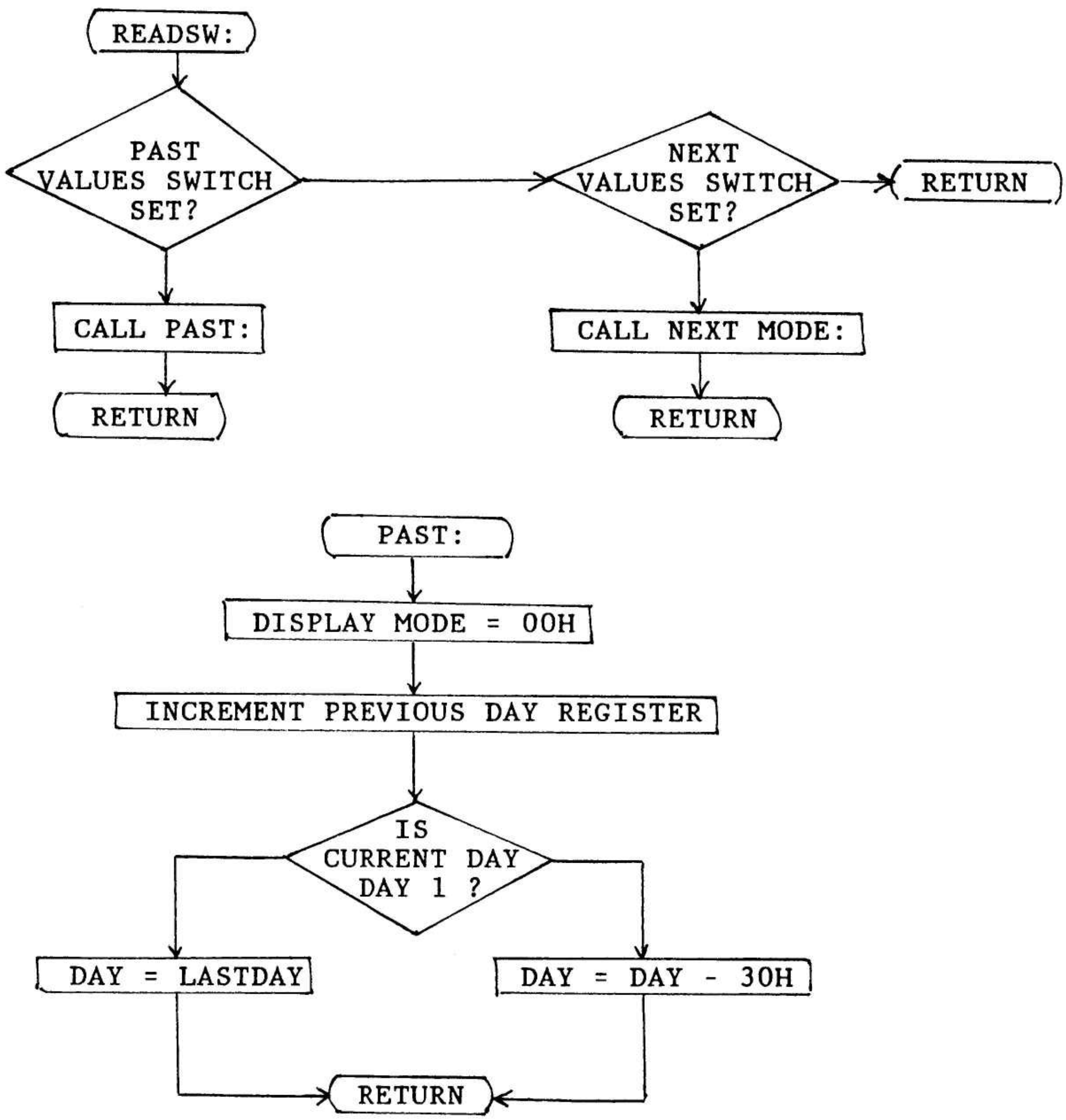

Flow Chart of Ripple (New Day) Routine



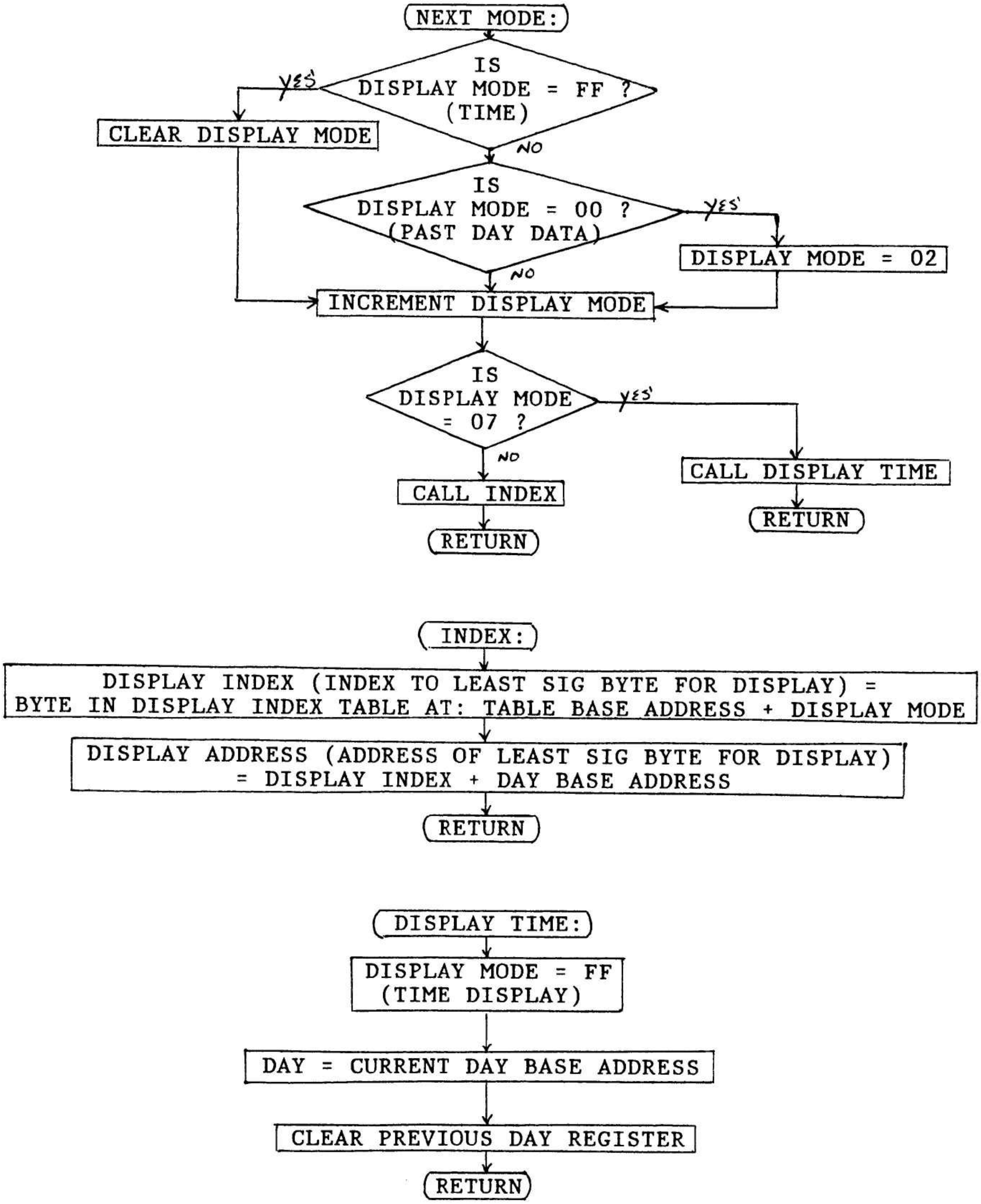

Flow Chart of Power Routine



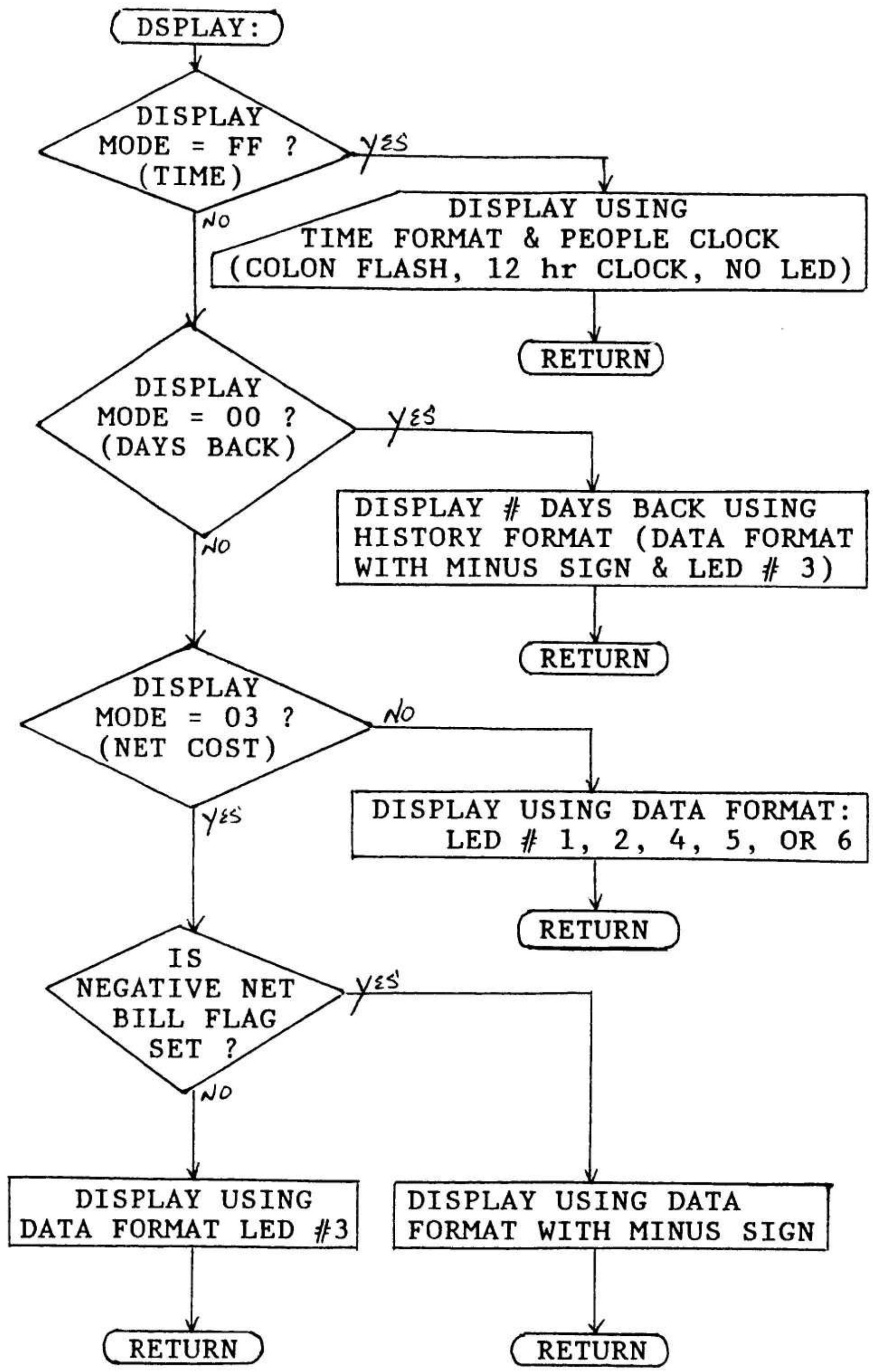

Flow Chart of Array Power Routine




Flowchart of READ SWITCH routine, part 1




Flow Chart of Read Switch Routine, part 2




Flow Chart of Display (Format) Routine

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                                 TITLE  COMMAND PROGRAM FOR DIGITAL METER

                        ;            -------------NOTATION--------------

                        ;        (HL) REFERS TO THE CONTENTS OF THE HL REGISTER.

                        ; [HL] REFERS TO THE CONTENTS AT THE MEMORY ADDRESS STORED IN (HL).

                        ;          LABEL (ANY LABEL WITHOUT () OR []) REFERS TO
                        ;   THE ADDRESS THAT THE PROGRAM USES WHEN 'LABEL' IS CALLED.

                        ;[LABEL] REFERS TO THE CONTENTS OF THE MEMORY AT THE ADDRESS 'LABEL'.


5FFF                    STACK EQU 5FFFH         ;NONDEFAULT ADDRESSES FOR STORING DATA

5FC3                    STKEND EQU STACK-60     ;60 BYTE STACK
5FBF                    DSPREG EQU STKEND-4     ;4 BYTE DiSPlay REGister FOR DATA STRING
                                                ;       TO BE SENT TO DISPLAY
5FBA                    DEMSUM EQU DSPREG-5     ;DEMand SUM = HOUSE NET (+) POWER READING SUM
5FB5                    DEMNEG EQU DEMSUM-5     ;DEMand NEGative = HOUSE NET (-) POWER SUM
5FB0                    ARRSUM EQU DEMNEG-5     ;ARRay SUM = INVERTOR (+) POWER READING SUM
5FAB                    ARRNEG EQU ARRSUM-5     ;ARRay NEGative = INVERTOR (-) POWER SUM
5FA2                    PRODCT EQU ARRNEG-9     ;PRODuCT = RESULT SPACE FOR FACTOR ROUTINE
5F99                    DFFRNC EQU PRODCT-9     ;DiFFeReNCe=RESULT SPACE FOR SUBTRACT ROUTINE
5F96                    CNVSPC EQU DFFRNC-3     ;CoNVersion SPaCe=RESULT SPACE OF BCD ROUTINE

                                                ;LOCATIONS FOR STORING ADDRESSES

5F94                    DSPADR EQU CNVSPC-2     ;DiSPlay ADdRess CONTAINS ONE OF THE
                                                ;ADDRESSES OF DISPLAYABLE QUANTITIES BELOW:
5F92                    DEMPWR EQU DSPADR-2     ;DEMand PoWeR = ADDR OF HOME DEMAND POWER
5F90                    ARRPWR EQU DEMPWR-2     ;ARRay PoWeR = ADDR OF INVERTOR POWER
5F8E                    DEMENG EQU ARRPWR-2     ;DEMand ENerGy = ADDR OF HOME DEMAND ENERGY
5F8C                    ARRENG EQU DEMENG-2     ;ARRay ENerGY = ADDR OF INVERTOR ENERGY
5F8A                    DMOVAR EQU ARRENG-2     ;DeMand OVer ARray = ADDRESS OF DEMAND IN
                                                ;                    EXCESS OF ARRAY ENERGY
5F88                    AROVDM EQU DMOVAR-2     ;ARray OVer DeMand = ADDRESS OF ARRAY IN
                                                ;                    EXCESS OF DEMAND ENERGY
5F86                    DOACST EQU AROVDM-2     ;Demand Over Array CoST LOCATION
5F84                    AODCST EQU DOACST-2     ;Array Over Demand CoST (VALUE) LOCATION
5F82                    DEMCST EQU AODCST-2     ;DEMand CoST = ENERGY DEMAND COST w/o ARRAY
5F80                    NETCST EQU DEMCST-2     ;NET CoST = NET DAILY BILL LOCATION

5F80                    MEMEND EQU NETCST       ;BEGINNING OF NON-DEFAULT MEMORY LOCATIONS

5F80                    DBEND EQU MEMEND        ;END OF DEFAULT VALUES DATABASE
                                                ;DEFAULT ADDRESSES LOADED INTO RAM FROM TOP
                                                ;SEE END OF THIS PROGRAM FOR DEFAULT VALUES
5F7F                    DSPMOD EQU DBEND-1      ;DiSPlay MODe = LED CODE FOR DISPLAY
5F78                    TMRS EQU DSPMOD-7       ;TiMeRS = OFF-BOARD TIMER SET VALUES
5F77                    OUTREG EQU TMRS-1       ;OUTput REGister = STATUS OF OUTPUT PORT
5F76                    HRS EQU OUTREG-1        ;HouRS = HOUR VALUE OF 24 HOUR BCD CLOCK
5F75                    MIN EQU HRS-1           ;MINutes = BCD MINUTES VALUE FOR CLOCK
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5F74                    SEC EQU MIN-1           ;SEConds = BCD SECONDS VALUE FOR CLOCK
5F73                    COUNT EQU SEC-1         ;COUNT = 1/4 SECOND COUNTER VALUE
5F72                    FLOW EQU COUNT-1        ;FLOW = 00 FOR + POWER FLOW, 01 FOR - POWER
5F71                    NUMBIT EQU FLOW-1       ;NUMBIT = NUMBER OF BITS IN FACTOR
5F70                    INPOW1 EQU NUMBIT-1     ;FIRST INvertor POWer FACTOR  (SEE ROLE)
5F6F                    INPOW2 EQU INPOW1-1     ;SECOND INvertor POWer FACTOR
5F6E                    DEMPW1 EQU INPOW2-1     ;FIRST DEMand PoWer FACTOR
5F6D                    DEMPW2 EQU DEMPW1-1     ;SECOND DEMand PoWer FACTOR
5F6C                    PRVDAY EQU DEMPW2-1     ;PReVious DAY = # DAYS BACK OF DISPLAYED DATA
5F6A                    DAY1 EQU PRVDAY-2       ;DAY1 = FIRST DAY'S BASE DATA STORAGE ADDRESS
5F68                    LSTDAY EQU DAY1-2       ;LaST DAY = LAST DAY'S BASE DATA ADDRESS
5F66                    DAY EQU LSTDAY-2        ;DAY = BASE ADDRESS FOR TODAY'S DATA

5F5F                    DSPIND EQU DAY-7        ;DiSPlay INDex = TABLE OF INDICES FOR INDEXED
                                                ;ADDRESSING.  USES DiSPlay MODe (LED CODE) TO
                                                ;   ACCESS ADDRESS OF DATA FOR DISPLAY AT
                                                ;      DAY BASE ADDRESS + INDEX f(DSPMOD)

5F5E                    VMUX EQU DSPIND-1       ;Voltage MUltipleXor channel
5F5D                    IMUX EQU VMUX-1         ;I (current) MUltipleXor channel

5F5C                    RATE EQU IMUX-1         ;RATE CONTAINS ONE OF THE COST FACTORS BELOW
5F5B                    BUYBAK EQU RATE-1       ;BUYBAcK = BUYBACK RATE FACTOR ==> $/kWh
5F5A                    DEMCHG EQU BUYBAK-1     ;DEMand CHarGe = ELECTRICITY COST ==> $/kWh

5F5A                    DBBEG EQU DEMCHG        ;BEGINNING OF DEFAULT DATABASE


9000                    TIMER0 EQU 9000H        ;HARDWARE LOCATIONS OF OFF-BOARD TIMER,
9100                    TIMER1 EQU TIMER0+100H
9200                    TIMER2 EQU TIMER1+100H
9300                    TIMER3 EQU TIMER2+100H
A000                    ADC EQU 0A000H          ;       ANALOG TO DIGITAL CHIP, &
8000                    DAC EQU 8000H           ;        DIGITAL TO ANALOG CHIP.


0002                    PPRT   EQU 00000010B    ;Parallel PoRT STATUS
0000                    MUXV1  EQU 00000000B    ;LOAD VOLTS 1    CH #0
0008                    MUXI1  EQU 00001000B    ;LOAD AMPS 1     CH #1
0010                    MUXV2  EQU 00010000B    ;LOAD VOLTS 2    CH #2
0018                    MUXI2  EQU 00011000B    ;LOAD AMPS 2     CH #3
0020                    MUXIPV EQU 00100000B    ;PV POWER CONDITIONER AMPS    CH #4
                                                ;CH 5, 6, & 7 OPEN

                        .PHASE 4000H    ;THIS PROGRAM OCCUPIES 4000H TO 47A0H IN THE MEMORY

4000   C3 4012          JMP    INIT             ;TO START THE PROGRAM THE MICROPROCESSOR
                                                ;MUST BE SENT HERE (4000H) WHICH STARTS THE
                                                ;INITIALIZATION PROCESS.
4003   C3 400F          JMP    NMI              ;   THESE FOUR JUMP STATEMENTS FOLLOW
4006   C3 4010          JMP    ADINT            ;THE INITIAL JUMP AND ARE THE DESTINATION
4009   C3 4011          JMP    CPINT            ;OF THE INTERRUPTS FROM 10C4H THRU 10CFH
400C   C3 4040          JMP    BODINT

400F   C9         NMI:  RET
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4010    C9              ADINT:  RET

4011    C9              CPINT:  RET

                        ;-----------------------------------------------------------------------

4012    31 5FFF         INIT:   LXI     SP,STACK        ;SET UP STACK POINTER
4015    CD 4089                 CALL    STMEM           ;SET UP MEMORY
4018    CD 40A7                 CALL    STDAC           ;SET UP D/A
401B    CD 40A3                 CALL    STADC           ;SET UP A/D
401E    CD 40AD                 CALL    STPRT           ;SET UP PARALLEL PORTS
4021    CD 40B7                 CALL    STINT           ;SET UP INTERRUPT JUMPS
4024    CD 40DC                 CALL    STDSP           ;SET UP DISPLAY
4027    2A 5F66                 LHLD    DAY             ;(HL) = [DAY]
402A    CD 4334                 CALL    CLRMEM          ;ASSIGNS MEMORY LABELS AND CLEARS
402D    CD 42F5                 CALL    CLRSUM          ;CLEARS ARRSUM, DEMSUM, ARRNEG, & DEMNEG
4030    CD 405A                 CALL    ALTDEF          ;GO TO CHANGE DEFAULTS IF DESIRED
4033    CD 4063                 CALL    STTMRS          ;SET UP TIMERS

4036    FF              DB      0FFH                    ;BREAKPOINT FOR SETTING INITIAL TIME

4037    3E 1B                   MVI     A,00011011B     ;SET UP INTERRUPT MASKS FOR START
4039    30                      SIM
403A    FB                      EI                      ;ENABLE INTERRUPTS

403B    D3 19           WAIT:   OUT     19H             ;GO INTO WAIT MODE AND LOOP BACK TO WAIT
403D    C3 403B                 JMP     WAIT            ; WHEN MAIN BODY IS DONE EACH 1/4 SECOND

                        ;-----------------------------------------------------------------------

                                MAX TIME: 175 m sec
4040    CD 410E         BODINT: CALL    SECOND  ;1/4 SEC TIMER DECREMENTED
4043    CC 4116                 CZ      INCTIM  ;EACH SECOND THE TIME IS INCREMENTED, POWER &
                                                ;       ENERGY VALUES ARE UPDATED.
4046    CD 4392                 CALL    DEMND1  ;1/4 SECOND HOUSE LINE 1 POWER READINGS TAKEN
4049    CD 43A6                 CALL    DEMND2  ;1/4 SECOND HOUSE LINE 2 POWER READINGS TAKEN
404C    CD 4473                 CALL    ARRAY   ;1/4 SECOND POWER READINGS TAKEN ON INVERTOR
404F    CD 4550                 CALL    READSW  ;DISPLAY SWITCHES CHECKED EVERY 1/4 SECOND
4052    CD 4552                 CALL    DSPLAY  ;DISPLAY UPDATED EVERY 1/4 SEC
4055    3E 09                   MVI     A,00001001B     ;MASK ALL BUT 1/4 SEC INTERRUPT
4057    30                      SIM
4058    FB                      EI
4059    C9                      RET             ;               RETURN TO WAIT MODE
                                                ;       & WAIT FOR NEXT 1/4 SEC INTERRUPT

