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Phase II Report on Energy Efficient Electronic Ballasts for A Two-40 Watt Fluorescent Lamp System

IOTA Engineering, Inc.

July 1978

Lawrence Berkeley Laboratory University of California/Berkeley

Prepared for the U.S. Department of Energy under Contract No. W-7405-ENG-48

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PHASE II REPORT

ON

ENERGY EFFICIENT ELECTRONIC BALLASTS

FOR A TWO-40 WATT FLUORESCENT LAMP SYSTEM

This work was done with support from the Office of Conservation and Solar Application, Division of Buildings and Community Systems, of the U. S. Department of Energy.

1.0 COVER PAGE

PHASE II REPORT

ON

ENERGY EFFICIENT ELECTRONIC BALLASTS FOR A TWO-40WATT FLUORESCENT LAMP SYSTEM

JULY 1978

Prepared For

LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA

UNDER SUBCONTRACT 2253202

BY

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2.0 ABSTRACT

2.1 The Department of Energy (DOE) through one of its operating contractors, Lawrence Berkeley Laboratory (LBL) of the University of California, has established a project aimed at accelerating the commercialization of electronic ballasts. During the Phase I portion of the project IOTA delivered a small quantity of ballasts and other hardware for independent testing by LBL and an outside laboratory. Results verified the IOTA claims for energy savings and other unique and advantageous features of the electronic ballast.

2.2 This report covers IOTA's part in the Phase II portion of the project which was conceived by LBL as a large scale field demonstration. The demonstration is being conducted by LBL and the Pacific Gas and Electric Company in the PG&E headquarters building in downtown San Francisco. IOTA's primary role in this portion of the program has been to complete the necessary engineering and to manufacture or procure the test demonstration hardware. Included are two models of energy saving ballasts; two dimmer systems that show the potential for additional power savings; and, two models of Automatic Emergency Light Systems. Ballasts were manufactured by EXCEL Division of Beatrice Foods under subcontract to IOTA. EXCEL will produce and market electronic ballasts using IOTA's patented circuits under terms of a contractual agreement.

2.3 Installation of ballasts and the beginning of actual test operations were originally scheduled for February 1978. However, slippages in hardware deliveries have caused a three-month delay. Testing at PG&E is now scheduled to begin in June 1978.

2.4 Even though broad scale results from the Phase II demonstration at PG&E are not yet available, performance and versatility advantages of the electronic ballast have been demonstrated. They offer a clear incentive to the industry for development and production of reliable hardware that will be competitively saleable on a long term cost-of-lighting basis.

2.5 Additional government sponsored work is recommended. Areas needing attention are: EMI; adaptations for solar-powered photovoltaic electrical systems; and, electronic ballasts for high output fluorescent and HID lamps.

TABLE OF CONTENTS

	PAGE
1.0 COVER PAGE	1
2.0 ABSTRACT	2
3.0 TABLE OF CONTENTS	3
4.0 THE PROGRAM AND CONTRACT	4
5.0 TECHNICAL SCOPE OF WORK -- THE TASKS	7
6.0 APPROACH	9
7.0 DISCUSSION OF WORK TASKS AND RESULTS	11
7.1 Engineering Changes for EXCEL Manufactured Prototypes	11
7.2 Discussion of EMI	12
7.3 EXCEL Subcontract	13
7.4 Continuous Dimming Demonstrator	16
7.5 Emergency Light Systems	21
7.6 Accelerated Start-Life Testing	31
7.7 Tests with a Closed Fixture	34
7.8 Certification	37
7.9 Failure Analysis	38
7.10 Commercialization Strategy	39
7.11 Product Literature	41
8.0 RECOMMENDATIONS	43
APPENDIX 1 -- PROGRAM WORK PLAN	44
APPENDIX 2 -- EMI REPORT BY DR. ALFRED J. HOEHN	48
APPENDIX 3 -- PERFORMANCE DATA ON EXCEL MANUFACTURED BALLASTS	56
APPENDIX 4 -- PRODUCT LITERATURE	61
APPENDIX 5 -- LIGHTING RESEARCH LABORATORY REPORT (Excerpts)	75
APPENDIX 6 -- EXCEL CONTRIBUTION	86

4.0 THE PROGRAM AND CONTRACT

4.1 OBJECTIVES AND BACKGROUND

4.1.1 The United States Department of Energy (DOE) has established a number of programs aimed at reducing the use of energy that must be derived from fossil fuels. One of the areas where potential savings are appreciable is in LIGHTING since design constraints for installations have generally considered first costs and rarely the operational cost (in the consumption of energy). The Consumer Products and Technology branch of the DOE has established projects to improve the efficiency of lighting systems. The Lawrence Berkeley Laboratory (LBL) of the University of California is an operating contractor under DOE. They are planning and managing a number of projects to implement the DOE objectives. Electronic ballasts that power standard fluorescent lamps at high oscillating frequencies have been shown to save appreciable energy while producing a better quality of light. One of LBL's projects is to help accelerate the commercialization of these ballasts by assisting in their development and/or demonstration.

4.1.2 IOTA Engineering was one of two winners in February 1977 in a national competition on a project to "demonstrate energy efficient electronic ballasts." The program was envisioned to have two Phases.

4.2 PHASE I CONTRACT

4.2.1 The Phase I program was designed to bring the electronic ballast to the point where hardware was available for (1) verification performance testing by an independent laboratory, and (2) in-house performance and system-life testing by LBL.

4.2.2 IOTA delivered twelve units which included two different model ballasts. One was optimized for an approximately 6000 lumen light

level. The other was for a 5000 lumen light output. The ballasts were all for 2-40W lamp fixtures since the 40W lamp accounts for nearly 40% of the total lamp sales. IOTA's ballasts were delivered in June 1977. Delivery of fifty additional units for LBL testing was completed in November 1977.

4.2.3 Program results were reported in a Phase I report dated August 1977 and in an Amendment I report dated November 1977.

4.3 PHASE II CONTRACT

4.3.1 The Phase II part of the LBL program, which is the subject of this report, was designed to demonstrate in a commercial type office building a significant number of electronic ballasts. The objective was to operate the ballasts over an appreciable time period in normal work areas. LBL has arranged for the demonstration to take place at the headquarters building of the Pacific Gas and Electric Company in downtown San Francisco. One floor of this building has been designated as the area for evaluation of the IOTA designed ballasts. Baseline data has been obtained after installing new lamps and 120 volt magnetic core ballasts and operating for a period of at least six months. Instrumentation has been installed to monitor instantaneous and time performance of the lighting system. Power for the lights is isolated. Electronic ballasts will be installed at the conclusion of the baseline test and will be operated under identical circumstances for at