                        ;-----------------------------------------------------------------------


405A                    ALTDEF: ;ALTer DEFaults CHECKS TO SEE IF SWITCH IS SET TO ENABLE AN EXTERNAL
                                ;SOURCE TO CHANGE SOME OF THE DEFAULT VALUES. IF NOT, IT USES THE
                                ;SET DEFAULTS AND RESUMES INITIALIZATION

                                ;SMASHES: A      INPUTS: NONE    OUTPUTS: NONE
                                ;FLAGS: ALL      MAX TIME: UNBOUNDED

405A    DB 11                   IN      11H             ;READ PORT A
```

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405C    E6 10                   ANI     00010000B       ;SINGLE OUT ALTDEF BIT
405E    C4 4062                 CNZ     COMPINT         ;ALLOW COMPUTER INTERACTION
                                                        ;IF DESIRED (NOT SET UP AS OF 1 MAY 1986)
4061    C9                      RET                     ;AND RETURN

4062    C9              COMPINT:RET                     ;       TABLED UNTIL LATER

                        ;-----------------------------------------------------------------------

4063                    STTMRS: ;SeT TiMeRS: LOADS 82C53 TIMER WHICH IS LOCATED ON A PERIPHERAL
                                ;BOARD. TIMERO CONTROLS THE A/D SIGNAL READ TIMING.
                                ;TIMERS 1 & 2 ARE COMBINED TO GET 1/4 SECOND TIMING PULSES.
                                ;TIMER 3 IS THE TIMER CONTROL ADDRESS.

                                ;SMASHES: A,DE,HL       INPUTS: NONE    OUTPUTS: NONE
                                ;FLAGS: NONE            MAX TIME:

                                ;TIMER0=9000H
                                ;TIMER1=TIMER0+100H
                                ;TIMER2=TIMER1+100H
                                ;TIMER3=TIMER2+100H

4063    11 5F78                 LXI     D,TMRS          ;LOAD IN TIMER DATA ADDRESS MINUS ONE
4066    21 9300                 LXI     H,TIMER3        ;LOAD TIMER CONTROL ADDRESS
4069    36 3E                   MVI     M,00111110B     ;SET UP COUNTER 0 WITH BINARY MODE 3
406B    36 7C                   MVI     M,01111100B     ;SET UP COUNTER 1 WITH BINARY MODE 2
406D    36 BC                   MVI     M,10111100B     ;SET UP COUNTER 2 WITH BINARY MODE 2
406F    21 9000                 LXI     H,TIMER0        ;LOAD COUNTER 0 ADDRESS
4072    CD 4082                 CALL    STRTMR          ;AND LOAD IN CORRESPONDING VALUE
4075    21 9100                 LXI     H,TIMER1        ;LOAD COUNTER 1 ADDRESS
4078    CD 4082                 CALL    STRTMR          ;AND LOAD IN CORRESPONDING VALUE
407B    21 9200                 LXI     H,TIMER2        ;LOAD COUNTER 2 ADDRESS
407E    CD 4082                 CALL    STRTMR          ;AND LOAD IN CORRESPONDING VALUE
4081    C9                      RET                     ;AND RETURN

4082                    STRTMR: ;SToRe TIMeR values TAKES TWO BYTES OF DATA AT ADDRESS IN (DE)
                                ;       AND LOADS IT INTO THE LOCATION ADDRESSED BY (HL).

                                ;SMASHES: A,DE    INPUTS: ADDRESSES IN DE,HL    MAX TIME:
                                ;OUTPUTS: NEXT ADDRESS IN (DE)  FLAGS: NONE

4082    13                      INX     D               ;INCREMENT (DE) FOR LSBYTE LOCATION
4083    1A                      LDAX    D               ;PUT DATA ADDRESSED IN (DE) INTO (A)
4084    77                      MOV     M,A             ;PUT THAT LEAST BYTE IN MEMORY
4085    13                      INX     D               ;INCREMENT (DE) FOR MSBYTE LOCATION
4086    1A                      LDAX    D               ;PUT DATA ADDRESSED IN (DE) INTO (A)
4087    77                      MOV     M,A             ;PUT MSBYTE INTO MEMORY
4088    C9                      RET                     ;AND RETURN

                        ;-----------------------------------------------------------------------

4089                    STMEM:  ;SeT MEMory: SETS UP MEMORY DEFAULTS BY PUTTING EPROM VALUES INTO
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                                       ; RAM SO THEY MAY BE CHANGED AT ALTDEFault OR INITIAL BREAKPOINT.

                                       ;SMASHES: A,BC,DE,HL    INPUTS: NONE    OUTPUTS: NONE
                                       ;FLAGS: ALL     MAX TIME:

 4089    21 5F5A                       LXI     H,DBBEG         ;(HL) = START ADDRESS OF RAM DEFAULT TABLE
 408C    11 4555                       LXI     D,DATBAS        ;(DE) = ADDRESS OF ROM DEFAULT TABLE
                                                               ;       AT THE END OF THIS PROGRAM
 408F    01 5F80                       LXI     B,DBEND         ;(BC) = END ADDRESS OF RAM DEFAULT TABLE

 4092    1A                    MEMLP:  LDAX    D               ;GET VALUE FROM EPROM INTO (A)
 4093    77                            MOV     M,A             ;AND MOVE INTO MEMORY
 4094    23                            INX     H               ;INCREMENT MEMORY ADDRESS
 4095    CD 409D                       CALL    CMPBH           ;COMPARE (BC) TO (HL): CHECK FOR LAST ADDRESS
 4098    C8                            RZ                      ;       RETURN IF AT LAST ADDRESS
 4099    13                            INX     D               ;  ELSE: INCREMENT ROM ADDRESS
 409A    C3 4092                       JMP     MEMLP           ;        AND LOOP BACK


 409D                          CMPBH:  ;CoMPare BH COMPARES (BC) WITH (HL)
                                       ;AND RETURNS WITH THE ZERO FLAG SET IF THEY ARE EQUAL.

                                       ;SMASHES: A     INPUTS: BC,HL   OUTPUTS: Z,BC,HL DATA
                                       ;FLAGS: ALL     MAX TIME:

 409D    78                            MOV     A,B             ;PUT B INTO A
 409E    BC                            CMP     H               ;COMPARE WITH H
 409F    C0                            RNZ                     ;IF NOT EQUAL THEN RETURN
 40A0    79                            MOV     A,C             ;ELSE MOVE C INTO A
 40A1    BD                            CMP     L               ;AND COMPARE WITH L
 40A2    C9                            RET                     ;AND RETURN, WITH Z SET IF EQUAL

                               ;-----------------------------------------------------------------------


 40A3                          STADC:  ;SeT Analog to Digital Convertor: INITIALIZES A/D BY DOING A READ

                                       ;SMASHES: A     INPUTS: NONE    OUTPUTS: NONE
                                       ;FLAGS: ALL     MAX TIME:

                                       ;ADC=0A00H

 40A3    3A A000                       LDA     ADC             ;PERFORM A READ
 40A6    C9                            RET                     ;AND RETURN

                               ;-----------------------------------------------------------------------


 40A7                          STDAC:  ;SeT Digital to Analogue Chip:
                                       ;PUTS 00H (ZERO AMPS) INTO D/A SO AS NOT TO DRAIN PV MODULE.

                                       ;SMASHES: A,HL  INPUTS: NONE    OUTPUTS: NONE
                                       ;FLAGS: ALL     MAX TIME:

                                       ;DAC=8000H
```

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40A7    21 8000             LXI     H,DAC           ;(HL) =  D/A ADDRESS
40AA    AF                  XRA     A               ;CLEAR (A)
40AB    77                  MOV     M,A             ;OUTPUT TO D/A
40AC    C9                  RET                     ;AND RETURN

                    ;----------------------------------------------------------------------

40AD                STPRT:  ;SeT PoRTs: SETS UP PARALLEL PORTS.  PORT 10H IS THE COMMAND/STATUS
                            ;REGISTER.  PORT 11H IS PORT A AND IS SET UP AS AN INPUT PORT WITH
                            ;PULLUPS.  PORT 12H IS PORT B AND IS SET UP AS AN OUTPUT PORT.  PORT
                            ;13H IS PORT C AND IS SET UP AS AN INPUT PORT BUT IS CURRENTLY NOT
                            ;BEING USED.  PORT 14H IS THE LOW 8 BITS OF THE ON-BOARD TIMER AND
                            ;PORT 15H IS THE UPPER 6 BITS OF THE TIMER WITH THE LEFTOVER 2 BITS
                            ;USED FOR THE TIMER COMMANDS.

                            ;SMASHES: A      INPUTS: NONE     OUTPUTS: NONE
                            ;FLAGS: NONE     MAX TIME:

                            ;PPRT EQU 00000010B

40AD    3E 42               MVI     A,PPRT OR 40H   ;SET UP PARALLEL PORTS AND TIMER STOP
40AF    D3 10               OUT     10H             ;AND SEND
40B1    3A 5F77             LDA     OUTREG          ;GET VALUE OF OUTPUT REGISTER
40B4    D3 12               OUT     12H             ;AND SEND
40B6    C9                  RET

                    ;----------------------------------------------------------------------

40B7    21 03C3     STINT:  LXI     H,03C3H         ;SET INTerruPts LOADS THE INTERRUPT JUMP
40BA    22 10C4             SHLD    10C4H           ;STATEMENTS IN THE ON-BOARD RAM OF THE
40BD    21 C340             LXI     H,0C340H        ;MICROPROCESSOR.  THE DESTINATIONS OF THESE
40C0    22 10C6             SHLD    10C6H           ;INTERRUPT JUMPS ARE FIXED ADDRESSES,
40C3    21 4006             LXI     H,4006H         ;IMMEDIATELY FOLLOWING THE INITIALIZE JUMP
40C6    22 10C8             SHLD    10C8H           ;STATEMENT AT 4000H.
40C9    21 09C3             LXI     H,09C3H
40CC    22 10CA             SHLD    10CAH
40CF    21 C340             LXI     H,0C340H
40D2    22 10CC             SHLD    10CCH
40D5    21 400C             LXI     H,400CH
40D8    22 10CE             SHLD    10CEH
40DB    C9                  RET

                    ;----------------------------------------------------------------------

40DC                STDSP:  ;SeT DiSPlay SETS UP DISPLAY AND TESTS ALL PARTS OF VISUAL DISPLAY
                            ;TO SEE IF THEY ARE OPERATING CORRECTLY.  DISPLAYS ALL LCD ELEMENTS
                            ;     AND LIGHTS THE 6 LEDS ONE AT A TIME FOR ~ 1/3 SECOND EACH.

                            ;SMASHES: A,D,HL         INPUTS: NONE     OUTPUTS: NONE
                            ;FLAGS: ALL      MAX TIME:

40DC    3E A0               MVI     A,0A0H          ;SET UP TIMER WITH 3D0H=976D
40DE    D3 14               OUT     14H             ;PLUS 0C000H FOR CONTINUOUS PULSES
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40E0    3E C7                   MVI     A,0C7H          ;AND SEND OUT TO PORTS 14H AND 15H
40E2    D3 15                   OUT     15H
40E4    3E C2                   MVI     A,PPRT OR 0C0H  ;START THE TIMER
40E6    D3 10                   OUT     10H
40E8    21 5FBF                 LXI     H,DSPREG        ;(HL) = DISPLAY REGISTER START ADDRESS
40EB    E5                      PUSH    H               ;SAVE ADDRESS ON STACK FOR LATER
40EC    3E 1F                   MVI     A,1FH           ;LED #1, COLON, DECIMAL POINTS & START BIT
40EE    77                      MOV     M,A             ;STORED AT DSPREG
40EF    23                      INX     H               ;(HL) = DSPREG + 1
40F0    3E 88                   MVI     A,88H
40F2    77                      MOV     M,A             ;STORE 88H (MOST SIGNIFICANT DIGITS) THERE
40F3    23                      INX     H               ;(HL) = DSPREG + 2
40F4    77                      MOV     M,A             ;STORE 88H (LEAST SIGNIFICANT DIGITS) THERE
40F5    E1                      POP     H               ;RESTORE DSPREG ADDRESS IN (HL)
40F6    D3 19           LEDTST: OUT     19H             ;GO INTO WAIT MODE FOR ~1/3 SECONDS
40F8    E5                      PUSH    H               ;SAVE (HL) ON STACK: IT NEEDS TO BE PROTECTED
                                                        ;FROM THE DSP ROUTINE WHICH SMASHES (HL)!
40F9    CD 4553                 CALL    DSP             ;COME OUT OF WAIT AND DISPLAY
40FC    E1                      POP     H               ;TAKE (HL) OFF THE SHELF
40FD    7E                      MOV     A,M             ;GET [DSPREG] CONTENTS INTO (A)
40FE    C6 10                   ADI     10H             ;INCREMENT LED CODE
4100    FE 7F                   CPI     07FH            ;[DSPREG] = 7FH AFTER 6 LEDS
4102    CA 4109                 JZ      STDEND          ;END TEST IF THE 6 LEDS ARE DONE
4105    77                      MOV     M,A             ;ELSE STORE BACK IN DSPREG LOCATION AT (HL)
4106    C3 40F6                 JMP     LEDTST          ;AND CONTINUE LED TEST

4109    3E 42           STDEND: MVI     A,PPRT OR 40H   ;STOP TIMER
410B    D3 10                   OUT     10H
410D    C9                      RET                     ;AND RETURN

                        ;------------------------------------------------------------------------

410E                    SECOND: ;DECREMENTS 1/4 SECOND DOWN COUNTER LOCATED AT [COUNT] AND
                                ;         RETURNS WITH ZERO SET IF ONE SECOND HAS PASSED.

                                ;SMASHES: NONE    INPUTS: NONE   OUTPUTS: [COUNT] = [COUNT] - 1
                                ;FLAGS: ZERO SET FOR ONE SECOND PASSED     MAX TIME:

410E    3A 5F73                 LDA     COUNT   ;DECREMENT 1/4 SECOND COUNTER
4111    3D                      DCR     A
4112    32 5F73                 STA     COUNT
4115    C9                      RET

                        ;------------------------------------------------------------------------

4116                    INCTIM: ;INCrement TIMe IS CALLED EVERY SECOND.  IT REPLENISHES THE
                                ;1/4 SECOND DOWN COUNTER AT [COUNT], CALLS ROLE TO UPDATE POWERS AND
                                ;ENERGIES, AND INCREMENTS THE SECOND REGISTER AND OTHER TIME
                                ;REGISTERS IF APPROPRIATE.

                                ;SMASHES: ALL   INPUTS: NONE    FLAGS: ALL
                                ;OUTPUTS: COUNT = 04H, POWERS UPDATED, TIME INCREMENTED ONE SECOND
                                ;MAX TIME: ~ 25 MILLISECONDS (MOSTLY ROLE)
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4116    3E 04                   MVI     A,04H
4118    32 5F73                 STA     COUNT   ;REPLENISH 1/4 SECOND COUNTER
411B    CD 4159                 CALL    ROLE    ;PWRS & ENERGIES UPDATED
411E    CD 412B                 CALL    INCSEC  ;INCREMENT CLOCK VALUES
4121    CC 4132                 CZ      INCMIN
4124    CC 4148                 CZ      INCHRS
4127    CC 4316                 CZ      RIPPLE  ;DAY = DAY+30H, NEW STORAGE ADDRESSES,
                                                ;ALL NEW STORAGE LOCATIONS CLEARED.
412A    C9                      RET

                        ;-----------------------------------------------------------------------

412B                    INCSEC: ;INCrement SEConds INCREMENTS THE SECOND VALUE BY LOADING THE SECOND
                                ;ADDRESS AND THEN CALLING INC60.
                                ;THE ZERO FLAG IS SET WHEN 60 SECONDS HAVE PASSED.

                                ;SMASHES: A,HL  INPUTS: NONE    OUTPUTS: SECOND ADDRESS IN (HL)
                                ;                                ZERO FLAG SET IF ONE MINUTE PASSED
                                ;FLAGS: ALL     MAX TIME:

412B    21 5F74                 LXI     H,SEC           ;LOAD SECONDS ADDRESS IN (HL)
412E    CD 4139                 CALL    INC60           ;INCREMENT: SET ZERO FLAG IF SEC = 60
4131    C9                      RET                     ;AND RETURN

                        ;-----------------------------------------------------------------------

4132                    INCMIN: ;INCrement MINutes INCREMENTS THE MINUTE VALUE BY LOADING THE MINUTE
                                ;ADDRESS AND THEN CALLING INC60.
                                ;THE ZERO FLAG IS SET IF ONE HOUR HAS PASSED.

                                ;SMASHES: A,HL  INPUTS: NONE    OUTPUTS: MINUTE ADDRESS IN (HL)
                                ;                                ZERO FLAG SET IF ONE HOUR HAS PASSED
                                ;FLAGS: ALL     MAX TIME:

4132    21 5F75                 LXI     H,MIN           ;LOAD MINUTES ADDRESS IN HL
4135    CD 4139                 CALL    INC60           ;INCREMENT: SET ZERO FLAG IF MIN = 60
4138    C9                      RET                     ;AND RET

4139                    INC60:  ;INCrement values using 60 decimal number system:
                                ;THIS PROGRAM TAKES AN ADDRESS
                                ;OF A BINARY CODED DECIMAL THAT CAN RANGE FROM 0-59H, INCREMENTS IT,
                                ;AND PUTS IT BACK IN MEMORY. IF AN INCREMENT IS FROM 59H,
                                ;IT CLEARS THE VALUE IN MEMORY AND SETS THE ZERO FLAG.
                                ;THE PROGRAM EXITS WITH THE MEMORY ADDRESS LEFT INTACT IN (HL)

                                ;SMASHES: A     INPUT: ADDRESS IN (HL)  OUTPUT: ADDRESS IN (HL)
                                ;                                               OVERFLOW IN Z
                                ;FLAGS: ALL     MAX TIME:

4139    7E                      MOV     A,M             ;GET DESIRED INCREMENTEE
413A    C6 01                   ADI     01H             ;INCREMENT BY ADDING (TO USE DAA COMMAND)
413C    27                      DAA                     ;DECIMAL ADJUST IT
413D    FE 60                   CPI     60H             ;COMPARE IT TO 60
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 413F    CA 4145                   JZ      STZ             ;IF 60, GO TO SeT Zero
 4142    B7                        ORA     A               ;ELSE CLEAR Z
 4143    77                        MOV     M,A             ;AND PUT DECIMAL INCREMENTED VALUE IN MEMORY
 4144    C9                        RET                     ;AND RETURN
 4145    AF                STZ:    XRA     A               ;CLEAR (A) AND SET Z
 4146    77                        MOV     M,A             ;STORE IN MEMORY AT (HL)
 4147    C9                        RET                     ;AND RETURN

                           ;------------------------------------------------------------------------

 4148                      INCHRS: ;INCrement HouRS INCREMENTS THE HOURS REGISTER FROM 0 TO 23 BCD.
                                   ;MILITARY TIME VALUES ARE USED (24 HOUR CLOCK).
                                   ;IF A NEW DAY HAS OCCURRED, THE ZERO FLAG IS RETURNED SET.

                                   ;SMASHES: A,HL  INPUT: NONE     OUTPUT: NONE
                                   ;FLAGS: ALL     MAX TIME:

 4148    21 5F76                   LXI     H,HRS           ;LOAD HOURS ADDRESS IN (HL)
 414B    7E                        MOV     A,M             ;PUT HOURS VALUE IN (A)
 414C    FE 23                     CPI     23H             ;COMPARE TO 11PM EQUIVALENT
 414E    CA 4156                   JZ      NEWDAY          ;PREPARE FOR NEW DAY IF LAST HOUR WAS 11 PM
 4151    C6 01                     ADI     01H             ;ELSE, INCREMENT BY ADDING (TO USE DAA)
 4153    27                        DAA                     ;DECIMAL ADJUST IT
 4154    77                        MOV     M,A             ;PLACE INCREMENTED HOUR BACK IN MEMORY
 4155    C9                        RET                     ;AND RETURN
 4156    AF                NEWDAY: XRA     A               ;CLEAR (A)
 4157    77                        MOV     M,A             ;STORE IN MEMORY AT HOUR LOCATION AT (HL)
 4158    C9                        RET                     ;AND RETURN


                           ;_________________POWER & ENERGY ONE SECOND UPDATE ROUTINE__________________


 4159                      ROLE:   ;UPDATES ALL POWER AND ENERGY VALUES ONCE EACH SECOND.

                                   ;       ROLE is a long routine that calls many subroutines
                                   ;   and has a few natural divisions: power, energy, and costs.
                                   ;   Hence, it is divided with lines at those natural divisions
                                   ;           for ease of presentation and analysis.

                                   ;SMASHES: ALL   INPUTS: NONE   OUTPUTS: UPDATED POWERS & ENERGIES
                                   ;FLAGS: ALL     MAX TIME: ~ 26 MILLISECONDS


                                   ;       -------house array invertor power section-------------

 4159    06 04                     MVI     B,04H           ;(B) = MAX POSSIBLE # BYTES IN SUMS
 415B    11 5FB0                   LXI     D,ARRSUM        ;(DE) = ADDR OF GREATOR
 415E    21 5FAB                   LXI     H,ARRNEG        ;(HL) = ADDR OF LESSOR
 4161    CD 44F6                   CALL    SBTRCT          ;[ARRSUM] = [ARRSUM] - [ARRNEG]
                                                           ;ONE SECOND ARRAY READING SUM AT DFFRNC, (DE)
                                                           ;----ASSUME NO NET NEGATIVE POWER FLOW----

                                   ;SINCE THE ARRAY INVERTOR 220V OUTPUT IS TIED ACROSS THE HOUSE 220V
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                        ;LINES, WE USE 2 x VT(120V) = 2 x 40:1 = 80:1 = VT(220).  CT = 3:1.
                        ;VOLTAGE BIT STRENGTH = 1.5625 V/BIT (THIS IS THE SAME AS THE 120V
                        ;CASE BELOW BECAUSE, THOUGH THE ACTUAL VOLTAGE AMPLITUDE IS DOUBLED
                        ;FROM 120V TO 240V, SO IS THE BIT RANGE FROM 128 TO 256 BITS!).  THE
                        ;CURRENT BIT STRENGTH = .1172 A/BIT.  ==> POWER READING BIT STRENGTH
                        ; = .1831 W/BIT.  AS THE RESULTING POWER IS THE SUM OF 82 PRODUCTS
                        ;TAKEN 4 TIMES EACH SECOND, BUT WE CONVERT FOR DISPLAY ONLY THE TWO
                        ;        MOST SIGNIFICANT BYTES OF A THREE BYTE SUM,
                        ;       THE BIT STRENGTH IN THE FINAL SUM EACH SECOND =
                        ;        0.1831 x [256 / (82 x 4)] = 0.14291159 W/BIT.

4164    06 04           MVI     B,04H   ;(B) = # BYTES IN PRODUCT
4166    3E 08           MVI     A,08H   ;(DE) = DIFFERENCE ADDRESS FROM ABOVE
4168    32 5F71         STA     NUMBIT  ;[NUMBIT] = # BITS IN FACTOR
416B    0E 2A           MVI     C,2AH   ;FIRST INVERTOR POWER FACTOR 2AH/FFH = .1640625
416D    CD 4554         CALL    FACTOR  ;PRODUCT / 256 IS 114.8% OF ACTUAL PWR OUTPUT

4170    11 5F99         LXI     D,DFFRNC ;(DE) = DIFFERENCE ADDRESS
4173    06 04           MVI     B,04H   ;SHIFT 4 BYTE PRODUCT TEMPORARIILY INTO DFFRNC
4175    CD 4370         CALL    SHIFT   ;SO THAT NEXT FACTOR ROUTINE CAN OPERATE ON IT

4178    11 5F99         LXI     D,DFFRNC ;(DE) = ADDR OF PREVIOUS FACTOR ROUTINE RESULT
417B    06 05           MVI     B,05H   ;(B) = # BYTES IN PRODUCT
417D    3E 08           MVI     A,08H
417F    32 5F71         STA     NUMBIT  ;[NUMBIT] = # BITS IN FACTOR
4182    0E DF           MVI     C,0DFH  ;SECOND INVERTOR POWER FACTOR DFH x 2AH / FFH x FFH =
4184    CD 4554         CALL    FACTOR  ;0.14291382 OR 100.0015625% OF ACTUAL PWR OUTPUT

4187    06 03           MVI     B,03H
4189    23              INX     H       ;PRODUCT/256
418A    23              INX     H       ;PRODUCT/(256 x 256) = ARRAY INVERTOR POWER
418B    11 5FB0         LXI     D,ARRSUM
418E    CD 4370         CALL    SHIFT   ;[ARRSUM] = [ARRSUM]x.14291382 = ARRAY POWER (W-SEC)

                ;       -----------------house 2 line feed power section--------------

4191    06 04           MVI     B,04H
4193    11 5FBA         LXI     D,DEMSUM
4196    21 5FB5         LXI     H,DEMNEG
4199    CD 44F6         CALL    SBTRCT          ;NET POWER FLOW AT DFFRNC, (C)= - FLOW FLAG
419C    79              MOV     A,C             ;NEGATIVE POWER FLOW FLAG INTO (ACC)
419D    32 5F72         STA     FLOW            ;FLAG STORED AT FLOW

                        ;FOR HOUSE DEMAND READINGS FROM VOLTAGE TRANSFORMERS OF 40:1,
                        ;CURRENT TRANSFORMERS OF 20:1, 82 POWER READINGS, 4 TIMES/SEC;
                        ;VOLTAGE READING DIGITAL BIT STRENGTH = 1.5625 V/BIT, CURRENT BIT
                        ;STRENGTH = 0.78125 A/BIT ==> POWER READING BIT STRENGTH =
                        ;1.2207 W/BIT.  AS THE RESULTING POWER IS THE SUM OF 82 PRODUCTS
                        ;TAKEN 4 TIMES EACH SECOND, BUT WE CONVERT FOR DISPLAY ONLY THE TWO
                        ;       MOST SIGNIFICANT BYTES OF A THREE BYTE SUM,
                        ;     THE BIT STRENGTH IN THE FINAL SUM EACH SECOND =
                        ;       1.2207 x [256 / (82 x 4)] = 0.9527439 W/BIT.

41A0    06 04           MVI     B,04H   ;# BYTES IN POWER x FACTOR
41A2    3E 08           MVI     A,08H   ;(DE) = NET POWER READING ADDRESS AT DiFFeReNCe
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41A4     32 5F71                  STA     NUMBIT  ;# BITS IN FACTOR STORED AT NUMBIT
41A7     0E 02                    MVI     C,02H   ;FACTOR OF 2 SIMPLY DOUBLES POWER
41A9     CD 4554                  CALL    FACTOR  ;DOUBLE POWER READING

41AC     11 5F99                  LXI     D,DFFRNC ;(DE) = DIFFERENCE ADDRESS
41AF     06 04                    MVI     B,04H   ;SHIFT 4 BYTE RESULT TEMPORARILY INTO DFFRNC
41B1     CD 4370                  CALL    SHIFT   ;SO THAT NEXT FACTOR ROUTINE CAN OPERATE ON IT

41B4     11 5F99                  LXI     D,DFFRNC ;(DE) = ADDR OF PREVIOUS FACTOR ROUTINE RESULT
41B7     06 05                    MVI     B,05H   ;# BYTES IN POWER x FACTOR
41B9     3E 08                    MVI     A,08H
41BB     32 5F71                  STA     NUMBIT  ;# BITS IN FACTOR STORED AT NUMBIT
41BE     0E 8C                    MVI     C,8CH   ;FIRST DEMAND POWER FACTOR 2 x 8CH/256 = 1.09375
41C0     CD 4554                  CALL    FACTOR  ;PRODUCT/256 = 114.8% OF ACTUAL DEMAND POWER.

41C3     11 5F99                  LXI     D,DFFRNC ;(DE) = DIFFERENCE ADDRESS
41C6     06 05                    MVI     B,05H   ;SHIFT 5 BYTE RESULT TEMPORARILY INTO DFFRNC
41C8     CD 4370                  CALL    SHIFT   ;SO THAT NEXT FACTOR ROUTINE CAN OPERATE ON IT

41CB     11 5F99                  LXI     D,DFFRNC ;(DE) = ADDR OF PREVIOUS FACTOR ROUTINE RESULT
41CE     06 06                    MVI     B,06H   ;# BYTES IN POWER x FACTOR
41D0     3E 08                    MVI     A,08H
41D2     32 5F71                  STA     NUMBIT  ;# BITS IN FACTOR STORED AT NUMBIT
41D5     0E DF                    MVI     C,0DFH  ;SECOND DEMAND POWER FACTOR 2 x 8CH x DFH / 256 x 256
41D7     CD 4554                  CALL    FACTOR  ; = 0.9527588 OR 100.0015625% OF ACTUAL DEMAND POWER.

41DA     06 03                    MVI     B,03H   ;LENGTH OF FACTORED POWER
41DC     23                       INX     H
41DD     23                       INX     H       ;SHIFT PRODUCT/(256 x 256) INTO DEMAND POWER LOCATION
41DE     11 5FBA                  LXI     D,DEMSUM
41E1     CD 4370                  CALL    SHIFT   ;[DEMSUM] = [DEMSUM]x.9527588= NET POWER FLOW (W-SEC)


                         ;        ---------------direction of net power flow section--------------

41E4     3A 5F72                  LDA     FLOW    ;RECOVER POWER FLOW FLAG
41E7     1F                       RAR             ;FLAG INTO CARRY
41E8     DA 41F9                  JC      ARRMOR  ;IF NET FLOW IS NEGATIVE, GO TO ARRMOR, ELSE:
                                                  ;HOUSE POWER DEMAND > ARRAY POWER SUPPLY &
                                                  ;[DEMSUM] = NET (+) PWR FLOW FROM UTILITY.
                                                  ;SO, POWER DEMAND = ARRAY SUPPLIED + UTILITY SUPPLIED
41EB     06 05                    MVI     B,05H
41ED     21 5FBA                  LXI     H,DEMSUM        ;(HL) = ADDR OF FINAL SUM
41F0     11 5FB0                  LXI     D,ARRSUM        ;(DE) = ADDR OF STRING TO BE ADDED
41F3     CD 437B                  CALL    ADDING          ;[DEMSUM] = [NET PWR FLOW + ARRSUM] = DEMAND
41F6     C3 420F                  JMP     ROLLON          ;         (DEMAND IN WATT SECONDS)


41F9                     ARRMOR:          ;ARRAY POWER SUPPLY > HOUSE POWER DEMAND &
                                          ;[DEMSUM] = NET (-) PWR FLOW TO UTILTIY.
                                          ;SO, POWER DEMAND = ARRAY POWER - POWER SOLD TO UTILITY
41F9     06 04                    MVI     B,04H
41FB     11 5FB0                  LXI     D,ARRSUM        ;(DE) = ADDR OF GREATOR
41FE     21 5FBA                  LXI     H,DEMSUM        ;(HL) = ADDR OF LESSOR  (NET NEG PWR FLOW)
4201     CD 44F6                  CALL    SBTRCT          ;(DFFRNC) = ARRAY - NET NEG PWR FLOW
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4204    06 04                   MVI     B,04H
4206    11 5FBA                 LXI     D,DEMSUM
4209    21 5F99                 LXI     H,DFFRNC
420C    CD 4370                 CALL    SHIFT           ;[DEMSUM] = [ARRSUM - NET PWR FLOW] = DEMAND
                                                        ;        (DEMAND IN WATT SECONDS)

                        ;   ---------------powers moved into displayable locations------------

420F    2A 5F92         ROLLON: LHLD    DEMPWR
4212    EB                      XCHG            ;(DE) = TODAY'S DEMAND ADDRESS
4213    21 5FBA                 LXI     H,DEMSUM ;(HL) = DEMSUM ADDRESS
4216    06 03                   MVI     B,03H   ;(B) = # BYTES TO BE SHIFTED TO STORAGE
4218    CD 4370                 CALL    SHIFT   ;[DEMPWR] = [DEMSUM]

421B    2A 5F90                 LHLD    ARRPWR
421E    EB                      XCHG
421F    21 5FB0                 LXI     H,ARRSUM
4222    06 03                   MVI     B,03H
4224    CD 4370                 CALL    SHIFT   ;[ARRPWR] = [ARRSUM]

                        ;    --------energy in kWh calculated from average power in watts----------

4227    2A 5F8E                 LHLD    DEMENG
422A    11 5FBA                 LXI     D,DEMSUM
422D    CD 423C                 CALL    ENERGY

4230    2A 5F8C                 LHLD    ARRENG
4233    11 5FB0                 LXI     D,ARRSUM
4236    CD 423C                 CALL    ENERGY
4239    C3 426F                 JMP     NOWERE

423C                    ENERGY: ;SINCE WE HAVE POWER READINGS IN WATT-SECONDS AT ONE BYTE
                                ;UP FROM THE LEAST SIG BYTE (XXXPWR/256), BUT WE NEED WATT-HOURS,
                                ;WE CAN LOOK 3 BYTES UP FROM LSBYTE ON THE 5 BYTE ENERGY SUM.
                                ;THE APPROPRIATE MULTIPLIER FOR THE ENERGY INCREMENT IN THIS CASE IS
                                ;          256x256/3600 = 18.2044 (W-SEC => W-HRS)

                                ;SMASHES: ALL   INPUTS: (DE) = ADDRESS OF POWER IN WATT-SECONDS
                                ;FLAGS: ALL             (HL) = ADDRESS OF ENERGY SUM
                                ;MAX TIME:      OUTPUTS: ENERGY INCREMENT (kWh) ADDED TO ENERGY SUM

423C    E5                      PUSH    H       ;XXXENG ENERGY SUM ADDRESS ONTO STACK
423D    D5                      PUSH    D       ;XXXSUM POWER/ENERGY INCREMENT ADDR ONTO STACK
423E    06 04                   MVI     B,04H   ;# BYTES IN POWER SUM x FACTOR
4240    0E 14                   MVI     C,14H   ;FIRST ENERGY FACTOR = 20D
4242    3E 08                   MVI     A,08H   ;       (DE) = BINARY POWER LOCATION
4244    32 5F71                 STA     NUMBIT  ;# BITS IN ENERGY FACTOR STORED AT NUMBIT
4247    CD 4554                 CALL    FACTOR  ;MULTIPLY BINARY POWER SUM BY ENERGY FACTOR

424A    11 5F99                 LXI     D,DFFRNC ;(DE) = DIFFERENCE ADDRESS
424D    06 04                   MVI     B,04H   ;SHIFT 4 BYTE RESULT TEMPORARILY INTO DFFRNC
424F    CD 4370                 CALL    SHIFT   ;SO THAT NEXT FACTOR ROUTINE CAN OPERATE ON IT
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4252    11 5F99             LXI     D,DFFRNC ;(DE) = ADDR OF PREVIOUS FACTOR ROUTINE RESULT
4255    06 05               MVI     B,05H   ;# BYTES IN ENERGY INCREMENT x FACTOR
4257    3E 08               MVI     A,08H
4259    32 5F71             STA     NUMBIT  ;# BITS IN FACTOR STORED AT NUMBIT
425C    0E E9               MVI     C,0E9H  ;SECOND ENERGY FACTOR 20 x 249/256 = 18.203
425E    CD 4554             CALL    FACTOR  ;PRODUCT/256 = 99.99275% OF 18.2044 (CORRECT FACTOR).
                                            ;GIVEN THAT THE POWER SUMS REPORT 100.0015625% OF
                                            ;OF ACTUAL POWER, THE COMBINED ACCURACY BECOMES
                                            ;99.994314% OF ACTUAL ENERGY!

4261    06 04               MVI     B,04H   ;LENGTH OF FACTORED ENERGY INCREMENT
4263    D1                  POP     D       ;(DE) = XXXSUM ADDRESS FOR ENERGY INCREMENT
4264    23                  INX     H       ;PRODUCT/256 = ENERGY INCREMENT
4265    CD 4370             CALL    SHIFT   ;[XXXSUM] = [XXXSUM] x 18.203 (ENERGY INCREMENT)
4268    E1                  POP     H       ;(HL) = ENERGY SUM ADDRESS, (DE) = ADDR OF ENERGY INC
4269    06 05               MVI     B,05H
426B    CD 437B             CALL    ADDING  ;[XXXENG] = [XXXENG] + [XXXSUM]
426E    C9                  RET

                    ;    ----------------differential energy and cost routines----------------

426F    06 04       NOWERE: MVI     B,04H
4271    11 5FBA             LXI     D,DEMSUM
4274    21 5FB0             LXI     H,ARRSUM
4277    CD 44F6             CALL    SBTRCT  ;[DFFRNC] = XXOVXX INCREMENT, CARRY SET IF ARR>DEM
                                            ;(DE) = DIFFERENCE ADDRESS
427A    DA 428E             JC      BABES   ;IF ARRAY POWER > HOUSE DEMAND ADD, GO TO BABES
                                            ;ELSE,

                                    ; ----------ADD TO DEMAND OVER ARRAY SUMS------------
427D    2A 5F86             LHLD    DOACST
4280    4D                  MOV     C,L     ;(BC) = DEMAND OVER ARRAY COST SUM ADDRESS
4281    44                  MOV     B,H
4282    2A 5F8A             LHLD    DMOVAR  ;(HL) = DEMAND/ARRAY ADDR FOR ENERGY INCREMENT
4285    3A 5F5A             LDA     DEMCHG  ;USE UTILITY RATE TO COMPUTE COST INCREMENT
4288    CD 42D1             CALL    CSTINC  ;DEMAND OVER ARRAY ENERGY & COST SUMS INCREMENTED
428B    C3 429C             JMP     EREWON


                                    ; -----------ADD TO ARRAY OVER DEMAND SUMS------------
428E    2A 5F84     BABES:  LHLD    AODCST
4291    4D                  MOV     C,L     ;(BC) = ARRAY OVER DEMAND VALUE SUM ADDRESS
4292    44                  MOV     B,H
4293    2A 5F88             LHLD    AROVDM  ;(HL) = ARRAY/DEM ADDR FOR ENERGY INCREMENT
4296    3A 5F5B             LDA     BUYBAK  ;USE BUYBACK RATE TO COMPUTE VALUE INCREMENT
4299    CD 42D1             CALL    CSTINC  ;ARRAY OVER DEMAND ENERGY & COST SUMS INCREMENTED


                                    ; ------------CALCULATE COST w/o ARRAY-----------------
429C    3A 5F5A     EREWON: LDA     DEMCHG
429F    32 5F5C             STA     RATE    ;DEMAND CHARGE RATE FACTOR INTO RATE LOCATION
42A2    2A 5F82             LHLD    DEMCST
42A5    4D                  MOV     C,L     ;(BC) = DEMAND COST SUM ADDRESS
42A6    44                  MOV     B,H
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42A7    11 5FBA                  LXI     D,DEMSUM ;(DE) = DEMAND ENERGY INCREMENT ADDRESS
42AA    CD 42DD                  CALL    CSTINK  ;[DEMCST] = [DEMCST + COST INCREMENT]

                         ;  -------------------net daily bill calculation---------------------
42AD    06 05                    MVI     B,05H
42AF    2A 5F86                  LHLD    DOACST
42B2    EB                       XCHG            ;(DE) = DEM/ARR COST ADDRESS
42B3    2A 5F84                  LHLD    AODCST  ;(HL) = ARR/DEM VALUE ADDRESS
42B6    CD 44F6                  CALL    SBTRCT  ;(DE) = DIFFERENCE ADDRESS, CARRY SET IF VALUE > COST

42B9    DA 42C1                  JC      FLAG
42BC    AF                       XRA     A       ;IF DAILY NET COST > 0, [NETCST] = [00 XX XX XX XX]
42BD    12                       STAX    D
42BE    C3 42C4                  JMP     FINISH

42C1    3E 01            FLAG:   MVI     A,01H   ;IF DAILY NET COST < 0, [NETCST] = [01 XX XX XX XX]
42C3    12                       STAX    D

42C4    06 05            FINISH: MVI     B,05H
42C6    2A 5F80                  LHLD    NETCST
42C9    EB                       XCHG            ;(DE) = NET COST ADDR, (HL) = COST DIFFERENCE ADDR
42CA    CD 4370                  CALL    SHIFT   ;[NETCST] = NET DAILY COST WITH FLAG FOR MINUS BILL
42CD    CD 42F5                  CALL    CLRSUM  ;CLEAR ALL SUMS FOR NEXT SECONDS DATA ACQUISISTION
42D0    C9                       RET             ;RETURN FROM ROLE


                         ;-------------------------------------------------------------------------

42D1                     CSTINC: ;CoST INCrement ADDS THE NET ENERGY FLOW TO A DIFFERENTIAL ENERGY SUM
                                 ;AND ADDS ITS COST(VALUE) TO A DIFFERENTIAL COST SUM.

                                 ;SMASHES: ALL    INPUTS: (BC) = DIFFERENTIAL COST SUM ADDRESS
                                 ;FLAGS: ALL              (HL) = DIFFERENTIAL ENERGY SUM ADDRESS
                                 ;MAX TIME:               (ACC) = ENERGY PRICE ($/kWh)
                                 ; OUTPUTS: DIFFERENTIAL COST AND ENERGY SUMS INCREMENTED

42D1    32 5F5C                  STA     RATE    ;MOVE APPROPRIATE RATE FROM ACC INTO RATE
42D4    C5                       PUSH    B       ;XOXCST COST (VALUE) SUM ADDRESS ONTO STACK
42D5    06 05                    MVI     B,05H
42D7    CD 437B                  CALL    ADDING  ;[XXOVXX] = [XXOVXX] + ENERGY INCREMENT
42DA    C3 42DE                  JMP     CSTCNT

42DD    C5               CSTINK: PUSH    B       ;XXXCST COST (VALUE) SUM ADDRESS ONTO STACK

42DE    06 05            CSTCNT: MVI     B,05H   ;(B) = # BYTES IN ENERGY INCREMENT x FACTOR
42E0    3E 08                    MVI     A,08H   ;[NUMBIT] = # BITS IN FACTOR
42E2    32 5F71                  STA     NUMBIT
42E5    3A 5F5C                  LDA     RATE    ;(C) = ELECTRICITY RATE FACTOR
42E8    4F                       MOV     C,A
                                                 ;(DE) = LOCATION OF ENERGY INCREMENT
42E9    CD 4554                  CALL    FACTOR  ;(HL) = ENERGY COST (VALUE) INCREMENT ADDR
42EC    23                       INX     H       ;PRODUCT/256 = ENERGY COST (VALUE) INCREMENT

42ED    D1                       POP     D       ;(DE) = XOXCST COST (VALUE) SUM ADDRESS
42EE    EB                       XCHG            ;(DE) INCREMENT ADDR, (HL) = COST (VALUE) SUM ADDR
42EF    06 05                    MVI     B,05H   ;(B) = LENGTH OF SUM, IN BYTES
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```
  42F1    CD 437B                     CALL    ADDING  ;[XOXCST] = [XOXCST] + COST INCREMENT
  42F4    C9                          RET

                             ;-----------------------------------------------------------------------

  42F5                       CLRSUM: ;CLEARS ALL TEMPORARY POWER READING SUMS FOR NEXT SECOND

                                     ;SMASHES: B,HL  INPUTS: NONE   OUTPUTS: CLEARED POWER SUMS
                                     ;FLAGS: ALL     MAX TIME:

  42F5    21 5FBA                     LXI     H,DEMSUM
  42F8    06 05                       MVI     B,05H
  42FA    CD 438A                     CALL    CLR     ;[DEMSUM] = [00 00 00 00 00]

  42FD    21 5FB0                     LXI     H,ARRSUM
  4300    06 05                       MVI     B,05H
  4302    CD 438A                     CALL    CLR     ;[ARRSUM] = [00 00 00 00 00]

  4305    21 5FB5                     LXI     H,DEMNEG
  4308    06 05                       MVI     B,05H
  430A    CD 438A                     CALL    CLR     ;[DEMNEG] = [00 00 00 00 00]

  430D    21 5FAB                     LXI     H,ARRNEG
  4310    06 05                       MVI     B,05H
  4312    CD 438A                     CALL    CLR     ;[ARRNEG] = [00 00 00 00 00]

  4315    C9                          RET
                             ;-------------------------------------------------------------------

  4316                       RIPPLE: ;MOVES 30H BYTES UP IN MEMORY FOR A NEW DAY,S CUMULATIVE VALUES

                                     ;SMASHES: BC,HL   INPUTS: NONE   MAX TIME:
                                     ;FLAGS: ALL       OUTPUTS: NEW DAY ADDR = DAY + 30H
                                     ;     ALL NEW MEMORY LOCATIONS FOR CUMULATIVE VALUES ARE CLEARED

  4316    2A 5F68                     LHLD    LSTDAY  ;(BC) = LSTDAY
  4319    44                          MOV     B,H
  431A    4D                          MOV     C,L
  431B    2A 5F66                     LHLD    DAY     ;(HL) = DAY
  431E    CD 409D                     CALL    CMPBH   ;ZERO FLAG SET IF DAY = LASTDAY
  4321    CA 432E                     JZ      TUCK

  4324    01 0030                     LXI     B,0030H
  4327    09                          DAD     B       ;(HL) = (HL) + 30H
  4328    22 5F66                     SHLD    DAY     ;DAY = DAY + 30H
  432B    C3 4334                     JMP     CLRMEM

  432E    2A 5F6A            TUCK:    LHLD    DAY1
  4331    22 5F66                     SHLD    DAY     ;DAY = DAY1

  4334    CD 4340            CLRMEM:  CALL    MEMLAB
  4337    06 30                       MVI     B,30H
  4339    CD 438A                     CALL    CLR     ;ALL 48 NEW MEM LOCATIONS CLEARED
  433C    CD 4551                     CALL    INDEX   ;AT MIDNIGHT DISPLAY NEW DAY'S VALUES
```

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 433F    C9                       RET

                          ;------------------------------------------------------------------------

 4340                     MEMLAB: ;MEMory LABel ASSIGNS LABELS TO ALL MEMORY LOCATIONS FOR A NEW DAY

                                  ;SMASHES: BC     INPUTS: (HL) = NEW BASE DAY ADDRESS
                                  ;FLAGS: ALL      OUTPUTS: NEW MEMORY LABELS FOR CUMULATIVE ADDRESSES
                                  ;MAX TIME:

 4340    E5                       PUSH    H
 4341    22 5F92                  SHLD    DEMPWR  ;[DEMPWR] = TODAY'S BASE ADDRESS
 4344    01 0003                  LXI     B,0003H
 4347    09                       DAD     B
 4348    22 5F90                  SHLD    ARRPWR
 434B    09                       DAD     B
 434C    22 5F8E                  SHLD    DEMENG  ;DEMAND ENERGY DAILY SUM
 434F    01 0005                  LXI     B,0005H
 4352    09                       DAD     B
 4353    22 5F8C                  SHLD    ARRENG  ;ARRAY ENERGY DAILY SUM
 4356    09                       DAD     B
 4357    22 5F8A                  SHLD    DMOVAR  ;NET DEMAND IN EXCESS OF ARRAY ENERGY SUM
 435A    09                       DAD     B
 435B    22 5F88                  SHLD    AROVDM  ;NET ARRAY IN EXCESS OF DEMAND ENERGY SUM
 435E    09                       DAD     B
 435F    22 5F86                  SHLD    DOACST  ;COST OF ENERGY BOUGHT SUM
 4362    09                       DAD     B
 4363    22 5F84                  SHLD    AODCST  ;VALUE OF ENERGY SOLD SUM
 4366    09                       DAD     B
 4367    22 5F82                  SHLD    DEMCST  ;'WOULD BE' COST OF ENERGY DEMAND w/o ARRAY
 436A    09                       DAD     B
 436B    22 5F80                  SHLD    NETCST  ;NET DIFFERENCE OF COSTS DAILY SUM
 436E    E1                       POP     H
 436F    C9                       RET


                          ;------------------------------------------------------------------------


 4370                     SHIFT:  ;MOVES A DATA STRING OF (B) BYTES FROM ADDRESS AT (HL)
                                  ;                 TO ADDRESS AT (DE).

                                  ;SMASHES: B,HL  INPUTS: (B) = LENGTH OF STRING IN BYTES
                                  ;FLAGS: ALL             (HL) = ADDR OF QUANTITY TO BE SHIFTED
                                  ;MAX TIME:              (DE) = ADDR OF RECEIVING LOCATION
                                  ;OUTPUTS: (DE) = RECEIVING LOCATION

 4370    D5                       PUSH    D       ;SAVE (DE) RECEIVING LOCATION ON STACK
 4371    7E               SHFT:   MOV     A,M
 4372    12                       STAX    D
 4373    23                       INX     H
 4374    13                       INX     D
 4375    05                       DCR     B
 4376    C2 4371                  JNZ     SHFT
 4379    D1                       POP     D       ;RETURN WITH RECEIVING LOCATION IN (DE)
```

```
 437A    C9                         RET

                            ;-----------------------------------------------------------------------

 437B                       ADDING: ;ADDS STRING OF LENGTH (B) BYTES AT (DE) TO SUM AT (HL).

                                    ;SMASHES: B      INPUTS: (B) = LENGTH OF STRING IN BYTES
                                    ;FLAGS: ALL              (HL) = ADDR OF FINAL SUM
                                    ;MAX TIME:               (DE) = ADDR OF STRING TO BE ADDED
                                    ;OUTPUTS: (HL) = ADDR OF FINAL SUM, (DE) = ADDR OF ADDED STRING

 437B    D5                         PUSH    D
 437C    E5                         PUSH    H
 437D    A7                         ANA     A       ;CLEAR CARRY
 437E    1A                 AD:     LDAX    D       ;BYTE FROM ADDEND
 437F    8E                         ADC     M       ;ADDED TO FINAL SUM
 4380    77                         MOV     M,A     ;STORE RESULT
 4381    13                         INX     D
 4382    23                         INX     H
 4383    05                         DCR     B
 4384    C2 437E                    JNZ     AD
 4387    E1                         POP     H
 4388    D1                         POP     D
 4389    C9                         RET

                            ;-----------------------------------------------------------------------

 438A                       CLR:    ;CLEARS A STRING OF (B) BYTES STARTING AT (HL)

                                    ;SMASHES: B,HL  INPUTS: (B) = # BYTES TO BE CLEARED
                                    ;FLAGS: ALL             (HL) = ADDR OF FIRST BYTE TO BE CLEARED

 438A    AF                         XRA     A
 438B    77                 AGAIN:  MOV     M,A
 438C    23                         INX     H
 438D    05                         DCR     B
 438E    C2 438B                    JNZ     AGAIN
 4391    C9                         RET


                            ;---------------------- POWER: HOUSE LINES 1 & 2 -------------------------


 4392    21 5F5D            DEMND1: LXI     H,IMUX
 4395    36 08                      MVI     M,MUXI1         ;LOAD AMPS 1 CHANNEL UNTO IMUX
 4397    21 5F5E                    LXI     H,VMUX
 439A    36 00                      MVI     M,MUXV1         ;LOAD VOLTS 1 CHANNEL INTO VMUX
 439C    21 5FBA                    LXI     H,DEMSUM        ;(HL) = DEMAND POSITIVE SUM ADDRESS
 439F    11 5FB5                    LXI     D,DEMNEG        ;(DE) = DEMAND NEGATIVE SUM ADDRESS
 43A2    CD 43BA                    CALL    POWER           ;TAKE POWER READINGS OVER ONE FULL CYCLE
 43A5    C9                         RET

 43A6    21 5F5D            DEMND2: LXI     H,IMUX
```

```
43A9    36 18                  MVI     M,MUXI2         ;LOAD AMPS 2 CHANNEL INTO IMUX
43AB    21 5F5E                LXI     H,VMUX
43AE    36 10                  MVI     M,MUXV2         ;LOAD VOLTS 2 CHANNEL INTO VMUX
43B0    21 5FBA                LXI     H,DEMSUM        ;ADD ALL POS INSTANTANEOUS POWERS TO [DEMSUM]
43B3    11 5FB5                LXI     D,DEMNEG        ;ADD ALL NEG INSTANTANEOUS POWERS TO [DEMNEG]
43B6    CD 43BA                CALL    POWER           ;TAKE POWER READINGS OVER ONE FULL CYCLE
43B9    C9                     RET

                       ;-----------------------------------------------------------------------

43BA                   POWER:  ;TAKES ALTERNATING CURRENT AND VOLTAGE READINGS FROM SELECTED LINES
                               ;OVER ONE FULL VOLTAGE CYCLE (165 TOTAL READINGS:83 amps & 82 volts).
                               ;THIS ROUTINE ASSUMES THAT THE A DIGITAL VALUE OF 80H CORRESPONDS TO
                               ;GROUND AT THE ANALOG INPUT AND SO, TREATS VALUES < 80H AS NEGATIVE.
                               ;EACH VOLTAGE IS MULTIPLIED BY THE MEDIAN VALUE OF IMMEDIATELY
                               ;ADJACENT CURRENT READINGS RESULTING IN 82 PRODUCTS.  THE POSITIVE &
                               ;NEGATIVE PRODUCTS ARE SUMMED SEPERATELY AT ADDRESSES SPECIFIED IN
                               ;(HL) AND (DE), RESPECTIVELY.

                               ;SMASHES: ALL   INPUTS: [IMUX] = MULTIPLEXOR CHANNEL FOR AMPS SIGNAL
                               ;FLAGS: ALL             [VMUX] = MUX CHANNEL FOR VOLTAGE SIGNAL
                               ;MAX TIME:  READ 17mS   (HL)   =  POSITIVE POWER SUM ADDRESS
                               ;           COMPUTE 30mS (DE)  =  NEGATIVE POWER SUM ADDRESS
                               ;OUTPUTS: UPDATED POSITIVE AND NEGATIVE POWER SUMS


43BA    D5                     PUSH    D       ;FINAL NEGATIVE POWER LOCATION ONTO STACK
43BB    E5                     PUSH    H       ;FINAL POWER LOCATION ONTO STACK
43BC    21 5E00        HISTRY: LXI     H,5E00H ;INITIALIZE V/A READING HISTORY POINTER

                       ;***MAIN POWER ROUTINE: ' READ ' loop stores raw i & v readings in memory-----

43BF    3A 5F5D        START:  LDA     IMUX    ;CURRENT INTO 5E00H BLOC EVENS TIL 5EA4H
43C2    CD 43DB                CALL    READ
43C5    77                     MOV     M,A
43C6    23                     INX     H
43C7    3E A5                  MVI     A,0A5H  ;READINGS OVER ONE FULL VOLTAGE CYCLE (7MC)
43C9    BD                     CMP     L       ;(4 MACHINE CYCLES)
43CA    CA 4427                JZ      CMPUTE  ;WHEN DONE, COMPUTE POWERS (10 MC)

43CD    3A 5F5E                LDA     VMUX    ;VOLTAGE INTO 5E00H BLOC ODDS TIL 5EA3H
43D0    CD 43DB                CALL    READ
43D3    77                     MOV     M,A
43D4    23                     INX     H
                                               ;THREE DELAY TRIM COMMANDS TAKE AS MUCH TIME AS THE
43D5    00                     NOP             ;TEST FOR LAST READING DOES ABOVE.
43D6    00                     NOP             ;'NOP'S DEMAND 4 MACHINE CYCLES EACH.
43D7    00                     NOP             ;THESE TRIMS ENSURE THAT VOLTS & AMPS READINGS ARE
                                               ;MADE EVERY .1016 mSEC: NO PHASE SHIFT IS INTRODUCED.
                                               ;AND NO PHASE SHIFT IS INTRODUCED.
43D8    C3 43BF                JMP     START   ;(10 MC)

                       ;-----------------------------------------------------------------------

43DB                   READ:   ;RETURNS WITH A DIGITAL VALUE IN (ACC) FOR AN ANALOG SIGNAL AT
                               ;THE MUX CHANNEL SPECIFIED IN (ACC) WHEN THE SUBROUTINE IS CALLED.
```

```
                              ;SMASHES: B     INPUTS: (A) = MUX CHANNEL FOR A/D CONVERSION (READ)
                              ;FLAGS: ALL     OUTPUTS: (A) = DIGITAL VALUE OF SPECIFIED LINE SIGNAL
                              ;MAX TIME:

 43DB    47                   MOV     B,A
 43DC    3A 5F77              LDA     OUTREG          ;SAMPLE MODE AND DEFAULT MUX
 43DF    E6 C7                ANI     11000111B
 43E1    B0                   ORA     B               ;OR IN MUX CHANNEL
 43E2    D3 12                OUT     12H
 43E4    32 5F77              STA     OUTREG          ;MUX CHANNEL + SAMPLE MODE AT OUTREG
 43E7    E6 FB                ANI     11111011B       ;ASSERT HOLD MODE
 43E9    D3 12                OUT     12H
 43EB    32 A000              STA     ADC             ;START A READ
 43EE    DB 11       KEEPON:  IN      11H
 43F0    E6 20                ANI     00100000B       ;ISOLATE -BUSY BIT
 43F2    CA 43EE              JZ      KEEPON          ;LOOP TIL READY
 43F5    3A 5F77              LDA     OUTREG          ;REASSERT SAMPLE MODE + MUX CHANNEL
 43F8    F6 04                ORI     00000100B       ;MAKE SURE OF SAMPLE MODE
 43FA    D3 12                OUT     12H
 43FC    3A A000              LDA     ADC             ;RETURN WITH DIGITAL VALUE IN ACC
 43FF    C9                   RET

                     ;---------------------------------------------------------------------------

 4400                DIGJST:  ;RAW READINGS STORED IN MEMORY IN CLUSTERS.  POWER IS CALCULATED BY
                              ;MULTIPLYING THE AVERAGE OF PRE + POST READINGS BY THE INTERMEDIATE.
                              ;DIGital JuSTification JUSTIFIES AN INTERMEDIATE READING TO 80H
                              ;(SEE 'JUSTIS' BELOW), COUNTS # OF NEGATIVE ARGUMENTS IN (B),
                              ;AND LOADS RESULT INTO (C).

                              ;SMASHES: A,B,C,E        INPUTS: (HL) = ADDRESS OF POST READING
                              ;FLAGS: ALL                       (B) NEGATIVE ARGUMENT COUNTER
                              ;MAX TIME                OUTPUTS: (C) = |INTERMED READING - 80H|
                              ;                          (B) IS INCREMENTED IF READING IS NEGATIVE
                              ;                                 INPUT (HL) IS PRESERVED

 4400    2B                   DCX     H       ;(HL) = ADDRESS OF INTERMEDIATE READING ( V OR I)
 4401    7E                   MOV     A,M
 4402    CD 4408              CALL    JUSTIS  ;(ACC) = |READING - 80H|, B REG INC IFF < 0
 4405    4F                   MOV     C,A     ;(C) = |READING - 80H|
 4406    23                   INX     H       ;(HL) = ADDRESS OF NEXT READING
 4407    C9                   RET

                     ;---------------------------------------------------------------------------

 4408                JUSTIS:  ;JUSTIFIES RAW READINGS TO |X - 80H| & INCREMENTS (B) IF NEGATIVE.

                              ;SMASHES: E     INPUTS: (A) = RAW DIGITAL READING
                              ;FLAGS: ALL     OUTPUTS: (A) = JUSTIFIED READING MAGNITUDE: |X-80H|
                              ;                        (B) INCREMENTED IF READING IS < 80H

 4408    5F                   MOV     E,A
 4409    D6 80                SUI     80H
 440B    F0                   RP
 440C    3E 80                MVI     A,80H
```

```
440E    93                      SUB     E
440F    04                      INR     B       ;COUNT NEGATIVE ARGUMENTS IN B REGISTER
4410    C9                      RET

                        ;-----------------------------------------------------------------------

4411                    BYTBYT: ;THIS 1BYTE x 1BYTE MULTIPLICATION ROUTINE GIVES POWER IN (BC) FOR
                                ;VOLTAGE IN (C) AND CURRENT IN (D) REGISTERS, RESPECTIVELY.

                                ;SMASHES: A,B,E         INPUTS: (C) = ONE BYTE MULTIPLIER
                                ;FLAGS: ALL                     (D) = ONE BYTE MULTIPLICAND
                                ;MAX TIME:              OUTPUTS: (BC) = PRODUCT

4411    06 00                   MVI     B,00H
4413    1E 08                   MVI     E,08H

4415    79                      MOV     A,C
4416    1F                      RAR
4417    4F                      MOV     C,A

4418    78              MULTK:  MOV     A,B
4419    D2 441D                 JNC     CNTK
441C    82                      ADD     D
441D    1F              CNTK:   RAR
441E    47                      MOV     B,A
441F    79                      MOV     A,C
4420    1F                      RAR
4421    4F                      MOV     C,A
4422    1D                      DCR     E
4423    C8                      RZ
4424    C3 4418                 JMP     MULTK

                        ;-----------------------------------------------------------------------

                        ;***MAIN POWER ROUTINE: 'compute' loop multiplies raw i & v readings to get
                        ;                       82 instantaneous powers for each voltage cycle.
                        ;                       Positive and negative powers are summed in
                        ;                       seperate locations specified by calling the program.

4427    21 5E00         CMPUTE: LXI     H,5E00H ;(HL) = STARTING LOCATION FOR V/A READINGS
442A    06 00           POWIE:  MVI     B,00H   ;CLEAR B REGISTER
442C    56                      MOV     D,M     ;FIRST CURRENT READING
442D    23                      INX     H
442E    23                      INX     H
442F    7E                      MOV     A,M     ;NEXT CURRENT
4430    82                      ADD     D       ;(ACC) = SUM OF TWO ADJACENT CURRENT READINGS
4431    1F                      RAR             ;(ACC) = SUM / 2 ==> AVERAGE CURRENT
4432    CD 4408                 CALL    JUSTIS  ;I AVG MAGNITUDE IN (ACC), (B) INC IFF Iavg < 0
4435    57                      MOV     D,A     ;|Iavg| INTO (D) REG

4436    CD 4400                 CALL    DIGJST  ;MEDIAN VOLTAGE READING JUSTIFIED.  B REG INC IFF < 0

4439    C5                      PUSH    B       ;SAVE B REG ON STACK
443A    CD 4411                 CALL    BYTBYT  ;(BC) = POWER

443D    D1                      POP     D       ;01H IN D REG IF PRODUCT IS NEGATIVE
```

```
443E    7A                      MOV     A,D
443F    D6 01                   SUI     01H     ;ZERO FLAG SET IF POWER IS NEGATIVE
4441    CA 444C                 JZ      PWRN

4444    E3                      XTHL            ;(SP) = NEXT i ADDR, (HL) = FINAL SUM ADDR
4445    CD 445E                 CALL    ADDINC  ;ADD (+) POWER READING TO FINAL (+) POWER SUM
4448    E3                      XTHL            ;(HL) = NEXT i ADDR, (SP) = FINAL SUM ADDR
                                                ;                   (SP) + 2 = XXXNEG ADDR
4449    C3 4455                 JMP     TST

444C    EB              PWRN:   XCHG            ;SAVE NEXT i ADDRESS IN (DE)
444D    E1                      POP     H
444E    E3                      XTHL            ;(HL) = XXXNEG ADDRESS, (SP) = FINAL SUM ADDR
444F    CD 445E                 CALL    ADDINC  ;ADD (-) POWER READING TO NEGATIVE POWER SUM
4452    E3                      XTHL
4453    E5                      PUSH    H       ;(SP) = FINAL SUM ADDR, (SP)+2 = XXXNEG ADDR
4454    EB                      XCHG            ;(HL) = NEXT i ADDRESS RESCUED FROM (DE)

4455    3E A4           TST:    MVI     A,0A4H  ;82 POWER READINGS
4457    BD                      CMP     L
4458    C2 442A                 JNZ     POWIE   ;DO ALL 82 POWERS BEFORE RETURNING
445B    E1                      POP     H       ;REMOVE FINAL SUM ADDR AND XXXNEG ADDR FROM STACK
445C    E1                      POP     H       ;(SP) & (SP) + 2, RESPECTIVELY

445D    C9                      RET             ;RETURN FROM POWER ROUTINE

                        ;-----------------------------------------------------------------------

445E                    ADDINC: ;ADD INCrement ADDS THE CONTENTS OF (BC) TO THE CONTENTS OF
                                ;THE MEMORY LOCATION AT (HL).

                                ;SMASHES: BC            INPUTS: (BC) = INCREMENT TO BE ADDED
                                ;FLAGS: ALL                     (HL) = LOCATION OF SUM
                                ;MAX TIME:              OUTPUTS: (BC) IS ADDED TO SUM AT (HL)

445E    E5                      PUSH    H       ;4 BYTE ROUTINE ADDS (BC) TO ADDRESS IN (HL)
445F    A7                      ANA     A       ;CLEAR CARRY
4460    79                      MOV     A,C     ;LSBYTE ADDED TO LSBYTE OF SUM
4461    8E                      ADC     M
4462    77                      MOV     M,A     ;STORED AT LSBYTE OF SUM
4463    23                      INX     H
4464    78                      MOV     A,B     ;NEXT BYTE ADDED TO NEXT BYTE OF SUM
4465    8E                      ADC     M
4466    77                      MOV     M,A
4467    23                      INX     H
4468    3E 00                   MVI     A,00H   ;CARRY ADDED TO NEXT BYTE OF SUM
446A    8E                      ADC     M
446B    77                      MOV     M,A
446C    23                      INX     H
446D    3E 00                   MVI     A,00H   ;CARRY ADDED TO FOURTH BYTE OF SUM
446F    8E                      ADC     M
4470    77                      MOV     M,A
4471    E1                      POP     H
4472    C9                      RET
                        ;----------------------POWER: ARRAY INVERTOR LINE-------------------------
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4473                    ARRAY:  ;THE ARRAY POWER ROUTINE CANNOT USE THE SAME LOOPS AS THE
                                ;HOUSE LINE ROUTINE BECAUSE SINCE THE ARRAY IS A 240V DEVICE,
                                ;THE PROGRAM MUST USE THE VOLTAGE DIFFERENCE BETWEEN THE TWO HOUSE
                                ;LINES AS THE INVERTOR VOLTAGE.  SINCE THE VOLTAGES MUST BE ADDED
                                ;AND THE MULTIPLEXOR CHANNELS MUST BE SWITHCHED BETWEEN V1 AND V2
                                ;WITH INTERMEDIATE CURRENT READINGS, THE 'START' LOOP IS COMPLICATED.
                                ;NONETHELESS, THE ARRAY AND POWER ROUTINES HAVE SOME SUBROUTINES IN
                                ;COMMON AND THEY FOLLOW THE SAME GENERAL FORMAT.

4473    21 5FB0                 LXI     H,ARRSUM
4476    11 5FAB                 LXI     D,ARRNEG
4479    D5                      PUSH    D       ;FINAL NEGATIVE POWER READING SUM ADDR ONTO STACK
447A    E5                      PUSH    H       ;FINAL + POWER READING SUM ADDR ONTO STACK

447B    21 5E00                 LXI     H,5E00H ;(HL) = V/A READINGS STORAGE LOCATION FOR ONE CYCLE

447E    1E 02           CHAN1:  MVI     E,02H   ;[7 MC] (E) = FLIP-FLOP FOR ALTERNATING V CHANNELS
4480    3E 00                   MVI     A,MUXV1 ;[7 MC] FIRST READING (HOUSE LINE 1 VOLTS) INTO 5E00H
4482    00                      NOP             ;[4 MC] SUBSEQUENT READINGS INTO 5E00H BLOC EVENS

4483    CD 43DB         INVERT: CALL    READ    ; VOLTAGE READINGS STORED AT EVENS UNTIL 5EA4H
4486    77                      MOV     M,A
4487    23                      INX     H
4488    3E A5                   MVI     A,0A5H  ;[7 MACHINE CYCLES]
448A    BD                      CMP     L       ;[4 MC]
448B    CA 449F                 JZ      KMPUTE  ;[10 MC] COMPUTE POWERS AFTER LAST READING (AT 5EA4H)
448E    00                      NOP             ;[4 MC]

448F    3E 20                   MVI     A,MUXIPV;[7 MC] INVERTOR i READINGS STORED IN 5E00H BLOC ODDS
4491    CD 43DB                 CALL    READ
4494    77                      MOV     M,A
4495    23                      INX     H
4496    1D                      DCR     E       ;[5 MC]
4497    CA 447E                 JZ      CHAN1   ;[10 MC]

449A    3E 10                   MVI     A,MUXV2 ;[7 MC] HOUSE LINE 2 VOLTS
449C    C3 4483                 JMP     INVERT  ;[10 MC]

                        ;-----------------------------------------------------------------------

449F                    KMPUTE:
                                ;       WE HOLD THESE TRUTHS TO BE SELF EVIDENT:
                                ;EACH CURRENT READING STORED IN 5E00H ODD BLOC WAS TAKEN AT THE MID-
                                ;POINT IN TIME BETWEEN IMMEDIATELY ADJACENT VOLTAGE READINGS IN
                                ;5E00H EVEN BLOC.  THEREFORE, THE VOLTAGE IN THE INVERTOR CIRCUIT
                                ;WHICH WAS COINCIDENT WITH EACH CURRENT READING WILL BE CLOSE TO THE
                                ;AVERAGE LINE-TO-LINE VOLTAGE (A LINEAR INTERPOLATION).  WE WILL USE
                                ;THE FOLLOWING SUM AS THE AVERAGE COINCIDENT VOLTAGE:
                                ; V1 + (-V2) = V21,  WHERE V1 = NEUTRAL-TO-LINE VOLTAGE
                                ;FOR HOUSE LINE 1, V2 = N-L VOLTAGE FOR LINE 2, V21 = LINE-TO-LINE
                                ;VOLTAGE ACROSS THE HOUSE LINES THAT THE INVERTOR FEEDS.

                                ;SINCE EACH VOLTAGE DIGITAL READING IS: 00H = MINIMUM, 80H = GROUND,
                                ;FFH = MAXIMUM, READING (R) - 80H = SIGNED DIGITAL READING.  HENCE,
                                ;FOR R1-80H = V1, R2-80H = V2 :  V21 = (R1-80H) - (R2-80H) = R1 - R2.
```

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                                     ;LINE 1 VOLTAGE READINGS ARE IN 5E00H BLOC AT 00, 04, 08,& 0C, UNTIL
                                     ;5EA4H.  LINE 2 READINGS AT 02, 06, 0A,& 0E.

449F    21 5E00                LXI     H,5E00H ;(HL) = ADDR OF READINGS
44A2    3E 02                  MVI     A,02H
44A4    32 5F72                STA     FLOW    ;[FLOW] = FLIP-FLOP REGISTER FOR VOLTAGE READINGS

44A7    06 00         POWARR:  MVI     B,00H   ;CLEAR B REGISTER FOR NEGATIVE POWER COUNTER

44A9    3A 5F72                LDA     FLOW
44AC    3D                     DCR     A       ;SET ZERO FLAG IF PRE VOLTAGE READING = LINE 2
44AD    32 5F72                STA     FLOW
44B0    CA 44BC                JZ      MIRROR

44B3    7E                     MOV     A,M     ;(A) = PRE VOLTAGE READING OF LINE 1
44B4    5E                     MOV     E,M     ;SAVE IN E REGISTER
44B5    23                     INX     H
44B6    23                     INX     H
44B7    56                     MOV     D,M     ;(D) = POST VOLTAGE READING OF LINE 2
44B8    92                     SUB     D       ;(ACC) = V21, CARRY FLAG SET IF V1 - V2 < 0
44B9    C3 44C7                JMP     SEE

44BC    3E 02         MIRROR:  MVI     A,02H
44BE    32 5F72                STA     FLOW    ;RESTORE FLIP-FLOP COUNTER IN FLOW TO 2
44C1    56                     MOV     D,M     ;(D) = PRE VOLTAGE READING OF LINE 2
44C2    23                     INX     H
44C3    23                     INX     H
44C4    7E                     MOV     A,M     ;(A) = POST VOLTAGE READING OF LINE 1
44C5    5E                     MOV     E,M     ;SAVE IN E REGISTER
44C6    92                     SUB     D       ;(ACC) = V21, CARRY FLAG SET IF V1 - V2 < 0

44C7    D2 44CD       SEE:     JNC     VMAG    ;BYPASS THE FOLLOWING IF V1 - V2 > 0
44CA    7A                     MOV     A,D
44CB    93                     SUB     E       ;(ACC) = V1 - V2 = V21 < 0
44CC    04                     INR     B       ;COUNT NEGATIVE VOLTAGE AS ONE NEGATIVE ARGUMENT

44CD    57            VMAG:    MOV     D,A     ;V21 INTO D REGISTER
44CE    CD 4400                CALL    DIGJST  ;JUSTIFIED CURRENT READING INTO C REGISTER
                                               ;AND B REGISTER INCREMENTED IFF iARRAY < 0

44D1    C5                     PUSH    B       ;SAVE B REG ON STACK
44D2    CD 4411                CALL    BYTBYT  ;(BC) = POWER

44D5    D1                     POP     D       ;01H IN D REG IF PRODUCT IS NEGATIVE
44D6    7A                     MOV     A,D
44D7    D6 01                  SUI     01H     ;ZERO FLAG SET IF POWER IS NEGATIVE
44D9    CA 44E4                JZ      PWRJ

44DC    E3                     XTHL            ;(SP) = NEXT i ADDR, (HL) = FINAL SUM ADDR
44DD    CD 445E                CALL    ADDINC  ;ADD (+) POWER READING TO FINAL (+) POWER SUM
44E0    E3                     XTHL            ;(HL) = NEXT i ADDR, (SP) = FINAL SUM ADDR
                                               ;                   (SP) + 2 = XXXNEG ADDR
44E1    C3 44ED                JMP     ARRTST

44E4    EB            PWRJ:    XCHG            ;SAVE NEXT i ADDRESS IN (DE)
44E5    E1                     POP     H
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```
 44E6    E3                         XTHL            ;(HL) = XXXNEG ADDRESS, (SP) = FINAL SUM ADDR
 44E7    CD 445E                    CALL    ADDINC  ;ADD (-) POWER READING TO NEGATIVE POWER SUM
 44EA    E3                         XTHL
 44EB    E5                         PUSH    H       ;(SP) = FINAL SUM ADDR, (SP)+2 = XXXNEG ADDR
 44EC    EB                         XCHG            ;(HL) = NEXT i ADDRESS [RECOVERED FROM (DE)]

 44ED    3E A4              ARRTST: MVI     A,0A4H  ;82 POWER READINGS
 44EF    BD                         CMP     L
 44F0    C2 44A7                    JNZ     POWARR  ;DO ALL 82 POWERS BEFORE RETURNING
 44F3    E1                         POP     H       ;REMOVE FINAL SUM ADDR AND XXXNEG ADDR FROM
 44F4    E1                         POP     H       ;(SP) & (SP) + 2, RESPECTIVELY

 44F5    C9                         RET             ;RETURN FROM ARRAY ROUTINE

                            ;-----------------------------------------------------------------------

 44F6                       SBTRCT: ;SuBTRaCT ROUTINE SUBTRACTS A STRING OF LENGTH (B) AT (HL)
                                    ;FROM STRING AT (DE) AND PLACES THE RESULT IN [DiFFeReNCe].
                                    ;THE CARRY FLAG IS SET IF THE STRING OF (B) BYTES AT (DE)
                                    ;IS ACTUALLY LESS THAN THE STRING OF (B) BYTES AT (HL).
                                    ;MOREOVER, THE ADDRESS OF THE RESULT IS PLACED IN (DE).
                                    ;MAX STRING LENGTH = 8 BYTES!

                                    ;SMASHES: A,B,C                 INPUTS: (B) = # BYTES
                                    ;FLAGS: ALL                      (DE) = ADDR OF GREATOR
                                    ;MAX TIME:                       (HL) = ADDRESS OF LESSOR
                                    ;                       OUTPUTS: (DE) = ADDR OF DIFFERENCE (DFFRNC)
                                    ;                                (HL) = ADDR OF GREATOR
                                    ;                                CARRY FLAG SET IF [HL] > [DE].

 44F6    D5                         PUSH    D       ;ADDR OF GREATOR ONTO STACK
 44F7    E5                         PUSH    H       ;ADDR OF LESSOR ONTO STACK
 44F8    C5                         PUSH    B
 44F9    21 5F99                    LXI     H,DFFRNC
 44FC    04                         INR     B
 44FD    CD 438A                    CALL    CLR     ;CLEAR DIFFERENCE SPACE OF (B) + 1 BYTES

 4500    C1                         POP     B       ;REPLENISH # BYTES IN B
 4501    E1                         POP     H       ;REPLENISH (HL) WITH ADDR OF LESSOR
 4502    E5                         PUSH    H       ;(SP) = ADDR OF LESSOR, (SP) + 2 = ADDR OF GREATOR

 4503    05                         DCR     B       ;INDEX TO MOST SIG BYTE
 4504    0E 00                      MVI     C,00H   ;CLR C REG, FOR  [HL] > [DE]  FLAG
 4506    7D                         MOV     A,L
 4507    80                         ADD     B
 4508    6F                         MOV     L,A     ;ADDR OF MSB IN [HL]
 4509    7B                         MOV     A,E
 450A    80                         ADD     B
 450B    5F                         MOV     E,A     ;ADDR OF MSB IN [DE]
 450C    04                         INR     B       ;RESTORE # BYTES IN B REG

 450D    1A                         LDAX    D       ;MSB OF [DE] INTO ACC
 450E    BE                         CMP     M       ;SUBTRACT MSB OF [HL] TO SET FLAGS:
                                                    ;(C) = 1 IF [HL] > [DE], (Z) = 1 IF MSB (HL) = (DE)
 450F    CC 453F                    CZ      GT      ;SET FLAGS FROM LESS SIG BYTES IF MSBYTES ARE EQUAL
 4512    E1                         POP     H       ;RESTORE [HL] & [DE] FROM THE SHELF
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4513    D1                      POP     D
4514    D2 451A                 JNC     SUBT    ;THE CARRY BIT IS SET AFTER A COMPARE OR SUBTRACT
                                                ;COMMAND TO INDICATE A NEGATIVE RESULT
4517    EB                      XCHG            ;SWAP [DE] FOR [HL]: MSBYTE OF (HL) > MSBYTE OF (DE)
4518    0E 01                   MVI     C,01H   ;ORIG [HL] > ORIG [DE] IS DENOTED BY 01H IN C REG

451A    E5              SUBT:   PUSH    H
451B    21 5F99                 LXI     H,DFFRNC
451E    E3                      XTHL            ;(HL) = ADDR OF LESSOR, (SP)=ADDR OF FINAL DIFFERENCE

451F    A7                      ANA     A       ;CLR CARRY
4520    1A                      LDAX    D       ;LSB OF GREATOR INTO ACC
4521    96                      SUB     M       ;SUBTRACT LSB OF LESSOR

4522    E3                      XTHL            ;(HL) = DFFRNC LSBYTE ADDR, (SP)= LESSOR LSBYTE ADDR
4523    77                      MOV     M,A     ;STORE DIFFERENCE BYTE AT (DFFRNC)
4524    23                      INX     H       ;PREPARE FOR NEXT BYTE
4525    E3                      XTHL            ;(SP) = (DFFRNCE) + 1, (HL) = (LESSOR)

4526    13                      INX     D
4527    23                      INX     H
4528    05                      DCR     B       ;NEXT BYTE
4529    CA 4538                 JZ      EXT     ;RETURN IF LAST

452C    1A              SBT:    LDAX    D       ;SUBSEQUENT BYTES SAME AS ABOVE BUT USING
452D    9E                      SBB     M       ;SBB : SUBTRACT WITH BORROW

452E    E3                      XTHL
452F    77                      MOV     M,A
4530    23                      INX     H
4531    E3                      XTHL

4532    13                      INX     D
4533    23                      INX     H
4534    05                      DCR     B
4535    C2 452C                 JNZ     SBT

4538    D1              EXT:    POP     D       ;(DE) = MSBYTE OF DIFFERENCE = TRASH
4539    11 5F99                 LXI     D,DFFRNC ;(DE) = ADDR OF DIFFERENCE
453C    79                      MOV     A,C
453D    1F                      RAR             ;MOVE [HL] > [DE]  FLAG INTO CARRY
453E    C9                      RET


453F                    GT:     ;Greater Than TESTS LESS SIGNIFICANT BYTES IF MSBYTES ARE EQUAL

453F    05                      DCR     B
4540    AF                      XRA     A
4541    B8                      CMP     B
4542    CA 454D                 JZ      ZILCH
4545    2B                      DCX     H
4546    1B                      DCX     D
4547    1A                      LDAX    D       ;NEXT LESS SIG BYTE
4548    BE                      CMP     M       ;SET FLAGS
4549    CA 453F                 JZ      GT
454C    C9                      RET
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 454D    06 01          ZILCH:  MVI     B,01H   ;RESTORE AT LEAST 01 INTO B REG
 454F    C9                     RET



 4550    C9             READSW: RET

 4551    C9             INDEX:  RET

 4552    C9             DSPLAY: RET

 4553    C9             DSP:    RET

 4554    C9             FACTOR: RET

 4555    C9             DATBAS: RET

                                END
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                                TITLE  COMMAND PROGRAM PART II

                        ;               -------------NOTATION--------------

                        ;         (HL) REFERS TO THE CONTENTS OF THE HL REGISTER.

                        ; [HL] REFERS TO THE CONTENTS AT THE MEMORY ADDRESS STORED IN (HL).

                        ;          LABEL (ANY LABEL WITHOUT () OR []) REFERS TO
                        ;    THE ADDRESS THAT THE PROGRAM USES WHEN 'LABEL' IS CALLED.

                        ;[LABEL] REFERS TO THE CONTENTS OF THE MEMORY AT THE ADDRESS 'LABEL'.


5FFF                    STACK EQU 5FFFH         ;NONDEFAULT ADDRESSES FOR STORING DATA

5FC3                    STKEND EQU STACK-60     ;60 BYTE STACK
5FBF                    DSPREG EQU STKEND-4     ;4 BYTE DiSPlay REGister FOR DATA STRING
                                                ;       TO BE SENT TO DISPLAY
5FBA                    DEMSUM EQU DSPREG-5     ;DEMand SUM = HOUSE NET (+) POWER READING SUM
5FB5                    DEMNEG EQU DEMSUM-5     ;DEMand NEGative = HOUSE NET (-) POWER SUM
5FB0                    ARRSUM EQU DEMNEG-5     ;ARRay SUM = INVERTOR (+) POWER READING SUM
5FAB                    ARRNEG EQU ARRSUM-5     ;ARRay NEGative = INVERTOR (-) POWER SUM
5FA2                    PRODCT EQU ARRNEG-9     ;PRODuCT = RESULT SPACE FOR FACTOR ROUTINE
5F99                    DFFRNC EQU PRODCT-9     ;DiFFeReNCe=RESULT SPACE FOR SUBTRACT ROUTINE
5F96                    CNVSPC EQU DFFRNC-3     ;CoNVersion SPaCe=RESULT SPACE OF BCD ROUTINE

                                                ;LOCATIONS FOR STORING ADDRESSES

5F94                    DSPADR EQU CNVSPC-2     ;DiSPlay ADdRess CONTAINS ONE OF THE
                                                ;ADDRESSES OF DISPLAYABLE QUANTITIES BELOW:
5F92                    DEMPWR EQU DSPADR-2     ;DEMand PoWeR = ADDR OF HOME DEMAND POWER
5F90                    ARRPWR EQU DEMPWR-2     ;ARRay PoWeR = ADDR OF INVERTOR POWER
5F8E                    DEMENG EQU ARRPWR-2     ;DEMand ENerGy = ADDR OF HOME DEMAND ENERGY
5F8C                    ARRENG EQU DEMENG-2     ;ARRay ENerGY = ADDR OF INVERTOR ENERGY
5F8A                    DMOVAR EQU ARRENG-2     ;DeMand OVer ARray = ADDRESS OF DEMAND IN
                                                ;                    EXCESS OF ARRAY ENERGY
5F88                    AROVDM EQU DMOVAR-2     ;ARray OVer DeMand = ADDRESS OF ARRAY IN
                                                ;                    EXCESS OF DEMAND ENERGY
5F86                    DOACST EQU AROVDM-2     ;Demand Over Array CoST LOCATION
5F84                    AODCST EQU DOACST-2     ;Array Over Demand CoST (VALUE) LOCATION
5F82                    DEMCST EQU AODCST-2     ;DEMand CoST = ENERGY DEMAND COST w/o ARRAY
5F80                    NETCST EQU DEMCST-2     ;NET CoST = NET DAILY BILL LOCATION

5F80                    MEMEND EQU NETCST       ;BEGINNING OF NON-DEFAULT MEMORY LOCATIONS

5F80                    DBEND EQU MEMEND        ;END OF DEFAULT VALUES DATABASE
                                                ;DEFAULT ADDRESSES LOADED INTO RAM FROM TOP
                                                ;SEE END OF THIS PROGRAM FOR DEFAULT VALUES
5F7F                    DSPMOD EQU DBEND-1      ;DiSPlay MODe = LED CODE FOR DISPLAY
5F78                    TMRS EQU DSPMOD-7       ;TiMeRS = OFF-BOARD TIMER SET VALUES
5F77                    OUTREG EQU TMRS-1       ;OUTPut REGister = STATUS OF OUTPUT PORT
5F76                    HRS EQU OUTREG-1        ;HouRS = HOUR VALUE OF 24 HOUR BCD CLOCK
5F75                    MIN EQU HRS-1           ;MINutes = BCD MINUTES VALUE FOR CLOCK
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 5F74                         SEC EQU MIN-1          ;SEConds = BCD SECONDS VALUE FOR CLOCK
 5F73                         COUNT EQU SEC-1        ;COUNT = 1/4 SECOND COUNTER VALUE
 5F72                         FLOW EQU COUNT-1       ;FLOW = 00 FOR + POWER FLOW, 01 FOR - POWER
 5F71                         NUMBIT EQU FLOW-1      ;NUMBIT = NUMBER OF BITS IN FACTOR
 5F70                         INPOW1 EQU NUMBIT-1    ;FIRST INvertor POWer FACTOR  (SEE ROLE)
 5F6F                         INPOW2 EQU INPOW1-1    ;SECOND INvertor POWer FACTOR
 5F6E                         DEMPW1 EQU INPOW2-1    ;FIRST DEMand PoWer FACTOR
 5F6D                         DEMPW2 EQU DEMPW1-1    ;SECOND DEMand PoWer FACTOR
 5F6C                         PRVDAY EQU DEMPW2-1    ;PReVious DAY = # DAYS BACK OF DISPLAYED DATA
 5F6A                         DAY1 EQU PRVDAY-2      ;DAY1 = FIRST DAY'S BASE DATA STORAGE ADDRESS
 5F68                         LSTDAY EQU DAY1-2      ;LaST DAY = LAST DAY'S BASE DATA ADDRESS
 5F66                         DAY EQU LSTDAY-2       ;DAY = BASE ADDRESS FOR TODAY'S DATA

 5F5F                         DSPIND EQU DAY-7       ;DiSPlay INDex = TABLE OF INDICES FOR INDEXED
                                                     ;ADDRESSING.  USES DiSPlay MODe (LED CODE) TO
                                                     ;   ACCESS ADDRESS OF DATA FOR DISPLAY AT
                                                     ;     DAY BASE ADDRESS + INDEX f(DSPMOD)

 5F5E                         VMUX EQU DSPIND-1      ;Voltage MUltipleXor channel
 5F5D                         IMUX EQU VMUX-1        ;I (current) MUltipleXor channel

 5F5C                         RATE EQU IMUX-1        ;RATE CONTAINS ONE OF THE COST FACTORS BELOW
 5F5B                         BUYBAK EQU RATE-1      ;BUYBAcK = BUYBACK RATE FACTOR ==> $/kWh
 5F5A                         DEMCHG EQU BUYBAK-1    ;DEMand CHarGe = ELECTRICITY COST ==> $/kWh

 5F5A                         DBBEG EQU DEMCHG       ;BEGINNING OF DEFAULT DATABASE


 9000                         TIMER0 EQU 9000H       ;HARDWARE LOCATIONS OF OFF-BOARD TIMER,
 9100                         TIMER1 EQU TIMER0+100H
 9200                         TIMER2 EQU TIMER1+100H
 9300                         TIMER3 EQU TIMER2+100H
 A000                         ADC EQU 0A000H         ;       ANALOG TO DIGITAL CHIP, &
 8000                         DAC EQU 8000H          ;        DIGITAL TO ANALOG CHIP.


 0002                         PPRT   EQU 00000010B   ;Parallel PoRT STATUS
 0000                         MUXV1  EQU 00000000B   ;LOAD VOLTS 1   CH #0
 0008                         MUXI1  EQU 00001000B   ;LOAD AMPS 1    CH #1
 0010                         MUXV2  EQU 00010000B   ;LOAD VOLTS 2   CH #2
 0018                         MUXI2  EQU 00011000B   ;LOAD AMPS 2    CH #3
 0020                         MUXIPV EQU 00100000B   ;PV POWER CONDITIONER AMPS    CH #4
                                                     ;CH 5, 6, & 7 OPEN

                              .PHASE 454EH    ;THIS PROGRAM OCCUPIES 4000H TO 47A0H IN THE MEMORY


 454E    C9           CMPBH:  RET

 454F    C9           CLR:    RET

                      ;__________________________READ SWITCH ROUTINE______________________________

 4550                 READSW: ;READ SWitch ROUTINE CHECKS IF EITHER OF THE SWITCHES ON THE DISPLAY
                              ;HAVE BEEN SET TO INDICATE A NEW VALUE SHOUL BE DISPLAYED.  SWITCHES
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                              ;ARE CHECKED EVERY 1/4 SEC.  THE PAST VALUES SWITCH CALLS UP A
                              ;SUBROUTINE THAT SUBTRACTS 30H FROM THE BASE DAY ADDRESS FOR
                              ;EACH PREVIOUS DAY (116 DAYS OF STORAGE CAPACITY) TO BE DISPLAYED.
                              ;THE NEXT VALUE SWITCH INCREMENTS THE DISPLAY MODE (WHICH IS USED TO
                              ;OBTAIN AN INDEX THAT POINTS TO THE PROPER LOCATION FOR DISPLAY DATA
                              ;WHEN ADDED THE THE BASE DAY ADDRESS) AND RETURNS TO CLOCK DISPLAY
                              ;UPON INCREMENTING PAST THE SIXTH DISPLAY LED (DSPMODE = 6).

                              ;SMASHES: A,BC,HL        INPUTS: NONE
                              ;FLAGS: ALL              OUTPUTS: UPDATED BASE DAY ADDRESS AND DSPMOD
                              ;MAX TIME:

4550  DB 11                   IN      11H      ;READ INPUT PORT STATUS
4552  E6 40                   ANI     40H      ;MASK TO READ SW#1 (PAST VALUES)
4554  C4 455F                 CNZ     PAST
4557  DB 11                   IN      11H
4559  E6 80                   ANI     80H      ;MASK TO READ SW#2 (NEXT VALUE)
455B  C4 4589                 CNZ     NXMODE
455E  C9                      RET

                    ;----------------------past values routine-------------------------

455F  AF            PAST:     XRA     A
4560  32 5F7F                 STA     DSPMOD   ;[DSPMOD] = 00H
4563  3A 5F6C                 LDA     PRVDAY
4566  C6 01                   ADI     01H
4568  27                      DAA
4569  32 5F6C                 STA     PRVDAY   ;[PRVDAY] = [PRVDAY + 1] BCD

456C  2A 5F6A                 LHLD    DAY1
456F  44                      MOV     B,H
4570  4D                      MOV     C,L
4571  2A 5F66                 LHLD    DAY      ;(BC)=[DAY1]   (HL)=[DAY]
4574  CD 454E                 CALL    CMPBH    ;ZERO SET IF DAY = DAY1
4577  C2 4581                 JNZ     NEXDAY

457A  2A 5F68                 LHLD    LSTDAY   ;(HL) = [LSTDAY]
457D  22 5F66                 SHLD    DAY      ;[DAY] = LASTDAY
4580  C9                      RET

4581  01 FFD0       NEXDAY:   LXI     B,0FFD0H        ;2'S COMP OF 30H
4584  09                      DAD     B        ;(HL) - 30H
4585  22 5F66                 SHLD    DAY      ;[DAY] = [DAY - 30H]
4588  C9                      RET

                    ;-----------------next display value routine----------------------

4589  3A 5F7F       NXMODE:   LDA     DSPMOD
458C  FE FF                   CPI     0FFH     ;TEST FOR TIME DISPLAY
458E  C2 4595                 JNZ     PRDIND
4591  AF                      XRA     A        ;CLEAR ACCUMULATOR FOR FIRST LED DISPLAY
4592  C3 459C                 JMP     NEXTMD

4595  FE 00         PRDIND:   CPI     00H      ;TEST FOR PREVIOUS DAY INDEX DISPLAY
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4597    C2 459C                 JNZ     NEXTMD

459A    3E 02                   MVI     A,02H   ;SETUP FOR DISPLAY OF PAST VALUES (DSPMODE = 03H)

459C    3C              NEXTMD: INR     A       ;[DSPMOD] = [DSPMOD + 1]
459D    FE 07                   CPI     07H
459F    CA 45B8                 JZ      DSPTIM  ;IF 7TH LED, DISPLAY TIME & RETURN TO TODAY
45A2    32 5F7F                 STA     DSPMOD  ;ELSE STORE NEXT DISPLAY MODE

45A5    3A 5F7F         INDEX:  LDA     DSPMOD
45A8    21 5F5F                 LXI     H,DSPIND  ;(HL) = ADDRESS OF DISPLAY INDEX TABLE
45AB    06 00                   MVI     B,00H
45AD    4F                      MOV     C,A     ;16 BIT INDEX (DSPMOD) IN (BC)
45AE    09                      DAD     B       ;(HL) = ADDRESS OF PROPER DISPLAY INDEX
45AF    4E                      MOV     C,M     ;(BC) = 16 BIT DISPLAY INDEX = f(DSPMOD)
45B0    2A 5F66                 LHLD    DAY     ;(HL) = [DAY]
45B3    09                      DAD     B       ;(HL) = [DAY] + DISPLAY INDEX
45B4    22 5F94                 SHLD    DSPADR  ;[DSPADR] = [DAY] + DISPLAY INDEX
45B7    C9                      RET             ;[DSPADR] = ADDRESS OF LS BYTE FOR DISPLAY

45B8    3E FF           DSPTIM: MVI     A,0FFH
45BA    32 5F7F                 STA     DSPMOD  ;[DSPMOD] = FF (INDICATES TIME DISPLAY)
45BD    2A 5F92                 LHLD    DEMPWR  ;(HL) = [DEMPWR]  (TODAY'S BASE ADDRESS)
45C0    22 5F66                 SHLD    DAY     ;[DAY] = TODAY (BASE FOR CURRENT VALUES DISPLAY)
45C3    3E 00                   MVI     A,00H
45C5    32 5F6C                 STA     PRVDAY  ;[PRVDAY] = 00H (TODAY)
45C8    C9                      RET

                        ;_____________________DISPLAY FORMATTING ROUTINE_____________________________

45C9                    DSPLAY: ;CHECKS DSPMOD (LED CODE) TO SEE WHICH FORMAT IS APPROPRIATE.
                                ;FORMATS USED BELOW INCLUDE: FLASHING COLON FORMAT FOR CLOCK,
                                ;FIXED DECIMAL FOR TWO SIGNIFICANT DIGIT DATA DISPLAY, A MINUS IN
                                ;MSDIGIT FOR # DAYS BACK DISPLAY, A MINUS IN MSDIGIT WITH FIXED
                                ;DECIMAL FOR NEGATIVE BILL DISPLAY.

                                ;SMASHES: A,B,C,HL        INPUTS: NONE
                                ;FLAGS: ALL               OUTPUTS: LOADS DiSPlay REGister WITH DATA
                                ;MAX TIME: 4mS  FOR SERIAL SEND TO DISPLAY AND CALLS FOR THE SEND.

45C9    21 5FBF                 LXI     H,DSPREG ;(HL) = DISPLAY REGISTER ADDR (LED CODE, DEC, COL)
45CC    3A 5F7F                 LDA     DSPMOD  ;(A) = [DSPMOD]: DISPLAY MODE CHOOSES DISPLAY FORMAT
45CF    FE FF                   CPI     0FFH
45D1    C2 4620                 JNZ     DAYSBK  ;IF [DSPMOD] = FF DISPLAY TIME

45D4    CD 45E0                 CALL    TIMFMT  ;SET UP FOR TIME DISPLAY
45D7    CD 46DE                 CALL    DSP
45DA    C9                      RET

45DB    0F              ROTE:   RRC
45DC    0F                      RRC
45DD    0F                      RRC
45DE    0F                      RRC
45DF    C9                      RET
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                            ;-------a user friendly clock format: blinking colon 12 hour display-----

45E0    3A 5F73             TIMFMT: LDA     COUNT           ;DISPLAY NO COLON FOR 1/4 SEC WHEN
45E3    FE 01                       CPI     01H             ;COUNT = 01
45E5    CA 4616                     JZ      NOCOL

45E8    36 03                       MVI     M,00000011B     ;COLON (HIGH), NO LEDS, + START BIT

45EA    23                  BLINK:  INX     H               ;(HL) = DSPREG + 1  (HOURS DIGITS)
45EB    AF                          XRA     A               ;CLEAR FLAGS
45EC    3A 5F76                     LDA     HRS
45EF    FE 00                       CPI     00H             ;IS IT THE MIDNITE HOUR?, SIGN FLAG = 0
45F1    CA 461B                     JZ      MDNITE
45F4    FE 13                       CPI     13H             ;IF HOURS IS AM, SIGN BIT = 1,
45F6    FA 45FE                     JM      PPLTIM          ;NO NEED TO ALTER HOUR VALUE

45F9    C6 08                       ADI     08H             ;24 HR CLOCK DECIMAL VALUE
45FB    27                          DAA
45FC    D6 20                       SUI     20H             ; + 8 BCD - 20 BCD = - 12 BCD!

45FE    47                  PPLTIM: MOV     B,A             ;SAVE HRS DIGITS IN B REGISTER
45FF    E6 F0                       ANI     0F0H            ;MASK OFF MSDIGIT (MSNIBBLE HERE)
4601    FE 00                       CPI     00H             ;SEE IF MSDIGIT = ZERO
4603    78                          MOV     A,B             ;RECOVER HOURS DIGITS FROM B REG
4604    C2 4609                     JNZ     DSPMIN          ;IF NON-ZERO: DISPLAY IT

4607    F6 F0                       ORI     0F0H            ;SET MSDIGIT MSNIBBLE HERE) TO BLANK (1111B)

4609    CD 45DB             DSPMIN: CALL    ROTE
460C    77                          MOV     M,A             ;PREPARED HRS DIGITS INTO DSPREG
460D    23                          INX     H               ;(HL) = DSPREG + 2  (MINUTE DIGITS)
460E    3A 5F75                     LDA     MIN
4611    CD 45DB                     CALL    ROTE
4614    77                          MOV     M,A             ;MIN LSDIGIT AND MSDIGIT
4615    C9                          RET

4616    36 01               NOCOL:  MVI     M,00000001B     ;NO LEDS, NO COLON, + START BIT
4618    C3 45EA                     JMP     BLINK

461B    3E 12               MDNITE: MVI     A,12H           ;SET UP FOR 12:xx AM DISPLAY
461D    C3 45FE                     JMP     PPLTIM

                            ;----------------back to the main routine-----------------------

4620    FE 00               DAYSBK: CPI     00H             ;       IF [DSPMOD] = 00H,
4622    C2 463A                     JNZ     DSDATA          ;   SET UP FOR # DAYS BACK INDEX
4625    CD 462C                     CALL    HSTFMT
4628    CD 46DE                     CALL    DSP
462B    C9                          RET

462C    36 31               HSTFMT: MVI     M,00110001B     ;LED 3 & NO POINTS (ACTIVE LOW) + START BIT
462E    23                          INX     H               ;(HL) = DSPREG + 1
462F    36 EF                       MVI     M,11101111B     ;MSDIGIT BLANK AND MINUS SIGN
4631    23                          INX     H               ;(HL) = DSPREG + 2
4632    3A 5F6C                     LDA     PRVDAY
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4635    CD 45DB                    CALL    ROTE
4638    77                         MOV     M,A             ;PREVIOUS DAY INDEX INTO NEXT DIGITS
4639    C9                         RET

463A    FE 03             DSDATA:  CPI     03H             ;       IF [DSPMOD] = 03H,
463C    CA 4653                    JZ      DSCOST          ;   SET UP FOR NET COST DISPLAY
463F    CD 4646                    CALL    DATFMT
4642    CD 46DE                    CALL    DSP
4645    C9                         RET

4646    CD 45DB           DATFMT:  CALL    ROTE
4649    E6 F0                      ANI     11110000B       ;MASK OFF LSNIBBLE
464B    F6 05                      ORI     00000101B       ;OR IN POINTS & START BIT AT LSNIBBLE
464D    77                         MOV     M,A             ;DSPMODE & DEC PT. 2 + START BIT
464E    23                         INX     H               ;(HL) = DSPREG + 1
464F    CD 4681                    CALL    BCD
4652    C9                         RET

4653    2A 5F80           DSCOST:  LHLD    NETCST          ;(HL) = ADDR OF DAILY NET COST FLAG
4656    7E                         MOV     A,M             ;COST FLAG INTO ACCUMULATOR
4657    21 5FBF                    LXI     H,DSPREG        ;(HL) RESTORED TO DSPREG ADDRESS
465A    1F                         RAR                     ;CARRY FLAG SET IF NET COST IS NEGATIVE
465B    3A 5F7F                    LDA     DSPMOD          ;(ACC) RESTORED TO DSPMOD
465E    DA 4670                    JC      PAYBAK
4661    CD 4646                    CALL    DATFMT
4664    21 5FBF                    LXI     H,DSPREG
4667    23                         INX     H               ;(HL) = DSPREG + 1
4668    7E                         MOV     A,M
4669    F6 0F                      ORI     00001111B       ;BLANK MOST SIGNIFICANT DIGIT
466B    77                         MOV     M,A
466C    CD 46DE                    CALL    DSP
466F    C9                         RET

4670    CD 4646           PAYBAK:  CALL    DATFMT  ;USE DATA FORMAT BUT PLACE '-' IN MS DIGIT
4673    21 5FBF                    LXI     H,DSPREG
4676    23                         INX     H       ;(HL) = DSPREG + 1
4677    7E                         MOV     A,M
4678    E6 F0                      ANI     11110000B ;MASK OFF MS DIGIT (LS NIBBLE HERE)
467A    F6 0E                      ORI     00001110B ;MOST SIG DIGIT = '-' (LS NIBBLE HERE)
467C    77                         MOV     M,A
467D    CD 46DE                    CALL    DSP
4680    C9                         RET

                          ;_______________HEX TO BINARY CODED DECIMAL CONVERSON ROUTINE_______________

4681                      BCD:     ;BCD ROUTINE TAKES A 2 BYTE HEX DATUM AT DSPADR AND CONVERTS
                                   ;IT INTO ITS BCD EQUIVALENT ROTATED ONE DIGIT TO THE RIGHT
                                   ;(I.E.: X/10) IN THE DISPLAY REGISTER.   INPUTS:(HL)=DSPREG+1

                                   ;SMASHES: ALL           INPUTS: (HL) = DSPREG + 1
                                   ;FLAGS: ALL             MAX TIME:  3 msec
                                   ;       OUTPUTS: HEX DATA FROM TWO BYTES AT [DSPADR]
                                   ;                CONVERTED INTO 4 DECIMAL DIGITS LOADED APPROPRIATELY
                                   ;                FOR DISPLAY AT [DSPREG].  THE DIGITS FOR DISPLAY ARE
                                   ;                ACTUALLY 1/10 OF THE DECIMAL EQUIVALENT OF THE HEX
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                                ;           DATA AT [DSPADR] SINCE THE DISPLAY HAS ONLY 4 DIGITS
                                ;           AND 2 BYTES OF HEX CAN EASILY EXCEED 4 DIGITS IN BCD.
                                ;       NEAT SOLUTION: THE LEAST SIGNIFICANT DIGIT FOR DISPLAY IS THE
                                ;           TENS DIGIT (NOT THE ONES DIGIT).  THE DATA FORMAT
                                ;           DISPLAYS kW & kWh TO TWO SIGNIFICANT DIGITS WHICH
                                ;           MEANS THAT THE LEAST SIG DIGIT IS THE TENS DIGIT!

4681    E5                      PUSH    H       ;SAVE DSPREG + 1 ON STACK

4682    06 03                   MVI     B,03H
4684    21 5F96                 LXI     H,CNVSPC ;CLEAR CONVERSION SPACE
4687    CD 454F                 CALL    CLR

468A    2A 5F94                 LHLD    DSPADR
468D    4E                      MOV     C,M     ;(C)=LSBYTE OF HEX FOR DISPLAY
468E    23                      INX     H
468F    46                      MOV     B,M     ;(B)=MSBYTE OF HEX FOR DISPLAY

4690    21 5F96                 LXI     H,CNVSPC
4693    23                      INX     H
4694    23                      INX     H       ;(HL) = CNVSPC + 2
4695    16 10                   MVI     D,10H   ;16 BIT COUNTER IN D REGISTER


4697    CD 46BF         LOOP:   CALL    DBLBCD  ;DOUBLES NUMBER IN BCD SPACE
469A    79                      MOV     A,C
469B    17                      RAL
469C    4F                      MOV     C,A
469D    78                      MOV     A,B
469E    17                      RAL
469F    47                      MOV     B,A     ;BC SHIFTED LEFT MSB INTO CARRY
46A0    DC 46CE                 CC      INCBCD  ;ADD BCD 01 TO BCD SPACE
46A3    15                      DCR     D
46A4    C2 4697                 JNZ     LOOP
                                        ;BCD DIGITS IN XX00,01,02 FROM MS TO LS DIGIT
                                        ;AND WE WANT :    | || |  DIGITS TO BE DISPLAYED!

46A7    21 5F96                 LXI     H,CNVSPC ;POINTER TO MSBYTE
46AA    CD 46B5                 CALL    MANIP   ;(ACC) = TWO DIGITS FOR DSPREG + 1
46AD    D1                      POP     D       ;GET DSPREG + 1 OFF STACK
46AE    12                      STAX    D       ;MS DIGITS TO DSPREG + 1
46AF    13                      INX     D       ;(HL) ALREADY AT CNVSPC+1 FROM MANIP ABOVE
46B0    CD 46B5                 CALL    MANIP
46B3    12                      STAX    D       ;LS DIGITS TO DSPREG + 2
46B4    C9                      RET

46B5    7E              MANIP:  MOV     A,M     ;MSDIGIT INTO ACC
46B6    E6 0F                   ANI     0FH     ;MASK MS NIBBLE
46B8    47                      MOV     B,A     ;SAVE IN B
46B9    23                      INX     H       ;POINTER TO NEXT BYTE
46BA    7E                      MOV     A,M
46BB    E6 F0                   ANI     0F0H    ;MASK LS NIBBLE
46BD    80                      ADD     B       ;ASSEMBLE TWO DIGITS
46BE    C9                      RET

46BF    E5              DBLBCD: PUSH    H
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46C0    1E 03                   MVI     E,03H
46C2    AF                      XRA     A
46C3    7E              DBLOOP: MOV     A,M
46C4    8E                      ADC     M
46C5    27                      DAA
46C6    77                      MOV     M,A
46C7    2B                      DCX     H
46C8    1D                      DCR     E
46C9    C2 46C3                 JNZ     DBLOOP
46CC    E1                      POP     H
46CD    C9                      RET

46CE    E5              INCBCD: PUSH    H
46CF    1E 03                   MVI     E,03H
46D1    37                      STC
46D2    3E 00           INLOOP: MVI     A,00H
46D4    8E                      ADC     M
46D5    27                      DAA
46D6    77                      MOV     M,A
46D7    2B                      DCX     H
46D8    1D                      DCR     E
46D9    C2 46D2                 JNZ     INLOOP
46DC    E1                      POP     H
46DD    C9                      RET


                        ;_________________SERIAL SEND DATA TO DISPLAY ROUTINE_______________________

46DE                    DSP:    ;DiSPlay SERIALLY SENDS DATA IN DiSPlay REGister TO DISPLAY

                                ;SMASHES: A,B,D,E,HL    INPUTS: DATA FOR DISPLAY READY IN DSPREG
                                ;FLAGS: ALL             OUTPUTS: LCDS SHOWING SOMETHING REASONABLE
                                ;MAX TIME:

46DE    3A 5F77                 LDA     OUTREG  ;SEND INITIAL LOW BIT BEFORE HIGH START BIT
46E1    E6 BF                   ANI     10111111B
46E3    D3 12                   OUT     12H
46E5    F6 80                   ORI     80H
46E7    D3 12                   OUT     12H
46E9    E6 7F                   ANI     7FH
46EB    D3 12                   OUT     12H

46ED    21 5FBF                 LXI     H,DSPREG ;BEGINNING OF DISPLAY LOCATONS
46F0    06 03                   MVI     B,03H   ;# BYTES TO BE SENT IN B REG

46F2    1E 08           BITE:   MVI     E,08H   ;(E) = 8 BIT / BYTE COUNTER
46F4    56                      MOV     D,M     ;[DSPREG] IS NOT DESTROYED BY SENDING
46F5    7A              BIT:    MOV     A,D
46F6    1F                      RAR
46F7    57                      MOV     D,A
46F8    D2 4705                 JNC     NEXT

46FB    3A 5F77                 LDA     OUTREG
46FE    F6 40                   ORI     01000000B
4700    D3 12                   OUT     12H             ;SEND '1'
4702    C3 470C                 JMP     CLOCK
```

```
4705    3A 5F77         NEXT:   LDA     OUTREG
4708    E6 BF                   ANI     10111111B
470A    D3 12                   OUT     12H      ;SEND '0'

470C    F6 80           CLOCK:  ORI     80H      ;TOGGLE CLOCK  (SENDING TO DECODERS IN DISPLAY)
470E    D3 12                   OUT     12H
4710    E6 7F                   ANI     7FH
4712    D3 12                   OUT     12H

4714    1D                      DCR     E
4715    7B                      MOV     A,E
4716    FE 00                   CPI     00H
4718    C2 46F5                 JNZ     BIT      ;SEND ALL 8 BITS BEFORE GETTING THE NEXT BYTE

471B    23                      INX     H
471C    05                      DCR     B
471D    78                      MOV     A,B
471E    FE 00                   CPI     00H
4720    C2 46F2                 JNZ     BITE     ;SEND ALL 3 BYTES BEFORE ENDING
4723    3A 5F77                 LDA     OUTREG   ;FINISH WITH DATA LINE HIGH
4726    F6 40                   ORI     01000000B
4728    D3 12                   OUT     12H
472A    C9                      RET

                        ;---------------FACTOR ROUTINE--------------------------------------

472B                    FACTOR: ;FACTOR MULTIPLIES A DATA STRING BY A GIVEN FACTOR.
                                ;A TEMPORARY PRODUCT SPACE IS USED FOR THE RESULT.
                                ;THE # BYTES IN THE FINAL PRODUCT CANNOT EXCEED 8!
                                ;MOREOVER, THE # BITS IN THE FACTOR CANNOT EXCEED 8.
                                ;IT IS THE RESPONSIBILITY OF THE USING PROGRAM TO SHIFT THIS
                                ;PRODUCT TO AN APPROPRIATE LOCATION.  THIS GIVES FLEXIBILITY IN
                                ;USING FACTORS > 256 OR FRACTIONS.

                                ;SMASHES: A,B,C,HL      FLAGS: ALL      MAX TIME: 2msec
                                ;INPUTS: (B) = # BYTES IN FINAL PRODUCT, (C) = FACTOR
                                ;(DE) = ORIGINAL DATA STRING LOCATION, [NUMBIT] = # BITS IN FACTOR
                                ;OUTPUTS:(HL) = PRODUCT STRING ADDRESS AT PRODCT

472B    C5                      PUSH    B
472C    04                      INR     B
472D    21 5FA2                 LXI     H,PRODCT
4730    E5                      PUSH    H
4731    CD 454F                 CALL    CLR      ;CLEAR PRODUCT SPACE + 1 BYTE
4734    E1                      POP     H
4735    C1                      POP     B

4736    79              MULT:   MOV     A,C
4737    1F                      RAR              ;ROTATE MULTIPLIER TO SET CARRY FLAG
4738    4F                      MOV     C,A

4739    D2 473F                 JNC     CONTIN
473C    CD 4763                 CALL    FCTADD   ;ADD MULTIPLICAND AT (DE) TO PRODUCT SPACE AT (HL)
473F    CD 474D         CONTIN: CALL    ROTATE   ;ROTATE ENTIRE PRODUCT SPACE AT (HL) ONE BIT RIGHT
```

```
4742    3A 5F71                 LDA     NUMBIT  ;GET 8 BIT COUNTER INTO ACCUMULATOR
4745    3D                      DCR     A
4746    32 5F71                 STA     NUMBIT  ;REPLACE 8 BIT COUNTER
4749    C8                      RZ              ;RETURN WITH PRODUCT AT (HL)
474A    C3 4736                 JMP     MULT

474D                    ROTATE:                 ;ROTATES STRING ONE BIT TO THE RIGHT
                                                ;INPUTS:(B) = LENGTH OF STRING IN BYTES
                                                ;       (HL) = BASE ADDRESS OF STRING (LSBYTE)

474D    E5                      PUSH    H
474E    C5                      PUSH    B       ;SAVE FACTOR FROM C REG!
474F    F5                      PUSH    PSW     ;SAVE CARRY FLAG FOR ROTATE BELOW!
4750    48                      MOV     C,B     ;SET UP FOR INDEXED ADDRESSING
4751    0D                      DCR     C
4752    06 00                   MVI     B,00H   ;(BC) = # BYTES INDEX FOR MSBYTE ADDR
4754    09                      DAD     B       ;(HL) = MSBYTE ADDR OF FINAL STRING
4755    F1                      POP     PSW     ;RESTORE CARRY FLAG
4756    C1                      POP     B       ;RESTORE # BYTES IN (B) AND ROTATED FACTOR IN (C)
4757    C5                      PUSH    B       ;(B) BACK ON SHELF TIL ROTATION IS DONE
4758    7E              ROT:    MOV     A,M
4759    1F                      RAR
475A    77                      MOV     M,A
475B    2B                      DCX     H       ;DATA STORED LSBYTE TO MSBYTE LEFT TO RIGHT
475C    05                      DCR     B
475D    C2 4758                 JNZ     ROT
4760    C1                      POP     B
4761    E1                      POP     H
4762    C9                      RET

4763                    FCTADD:                 ;INPUTS:(B) = LENGTH OF STRING IN BYTES
                                                ;       (HL) = ADDR OF FINAL SUM
                                                ;       (DE) = ADDR OF STRING TO BE ADDED

4763    AF                      XRA     A       ;CLEAR CARRY
4764    C5                      PUSH    B
4765    D5                      PUSH    D
4766    E5                      PUSH    H
4767    23                      INX     H       ;(HL)=ADDR OF LSBYTE OF FINAL STRING + 1
                                                ;FOR ADDING OF ORIGINAL TO FINAL ONE BYTE UP
                                                ;AND ROTATING INTO LSBYTE
                                                ;AFTER LOOPS = # BITS IN FACTOR
4768    05                      DCR     B       ;(B) = # BYTES IN ORIGINAL STRING ASSUMING FACTOR
                                                ;OF MULTIPLICATION IS ONE BYTE; (B) = COUNTER
4769    1A              FAD:    LDAX    D       ;BYTE FROM ADDEND
476A    8E                      ADC     M       ;ADDED TO FINAL SUM
476B    77                      MOV     M,A     ;STORE RESULT
476C    13                      INX     D
476D    23                      INX     H
476E    05                      DCR     B
476F    C2 4769                 JNZ     FAD
4772    E1                      POP     H
4773    D1                      POP     D
4774    C1                      POP     B
```

```
 4775    C9                      RET


                       ;--------------INITIAL DATABASE AND DEFAULT PARAMETERS-------------------

 4776    1A            DATBAS: DB     1AH          ;DEFAULT ELECTRICITY RATE = .1015625 $/kWh
 4777    1A                    DB     1AH          ;DEMAND CHARGE FACTOR/256 = $/kWh
 4778    1A                    DB     1AH          ;BUYBACK RATE FACTOR/256 = $/kWh
 4779    08                    DB     00001000B    ;IMUX CH #1
 477A    00                    DB     00000000B    ;VMUX CH #1
 477B    00                    DB     00H          ;DSPINDEX BASE
 477C    04                    DB     04H          ;ARRAY POWER INDEX (LED #1)
 477D    01                    DB     01H          ;HOME DEMAND POWER INDEX (LED #2)
 477E    2C                    DB     2CH          ;NET DAILY BILL INDEX (LED #3)
 477F    27                    DB     27H          ;DEMAND DAILY BILL (W/O ARRAY) INDEX (LED #4)
 4780    0E                    DB     0EH          ;ARRAY ENERGY INDEX (LED #5)
 4781    09                    DB     09H          ;HOME DEMAND ENERGY INDEX (LED #6)
 4782    4800                  DW     4800H        ;DEFAULT DAY ADDRESS (FIRST DAY)
 4784    5DC0                  DW     5DC0H        ;LAST DAY ADDRESS - 116 DAY STORAGE
 4786    4800                  DW     4800H        ;FIRST DAY ADDRESS
 4788    00                    DB     00H          ;PREVIOUS DAY COUNTER
 4789    DF                    DB     0DFH         ;SECOND DEMAND POWER FACTOR
 478A    8C                    DB     8CH          ;FIRST DEMAND POWER FACTOR
 478B    DF                    DB     0DFH         ;SECOND INVERTOR POWER FACTOR
 478C    2A                    DB     2AH          ;FIRST INVERTOR POWER FACTOR
 478D    08                    DB     08H          ;NUMBER OF BITS IN DEFAULT FACTOR
 478E    00                    DB     00H          ;NEGATIVE POWER FLOW FLAG
 478F    05                    DB     05H          ;1/4 SEC COUNTER (GETS DECREMENTED BEFORE
 4790    00                    DB     00H          ;SEC                  FIRST POWER READINGS)
 4791    00                    DB     00H          ;MIN
 4792    00                    DB     00H          ;HRS
 4793    46                    DB     01000110B    ;OUTREG
 4794    00                    DB     00H          ;TIMERCHANGE DEFAULT
 4795    009D                  DW     009DH        ;TIMER0 LOAD VALUE, WILL NEED TUNING
                                                   ;DEPENDENT ON SEC VALUE==>FREQUENCY
 4797    0097                  DW     0097H        ;TIMER1 LOAD VALUE, NEW VALUES AS OF
 4799    04DA                  DW     04DAH        ;TIMER2 LOAD VALUE, AS OF 5/8 [TWEEK ME!]
                                                   ;APPROXIMATE CRYSTAL FREQ = 3.000723750 MHz
 479B    FF                    DB     0FFH         ;DSPMOD

                               END
```

Macros: *INDEX TO PART I : BEFORE 4550*

Symbols:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| AD | 437E | ADC | A000 | ADDINC | 445E | ADDING | 437B |
| ADINT | 4010 | AGAIN | 438B | ALTDEF | 405A | AODCST | 5F84 |
| AROVDM | 5F88 | ARRAY | 4473 | ARRENG | 5F8C | ARRMOR | 41F9 |
| ARRNEG | 5FAB | ARRPWR | 5F90 | ARRSUM | 5FB0 | ARRTST | 44ED |
| BABES | 428E | BODINT | 4040 | BUYBAK | 5F5B | BYTBYT | 4411 |
| CHAN1 | 447E | CLR | 438A | CLRMEM | 4334 | CLRSUM | 42F5 |
| CMPBH | 409D | CMPUTE | 4427 | CNTK | 441D | CNVSPC | 5F96 |
| COMPIN | 4062 | COUNT | 5F73 | CPINT | 4011 | CSTCNT | 42DE |
| CSTINC | 42D1 | CSTINK | 42DD | DAC | 8000 | DATBAS | 4555 |
| DAY | 5F66 | DAY1 | 5F6A | DBBEG | 5F5A | DBEND | 5F80 |
| DEMCHG | 5F5A | DEMCST | 5F82 | DEMENG | 5F8E | DEMND1 | 4392 |
| DEMND2 | 43A6 | DEMNEG | 5FB5 | DEMPW1 | 5F6E | DEMPW2 | 5F6D |
| DEMPWR | 5F92 | DEMSUM | 5FBA | DFFRNC | 5F99 | DIGJST | 4400 |
| DMOVAR | 5F8A | DOACST | 5F86 | DSP | 4553 | DSPADR | 5F94 |
| DSPIND | 5F5F | DSPLAY | 4552 | DSPMOD | 5F7F | DSPREG | 5FBF |
| ENERGY | 423C | EREWON | 429C | EXT | 4538 | FACTOR | 4554 |
| FINISH | 42C4 | FLAG | 42C1 | FLOW | 5F72 | GT | 453F |
| HISTRY | 43BC | HRS | 5F76 | IMUX | 5F5D | INC60 | 4139 |
| INCHRS | 414B | INCMIN | 4132 | INCSEC | 412B | INCTIM | 4116 |
| INDEX | 4551 | INIT | 4012 | INPOW1 | 5F70 | INPOW2 | 5F6F |
| INVERT | 4483 | JUSTIS | 4408 | KEEPON | 43EE | KMPUTE | 449F |
| LEDTST | 40F6 | LSTDAY | 5F68 | MEMEND | 5F80 | MEMLAB | 4340 |
| MEMLP | 4092 | MIN | 5F75 | MIRROR | 44BC | MULTK | 4418 |
| MUXI1 | 0008 | MUXI2 | 0018 | MUXIPV | 0020 | MUXV1 | 0000 |
| MUXV2 | 0010 | NETCST | 5F80 | NEWDAY | 4156 | NMI | 400F |
| NOWERE | 426F | NUMBIT | 5F71 | OUTREG | 5F77 | POWARR | 44A7 |
| POWER | 43BA | POWIE | 442A | PPRT | 0002 | PRODCT | 5FA2 |
| PRVDAY | 5F6C | PWRJ | 44E4 | PWRN | 444C | RATE | 5F5C |
| READ | 43DB | READSW | 4550 | RIPPLE | 4316 | ROLE | 4159 |
| ROLLON | 420F | SBT | 452C | SBTRCT | 44F6 | SEC | 5F74 |
| SECOND | 410E | SEE | 44C7 | SHFT | 4371 | SHIFT | 4370 |
| STACK | 5FFF | STADC | 40A3 | START | 43BF | STDAC | 40A7 |
| STDEND | 4109 | STDSP | 40DC | STINT | 40B7 | STKEND | 5FC3 |
| STMEM | 4089 | STPRT | 40AD | STRTMR | 4082 | STTMRS | 4063 |
| STZ | 4145 | SUBT | 451A | TIMER0 | 9000 | TIMER1 | 9100 |
| TIMER2 | 9200 | TIMER3 | 9300 | TMRS | 5F78 | TST | 4455 |
| TUCK | 432E | VMAG | 44CD | VMUX | 5F5E | WAIT | 403B |
| ZILCH | 454D | | | | | | |

No Fatal error(s)

Macros: INDEX FOR PART II : AFTER 4550

Symbols:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ADC | A000 | ADDCST | 5F84 | AROVDM | 5F88 | ARRENG | 5F8C |
| ARRNEG | 5FAB | ARRPWR | 5F90 | ARRSUM | 5FB0 | BCD | 4681 |
| BIT | 46F5 | BITE | 46F2 | BLINK | 45EA | BUYBAK | 5F5B |
| CLOCK | 470C | CLR | 454F | CMPBH | 454E | CNVSPC | 5F96 |
| CONTIN | 473F | COUNT | 5F73 | DAC | 8000 | DATBAS | 4776 |
| DATFMT | 4646 | DAY | 5F66 | DAY1 | 5F6A | DAYSBK | 4620 |
| DBBEG | 5F5A | DBEND | 5F80 | DBLBCD | 46BF | DBLOOP | 46C3 |
| DEMCHG | 5F5A | DEMCST | 5F82 | DEMENG | 5F8E | DEMNEG | 5FB5 |
| DEMPW1 | 5F6E | DEMPW2 | 5F6D | DEMPWR | 5F92 | DEMSUM | 5FBA |
| DFFRNC | 5F99 | DMOVAR | 5F8A | DOACST | 5F86 | DSCOST | 4653 |
| DSDATA | 463A | DSP | 46DE | DSPADR | 5F94 | DSPIND | 5F5F |
| DSPLAY | 45C9 | DSPMIN | 4609 | DSPMOD | 5F7F | DSPREG | 5FBF |
| DSPTIM | 45B8 | FACTOR | 472B | FAD | 4769 | FCTADD | 4763 |
| FLOW | 5F72 | HRS | 5F76 | HSTFMT | 462C | IMUX | 5F5D |
| INCBCD | 46CE | INDEX | 45A5 | INLOOP | 46D2 | INPOW1 | 5F70 |
| INPOW2 | 5F6F | LOOP | 4697 | LSTDAY | 5F68 | MANIP | 46B5 |
| MDNITE | 461B | MEMEND | 5F80 | MIN | 5F75 | MULT | 4736 |
| MUXI1 | 0008 | MUXI2 | 0018 | MUXIPV | 0020 | MUXV1 | 0000 |
| MUXV2 | 0010 | NETCST | 5F80 | NEXDAY | 4581 | NEXT | 4705 |
| NEXTMD | 459C | NOCOL | 4616 | NUMBIT | 5F71 | NXMODE | 4589 |
| OUTREG | 5F77 | PAST | 455F | PAYBAK | 4670 | PPLTIM | 45FE |
| PPRT | 0002 | PRDIND | 4595 | PRODCT | 5FA2 | PRVDAY | 5F6C |
| RATE | 5F5C | READSW | 4550 | ROT | 4758 | ROTATE | 474D |
| ROTE | 45DB | SEC | 5F74 | STACK | 5FFF | STKEND | 5FC3 |
| TIMER0 | 9000 | TIMER1 | 9100 | TIMER2 | 9200 | TIMER3 | 9300 |
| TIMFMT | 45E0 | TMRS | 5F78 | VMUX | 5F5E | | |

No Fatal error(s)

# APPENDIX 2A

## SOLAR ROUTINE: PV MAX POWER ESTIMATION

```
                              TITLE  PVDEMO.PRN

 5FFF                         STACK EQU 5FFFH         ;NONDEFAULT ADDRESSES ARE PUT IN FROM
 5FC3                         STKEND EQU STACK-60     ;BOTTOM
 5FBF                         DSPREG EQU STKEND-4     ;LOCATIONS FOR STORING DATA
 5FBD                         MAXPOW EQU DSPREG-2
 5FBC                         OCVOLT EQU MAXPOW-1
 5FBB                         SCAMPS EQU OCVOLT-1
 5FB6                         DEMSUM EQU SCAMPS-5
 5FB1                         ARRSUM EQU DEMSUM-5
 5FAE                         NEGSUM EQU ARRSUM-3
 5FAB                         TEMSUM EQU NEGSUM-3
 5FA6                         TEMDOA EQU TEMSUM-5
 5FA1                         TEMAOD EQU TEMDOA-5
 5F98                         PRODCT EQU TEMAOD-9
 5F95                         CNVSPC EQU PRODCT-3

 5F93                         DSPADR EQU CNVSPC-2     ;LOCATIONS FOR STORING ADDRESSES
 5F91                         DEMPWR EQU DSPADR-2
 5F8F                         ARRPWR EQU DEMPWR-2
 5F8D                         DEMENG EQU ARRPWR-2
 5F8B                         ARRENG EQU DEMENG-2
 5F89                         DMOVAR EQU ARRENG-2
 5F87                         AROVDM EQU DMOVAR-2
 5F85                         DOACST EQU AROVDM-2
 5F83                         AODCST EQU DOACST-2
 5F81                         NETCST EQU AODCST-2

 5F81                         MEMEND EQU NETCST

 5F81                         DBEND EQU MEMEND

 5F80                         DSPMOD EQU DBEND-1      ;DEFAULT ADDRESSES LOADED FROM TOP
 5F79                         TMRS EQU DSPMOD-7
 5F78                         OUTREG EQU TMRS-1
 5F77                         HRS EQU OUTREG-1
 5F76                         MIN EQU HRS-1
 5F75                         SEC EQU MIN-1
 5F74                         COUNT EQU SEC-1
 5F73                         NUMBIT EQU COUNT-1
 5F72                         PRVDAY EQU NUMBIT-1
 5F70                         DAY1 EQU PRVDAY-2
 5F6E                         LSTDAY EQU DAY1-2
 5F6C                         DAY EQU LSTDAY-2
 5F62                         DSPIND EQU DAY-10
 5F61                         VMUX EQU DSPIND-1
 5F60                         IMUX EQU VMUX-1
 5F5F                         BUYBAK EQU IMUX-1
 5F5E                         DEMCHG EQU BUYBAK-1
 5F5D                         PVFCTR EQU DEMCHG-1

 5F5D                         DBBEG EQU PVFCTR


 9000                         TIMER0 EQU 9000H
 9100                         TIMER1 EQU TIMER0+100H
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PVDEMO.PRN      MACRO-80 3.4    01-Dec-80       PAGE    1-1


 9200                           TIMER2 EQU TIMER1+100H
 9300                           TIMER3 EQU TIMER2+100H
 A000                           ADC EQU 0A000H
 8000                           DAC EQU 8000H
 0002                           PPRT EQU 00000010B
 0000                           MUXV1  EQU 00000000B    ;LOAD VOLTS 1 AT CHANNEL 0
 0008                           MUXI1  EQU 00001000B    ;LOAD AMPS 1 AT CHANNEL 1
 0010                           PVSCCH EQU 00010000B    ;4 x PV SHORT CIRCUIT AMPS AT CHANNEL 2
 0030                           PVOCCH EQU 00110000B    ;1/4 PV OPEN CIRCUIT VOLTAGE AT CHANNEL 6

                                .PHASE 4000H

                                ;       TITLE  SOLAR.PRN


 4000   3A 5F78         SOLAR:  LDA     OUTREG
 4003   E6 C5                   ANI     11000101B       ;LOAD TESTING ASSERTED
 4005   F6 30                   ORI     PVOCCH          ;PV OPEN CIRCUIT CHANNEL ALL SET
 4007   D3 12                   OUT     12H             ;AND NOW MUXED IN
 4009   32 5F78                 STA     OUTREG          ;STORE PV CHANNEL + LOAD TEST AT OUTREG
 400C   00                      NOP

 400D   3E 00                   MVI     A,00H           ;OPEN CIRCUIT CURRENT
 400F   CD 407C                 CALL    SNDDAC          ;SEND ZERO AMPS TO D/A

 4012   06 18                   MVI     B,18H           ;~100 uSEC DELAY FOR MUX TO RISE TO
 4014   CD 4082                 CALL    DELAY           ;1/4 FULL ARRAY VOLTAGE FROM PREVIOUS VALUE

 4017   CD 4087                 CALL    READPV          ;GET VOLTAGE READING (1/4 ARRAY VOLTAGE)
 401A   CD 40B9                 CALL    JSTIFY          ;(OCVOLT) = (OCVOLT - 80H)
 401D   32 5FBC                 STA     OCVOLT          ;STORE AT Open Circuit VOLTage
 4020   00                      NOP                     ;(OCVOLT - 80H) x 20 / 128 = VOLTS
                                                        ;EACH BIT = 156.25mV

 4021   3E FF                   MVI     A,0FFH          ;INITIAL SHORT CIRCUIT CURRENT
 4023   CD 407C                 CALL    SNDDAC          ;SEND 1.27 AMPS TO D/A

 4026   06 10                   MVI     B,10H           ;~75 uSEC DELAY NEEDED FOR D/A CIRCUITRY TO
 4028   CD 4082                 CALL    DELAY           ;RESPOND TO SHORT CIRCUIT COMMAND

 402B   3A 5F78                 LDA     OUTREG
 402E   E6 C7                   ANI     11000111B
 4030   F6 10                   ORI     PVSCCH          ;CHANGE MUX TO PV SHORT CIRCUIT CHANNEL
 4032   D3 12                   OUT     12H
 4034   32 5F78                 STA     OUTREG
 4037   00                      NOP

 4038   CD 4087                 CALL    READPV          ;GET VOLTAGE ACROSS 1 OHM x 4 (OP AMP)
 403B   CD 40B9                 CALL    JSTIFY          ;(SCAMPS) = (SCAMPS - 80H)
 403E   32 5FBB                 STA     SCAMPS          ;STORE AT Short Circuit AMPS
 4041   00                      NOP                     ;(SCAMPS - 80H) / 1.25 x 128 = AMPS
                                                        ;EACH BIT = 9.76562mA
 4042   AF                      XRA     A               ;RESET D/A TO OPEN CIRCUIT
 4043   CD 407C                 CALL    SNDDAC

 4046   3A 5F78                 LDA     OUTREG
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```
4049    E6 C7                   ANI     11000111B       ;RESTORE DEFAULT MUX CHANNEL
404B    F6 02                   ORI     00000010B       ;AND NOT TESTING MODE
404D    D3 12                   OUT     12H
404F    32 5F78                 STA     OUTREG          ;RESTORE OUTREG
4052    00                      NOP

                        ;BIT STRENGTH FOR AMPS READING = 9.76562mA/BIT ON AN 80 BIT SCALE.
                        ;BIT STRENGTH FOR VOLTS = 156.25mV/BIT ON AN 80 BIT SCALE.
                        ;THE RESULTING i x v PRODUCT = 1.52587mVA/BIT.  EACH SECOND AT ROLE
                        ;THIS SUM OF PRODUCTS WILL BE CONVERTED TO A 200Wp ARRAY POWER
                        ;BY MULTIPLYING THE BIT STRENGTH BY 256 x [13.33 x 0.7 / 4] = .910,
                        ;WHERE 256 IS A RESULT OF LOOKING ONE BYTE HIGHER ON THE SUM, 13.33
                        ;IS THE NUMBER OF RA 15 PANELS A 200 kWp ARRAY WOULD REQUIRE, 4 IS
                        ;THE NUMBER OF PRODUCTS THAT COMPRISE THE SUM EACH SECOND, AND 0.7
                        ;IS THE MAX POWER FACTOR FOR THE ARRAY - AN ESTIMATE OF THE MAXIMUM
                        ;POWER POINT (IN WATTS) THAT CORRESPOND TO THE VALUES WE OBTAIN FOR
                        ;OPEN CIRCUIT VOLTAGE AND SHORT CIRCUIT CURRENT.  A SUBSEQUENT
                        ;MULTIPLICATION WILL BE NEEDED TO CONVERT THIS 200Wp SIMULATION INTO
                        ;THE DESIRED SIZE OF SIMULATED ARRAY.

4053    21 5FAB                 LXI     H,TEMSUM
4056    06 03                   MVI     B,03H
4058    CD 411C                 CALL    CLR     ;[TEMSUM] = [00 00 00]
405B    00                      NOP

405C    3A 5FBB                 LDA     SCAMPS  ;PV Isc x Voc PRODUCTS SUMMED 4 TIMES / SECOND
405F    57                      MOV     D,A
4060    3A 5FBC                 LDA     OCVOLT
4063    4F                      MOV     C,A
4064    CD 40A3                 CALL    MULTPV  ;RESULT IN (BC)
4067    00                      NOP

4068    21 5FAB                 LXI     H,TEMSUM
406B    71                      MOV     M,C     ;LSBYTE OF PRODUCT INTO TEMSUM
406C    23                      INX     H
406D    70                      MOV     M,B     ;MSBYTE OF PRODUCT INTO TEMSUM + 1
406E    00                      NOP

406F    21 5FB1                 LXI     H,ARRSUM
4072    11 5FAB                 LXI     D,TEMSUM
4075    06 03                   MVI     B,03H
4077    CD 411D                 CALL    ADDING  ;[ARRSUM] = [ARRSUM] + [TEMSUM]  (EACH 1/4 SEC)
407A    00                      NOP

407B    C9                      RET


407C    B7              SNDDAC: ORA     A               ;CLEAR CARRY
407D    17                      RAL                     ;SET UP FOR DAC
407E    32 8000                 STA     DAC             ;AND SEND
4081    C9                      RET

4082    05              DELAY:  DCR     B               ;INPUT: DOWN COUNTER IN B REGISTER
4083    C8                      RZ                      ;~4.5 MICROSECONDS PER DIGIT OR
4084    C3 4082                 JMP     DELAY           ;13 MACHINE CYCLES PER LOOP @ 3 MHZ
```

```
 4087    3A 5F78          READPV: LDA     OUTREG          ;GET OUTPUT PORT STATUS
 408A    E6 FB                    ANI     11111011B       ;ASSERT HOLD MODE
 408C    D3 12                    OUT     12H
 408E    32 A000                  STA     ADC             ;START A/D CONVERSION

 4091    DB 11            READY:  IN      11H             ;GET INPUT PORT VALUES
 4093    E6 20                    ANI     00100000B       ;ISOLATE -BUSY
 4095    CA 4091                  JZ      READY           ;LOOP IF DATA NOT READY
 4098    3A 5F78                  LDA     OUTREG          ;GET OUTPUT STATUS
 409B    F6 04                    ORI     00000100B       ;BACK INTO SAMPLE MODE
 409D    D3 12                    OUT     12H
 409F    3A A000                  LDA     ADC             ;GET DATA
 40A2    C9                       RET


 40A3    06 00            MULTPV: MVI     B,00H   ;GIVES PRODUCT IN BC FOR OCVOLTS IN C
 40A5    1E 08                    MVI     E,08H   ;AND SCAMPS IN D REGISTERS, RESPECTIVELY

 40A7    79                       MOV     A,C
 40A8    1F                       RAR
 40A9    4F                       MOV     C,A

 40AA    78               MULTJ:  MOV     A,B
 40AB    D2 40AF                  JNC     CNTJ
 40AE    82                       ADD     D
 40AF    1F               CNTJ:   RAR
 40B0    47                       MOV     B,A
 40B1    79                       MOV     A,C
 40B2    1F                       RAR
 40B3    4F                       MOV     C,A
 40B4    1D                       DCR     E
 40B5    C8                       RZ
 40B6    C3 40AA                  JMP     MULTJ


 40B9    D6 80            JSTIFY: SUI     80H     ;SUBTRACTS 80H FROM AN A/D CONVERSION
 40BB    FA 40C1                  JM      FILTER  ;IN ACCUMULATOR AND RETURNS WITH DIFFERENCE
 40BE    FE 01                    CPI     01H     ;ALSO FILTERS OUT ANY 01 READINGS
 40C0    C0                       RNZ
 40C1    3E 00            FILTER: MVI     A,00H
 40C3    C9                       RET

 40C4                     ROTRGT:         ;ROTATES STRING AT (HL) OF (C) BYTES (E) BITS RIGHT
 40C4    06 00                    MVI     B,00H   ;(BC) = 16 BIT INDEX FOR MOST SIG BYTE
 40C6    0D                       DCR     C
 40C7    09                       DAD     B       ;(HL) = LOCATION OF MOST SIG BYTE OF STRING
 40C8    E5                       PUSH    H
 40C9    0C                       INR     C
 40CA    C5                       PUSH    B       ;(C) = # BYTES TO BE ROTATED
 40CB    00                       NOP

 40CC    B7               NXTBIT: ORA     A       ;CLEAR CARRY
 40CD    7E               NXTBYT: MOV     A,M
 40CE    1F                       RAR             ;ROTATE BYTE ONE BIT RIGHT
 40CF    77                       MOV     M,A
 40D0    2B                       DCX     H
```

```
40D1    0D                  DCR     C
40D2    C2 40CD             JNZ     NXTBYT  ;DO ALL BYTES BEFORE CHECKING FOR NEXT BIT
40D5    C1                  POP     B
40D6    E1                  POP     H
40D7    1D                  DCR     E
40D8    C8                  RZ              ;RETURN IF CORRECT # BITS HAVE BEEN ROTATED
40D9    E5                  PUSH    H
40DA    C5                  PUSH    B
40DB    00                  NOP
40DC    C3 40CC             JMP     NXTBIT  ;ELSE ROTATE ALL BYTES ONE MORE BIT


40DF    06 03       ROLE:   MVI     B,03H   ;# BYTES IN POWER x FACTOR
40E1    3E 08               MVI     A,08H
40E3    32 5F73             STA     NUMBIT  ;# BITS IN FACTOR STORED AT NUMBIT
40E6    0E E9               MVI     C,0E9H  ;(E9H/FFH) = .910 REPRESENTS A 200 Wp ARRAY
40E8    11 5FB1             LXI     D,ARRSUM ;(DE) = Isc x Voc PRODUCT SUM ADDRESS
40EB    CD 411E             CALL    FACTOR  ;[PRODCT] = [ARRSUM x 233]
40EE    00                  NOP
40EF    06 03               MVI     B,03H   ;# BYTES IN FACTORED POWER
40F1    23                  INX     H       ;SHIFT RESULT/256 INTO ARRSUM LOCATION
40F2    CD 411B             CALL    SHIFT   ;[ARRSUM] = [ARRSUM] x .910 (233/256)
40F5    00                  NOP             ;FOR 200 Wp ARRAY

40F6    06 03               MVI     B,03H   ;# BYTES IN ARRSUM x FACTOR
40F8    3E 08               MVI     A,08H
40FA    32 5F73             STA     NUMBIT
40FD    3A 5F5D             LDA     PVFCTR  ;EACH MULTIPLE IS WORTH 200 Wp
4100    4F                  MOV     C,A     ;SO, A FACTOR OF 0AH = 10D SIMULATES A 2kWp ARRAY
4101    11 5FB1             LXI     D,ARRSUM
4104    CD 411E             CALL    FACTOR
4107    00                  NOP
4108    06 03               MVI     B,03H
410A    CD 411B             CALL    SHIFT   ;[ARRSUM] = [ARRSUM] x PVFCTR (SIMULATED POWER)
410D    00                  NOP

410E    2A 5F8F             LHLD    ARRPWR
4111    EB                  XCHG            ;(DE) = TODAY'S ARRAY POWER ADDRESS
4112    21 5FB1             LXI     H,ARRSUM ;(HL) = ARRSUM ADDRESS
4115    06 03               MVI     B,03H   ;(B) = # BYTES TO BE SHIFTED TO ARRPWR
4117    CD 411B             CALL    SHIFT   ;[ARRPWR] = [ARRSUM]
411A    00                  NOP


411B    C9          SHIFT:  RET

411C    C9          CLR:    RET

411D    C9          ADDING: RET

411E    C9          FACTOR: RET
```

```
  411F    0A               DATBAS: DB   0AH          ;PV FACTOR: 0AH = 2 kWP, 0FH = 3kWP,
                                                     ;14H = 4kWP, 1EH = 6kWP.
  4120    1A                       DB   1AH          ;DEMAND CHARGE FACTOR/256 = $/kWh
  4121    1A                       DB   1AH          ;BUYBACK RATE FACTOR/256 = $/kWh
  4122    08                       DB   00001000B    ;IMUX CH #1
  4123    00                       DB   00000000B    ;VMUX CH #1
  4124    00                       DB   00H          ;DSPINDEX BASE
  4125    04                       DB   04H          ;ARRAY POWER INDEX (LED #1)
  4126    01                       DB   01H          ;HOME POWER INDEX (LED #2)
  4127    27                       DB   27H          ;NET DAILY BILL INDEX (LED #3)
  4128    13                       DB   13H          ;DEM/ARR kWhrs PURCHASED INDEX (LED #4)
  4129    1D                       DB   1DH          ;DEM/ARR COST INDEX (LED #5)
  412A    18                       DB   18H          ;ARR/DEM kWhrs SOLD INDEX (LED #6)
  412B    22                       DB   22H          ;ARR/DEM VALUE INDEX (LED #7)
  412C    0E                       DB   0EH          ;DAILY ARRAY ENERGY kWh (LED #8)
  412D    09                       DB   09H          ;HOME DAILY DEMAND kWh (LED #9)
  412E    5000                     DW   5000H        ;DAY ADDRESS
  4130    5780                     DW   5780H        ;LAST DAY ADDRESS: GIVES 40 DAYS STORAGE
  4132    5000                     DW   5000H        ;FIRST DAY ADDRESS
  4134    00                       DB   00H          ;PREVIOUS DAY COUNTER
  4135    08                       DB   08H          ;NUMBER OF BITS IN DEFAULT FACTOR
  4136    04                       DB   04H          ;1/4 SEC COUNTER
  4137    00                       DB   00H          ;SEC
  4138    00                       DB   00H          ;MIN
  4139    00                       DB   00H          ;HRS
  413A    46                       DB   01000110B    ;OUTREG
  413B    00                       DB   00H          ;TIMERCHANGE DEFAULT
  413C    009D                     DW   009DH        ;TIMER0 LOAD VALUE, WILL NEED TUNING
                                                     ;DEPENDENT ON SEC VALUE==>FREQUENCY
  413E    0020                     DW   0020H        ;TIMER1 LOAD VALUE
  4140    16E6                     DW   16E6H        ;TIMER2 LOAD VALUE
                                                     ;APPROXIMATE CRYSTAL FREQ=2X(750.332KHz)
  4142    FF                       DB   0FFH         ;DSPMOD

                                   END
```

Macros:

Symbols:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ADC | A000 | ADDING | 411D | AODCST | 5F83 | AROVDM | 5F87 |
| ARRENG | 5F8B | ARRPWR | 5F8F | ARRSUM | 5FB1 | BUYBAK | 5F5F |
| CLR | 411C | CNTJ | 40AF | CNVSPC | 5F95 | COUNT | 5F74 |
| DAC | 8000 | DATBAS | 411F | DAY | 5F6C | DAY1 | 5F70 |
| DBBEG | 5F5D | DBEND | 5F81 | DELAY | 4082 | DEMCHG | 5F5E |
| DEMENG | 5F8D | DEMPWR | 5F91 | DEMSUM | 5FB6 | DMOVAR | 5F89 |
| DOACST | 5F85 | DSPADR | 5F93 | DSPIND | 5F62 | DSPMOD | 5F80 |
| DSPREG | 5FBF | FACTOR | 411E | FILTER | 40C1 | HRS | 5F77 |
| IMUX | 5F60 | JSTIFY | 40B9 | LSTDAY | 5F6E | MAXPOW | 5FBD |
| MEMEND | 5F81 | MIN | 5F76 | MULTJ | 40AA | MULTPV | 40A3 |
| MUXI1 | 0008 | MUXV1 | 0000 | NEGSUM | 5FAE | NETCST | 5F81 |
| NUMBIT | 5F73 | NXTBIT | 40CC | NXTBYT | 40CD | OCVOLT | 5FBC |
| OUTREG | 5F78 | PPRT | 0002 | PRODCT | 5F98 | PRVDAY | 5F72 |
| PVFCTR | 5F5D | PVOCCH | 0030 | PVSCCH | 0010 | READPV | 4087 |
| READY | 4091 | ROLE | 40DF | ROTRGT | 40C4 | SCAMPS | 5FBB |
| SEC | 5F75 | SHIFT | 411B | SNDDAC | 407C | SOLAR | 4000 |
| STACK | 5FFF | STKEND | 5FC3 | TEMAOD | 5FA1 | TEMDOA | 5FA6 |
| TEMSUM | 5FAB | TIMERO | 9000 | TIMER1 | 9100 | TIMER2 | 9200 |
| TIMER3 | 9300 | TMRS | 5F79 | VMUX | 5F61 | | |

No Fatal error(s)

# APPENDIX 2B

## PV MAX POWER ROUTINE

```
PVTEST.PRN        MACRO-80 3.4    01-Dec-80        PAGE    1

                                          TITLE  PVTEST.PRN

 5000                        OUTREG EQU 5000H
 0000                        PVCH EQU 00H
 5000                        VE EQU 5000H
 5000                        IMAX EQU 5000H
 5000                        CMPBH EQU 5000H
 5000                        CURINC EQU 5000H
 5000                        MAXPOW EQU 5000H
 5000                        ADC EQU 5000H
 5000                        CLRA EQU 5000H
 5000                        DAC EQU 5000H

 0000'   3A 5000             PVPWR:  LDA    OUTREG
 0003'   E6 C5                       ANI    11000101B
 0005'   F6 00                       ORI    PVCH          ;PV CHANNEL ALL SET
 0007'   D3 12                       OUT    12H           ;AND NOW MUXED IN
 0009'   32 5000                     STA    OUTREG        ;SAVE OUTREG STATUS
 000C'   3A 5000                     LDA    VE            ;NEGLIBLE VOLTAGE LEVEL
 000F'   57                          MOV    D,A           ;INTO D
 0010'   3A 5000                     LDA    IMAX          ;IMAX
 0013'   47                          MOV    B,A           ;BREG=CURRENT CURRENT
 0014'   B7                          ORA    A             ;CLEAR CARRY JUST IN CASE
 0015'   1F                          RAR                  ;DIVIDE BY TWO
 0016'   4F                          MOV    C,A           ;AND STORE INCREMENTEE IN CREG
 0017'   79                  PVLP1:  MOV    A,C           ;INCREMENTEE IN A
 0018'   B7                          ORA    A             ;SET ZERO FLAG IF EMPTY
 0019'   CA 003E'                    JZ     LOCMAX        ;ZERO=DEPARTURE
 001C'   78                          MOV    A,B           ;ELSE GET CURRENT IN A
 001D'   91                          SUB    C             ;DECREMENT...
 001E'   47                          MOV    B,A           ;STORE...
 001F'   CD 0081'            PVLP2:  CALL   SNDDAC        ;AND SEND
 0022'   CD 0086'                    CALL   RDPV1         ;START A/D
 0025'   79                          MOV    A,C           ;GET INCREMENTEE
 0026'   B7                          ORA    A             ;CLEAR ZERO FLAG
 0027'   1F                          RAR                  ;DIVIDE BY TWO
 0028'   4F                          MOV    C,A           ;AND STORE
 0029'   CD 0091'                    CALL   RDPV2         ;GET A/D READING
 002C'   5F                          MOV    E,A           ;STORE VOLTAGE IN E
 002D'   BA                          CMP    D             ;COMPARE TO VE
 002E'   CA 003E'                    JZ     LOCMAX        ;JACKPOT!... IF ZERO
 0031'   DA 0017'                    JC     PVLP1         ;GO TO DECREMENT IF NECESSARY
 0034'   79                          MOV    A,C           ;ELSE GET INCREMENTEE
 0035'   B7                          ORA    A             ;SET ZERO FLAG IF EMPTY
 0036'   CA 0068'                    JZ     NOPWR         ;ZERO=TODDLES
 0039'   80                          ADD    B             ;ELSE ADD CURRENT...
 003A'   47                          MOV    B,A           ;STORE...
 003B'   C3 001F'                    JMP    PVLP2         ;AND...

 003E'   4B                  LOCMAX: MOV    C,E           ;VOLTAGE NOW IN C
 003F'   50                          MOV    D,B           ;CURRENT NOW IN D
 0040'   CD 006E'                    CALL   MULTDC        ;MULTIPLY CURRENT AND VOLTAGE
 0043'   3A 5000                     LDA    CURINC        ;GET CURRENT INCREMENT VALUE
 0046'   5F                          MOV    E,A           ;INTO A
 0047'   69                  LCMXLP: MOV    L,C           ;PUT IN HIGHEST POWER LOCATION
 0048'   60                          MOV    H,B           ;
```

```
0049'   7A                         MOV   A,D          ;CURRENT IN A
004A'   93                         SUB   E            ;SUBTRACT INCREMENT FROM CURRENT
004B'   DA 0064'                   JC    STMXPR       ;EXIT IF NEGATIVE
004E'   57                         MOV   D,A          ;STORE NEW CURRENT
004F'   CD 0081'                   CALL  SNDDAC       ;OUTPUT CURRENT
0052'   CD 0086'                   CALL  RDPV1        ;START A/D CONVERSION
0055'   CD 0091'                   CALL  RDPV2        ;GET VOLTAGE VALUE
0058'   4F                         MOV   C,A          ;GET VOLTAGE IN C
0059'   D5                         PUSH  D            ;SAVE CURINC
005A'   CD 006E'                   CALL  MULTDC       ;GET NEW POWER
005D'   D1                         POP   D            ;RESTORE CURINC
005E'   CD 5000                    CALL  CMPBH        ;AND COMPARE
0061'   D2 0047'                   JNC   LCMXLP       ;CONTINUE IF STILL CLIMBING
0064'   22 5000          STMXPR:   SHLD  MAXPOW       ;ELSE STORE MAX POWER
0067'   C9                         RET

0068'   21 0000          NOPWR:    LXI   H,00H
006B'   C3 0064'                   JMP   STMXPR

006E'   06 00            MULTDC:   MVI   B,00H
0070'   1E 09                      MVI   E,09H
0072'   79               MULT1:    MOV   A,C
0073'   1F                         RAR
0074'   4F                         MOV   C,A
0075'   1D                         DCR   E
0076'   C8                         RZ
0077'   78                         MOV   A,B
0078'   D2 007C'                   JNC   MULT2
007B'   82                         ADD   D
007C'   1F               MULT2:    RAR
007D'   47                         MOV   B,A
007E'   C3 0072'                   JMP   MULT1


0081'   B7               SNDDAC:   ORA   A            ;CLEAR CARRY
0082'   17                         RAL                ;SET UP FOR DAC
0083'   32 5000                    STA   DAC          ;AND SEND

0086'   3A 5000          RDPV1:    LDA   OUTREG       ;GET OUTPUT PORT STATUS
0089'   E6 FB                      ANI   11111011B    ;ASSERT SAH HOLD MODE
008B'   D3 12                      OUT   12H          ;
008D'   32 5000                    STA   ADC          ;START A/D CONVERSION
0090'   C9                         RET

0091'   DB 11            RDPV2:    IN    11H          ;GET INPUT PORT VALUES
0093'   E6 20                      ANI   00100000B    ;ISOLATE -BUSY
0095'   CA 0091'                   JZ    RDPV2        ;LOOP IF DATA NOT READY
0098'   3A 5000                    LDA   OUTREG       ;GET OUTPUT STATUS
009B'   F6 04                      ORI   00000100B    ;THROW INTO SAMPLE MODE
009D'   3A 5000                    LDA   ADC          ;GET DATA
00A0'   17                         RAL                ;GET MSB IN CARRY
00A1'   D4 5000                    CNC   CLRA         ;IF NEGATIVE THEN NULLIFY
00A4'   1F                         RAR                ;RESTORE WITH MSB CLEARED
00A5'   C9                         RET                ;AND RETURN
```

```
  00A6'   C9              PWRACC: RET
  00A7'   C9              NEWDSP: RET
  00A8'   C9              ADINT:  RET
  00A9'   C9              CPINT:  RET
  00AA'   C9              NMI:    RET
                                  END
```

# APPENDIX 6

## PHOTOVOLTAIC VALUES INTERVIEW:

- Attitudes Toward Conservation
- Personal Commitment to Conserve vs. Comfort or Health
- Energy Invisibility
- Economic Considerations
- Attitudes Toward Solar Energy

# Photovoltaic Values Interview

## 1 Attitudes Toward Conservation

1.1 How did the energy crisis affect your energy consumption habits?
(Thermostat setting, lights, hot $H_2O$ heater, driving speed)

1.2 Did the energy crisis affect your energy related purchases?
(Insulation, refrigerator, high MPG car)

1.3 Thinking back over these purchases and changes in energy usage patterns, were they worth the trouble and investment? Would you do the same again?

1.4 Do you see the energy situation in the United States as a significant problem now or in the future?

1.5 Would more energy conservation by individuals contribute much to this country's energy independence? (carpooling, insulating)

1.6 Could you rank the following general categories by importance to you in forming your outlook on conservation:
national security and energy independence;
cost of energy efficient devices;
inconvenience of changing habits (wearing sweaters indoors, driving slow, carpools)

## 2 Personal commitment to conserve vs. comfort or health

2.1 What is your normal winter home thermostat setting?

2.2 How uncomfortable would you be if you turned it down 3°? Have you tried?

2.3 Would family health become a particular concern if you turned your thermostat down?

2.4 Is household energy conservation an important family concern or one of the minor ones?

## 3 Energy invisibility

3.1 If you were to try to cut down on home electricity consumption, what would be your top priority?

3.2 Which appliances or electrical devices consume the most in your home?

3.3 Can you tell from your electricity bill whether or not you are doing a better job conserving electricity one month to the next.

## 4 Economic Considerations

4.1 Have your energy conserving practices made a significant difference in your monthly utility bills? Do they make a big difference in general?

4.2 At what point (monthly cost) would you become concerned about your own home energy consumption?

4.3 Do you know the present rate you pay for electricity? At what rate would you start to seriously consider conserving? (15¢, 25¢, 50¢/Kwh)

4.4 In considering the purchase of a home energy saving device would it need to pay for itself in energy savings for you to purchase it? What is the payback period over which it would need to pay for itself?

4.5* Is the monthly electricity bill significant relative to other utility bills? (water, phone, oil, gas, etc.)

4.6* Have you noticed the effect of rising electricity prices on your family budget?

4.7* Have you found it necessary to look for ways to trim your family budget?

4.8* Which of the following annual income brackets is your household in?
$10,000 - $17,000
$17,000 - $26,000
$26,000 - $32,000
$32,000 - above

## 5 Attitudes toward solar energy

5.1 Is solar energy a desirable source for your household use? (PV, hot $H_2O$, space heat) What do you see as its major drawbacks?

*5.2 Do you know anyone who has a solar energy device or home design?

5.3 Have you ever considered installing a solar energy system? What were the main factors in your decision? (cost, uncertain payback, technical bugs, aesthetics)

5.4 Do renewable forms of energy present enough potential to replace more traditional energy forms in this country? (nuclear, coal, oil)

5.5 Would the ability to sell electricity back to the utility and, perhaps, to be electrically independent have much value to you?

5.6 Are you confident of a technical breakthrough that will give humankind a virtually unlimited, environmentally benign energy source in the near future?

5.7 Was the energy crisis a hoax?

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Thank-you for filling out your answers to these few questions and the time you took to sit down with me in the interview. All information will be treated as strictly confidential.

1. Is the monthly electricity bill significant relative to other utility bills? (water, phone, oil, gas, etc)

2. Have you noticed thje effect of rising electricity prices on your family budget?

3. Have you found it necessary to look for ways to trim your family budget?

4. Which of the following annual income brackets is your household in?

   $10,000 - $17,000
   $17,000 - $26,000
   $26,000 - $35,000
   $35,000 - up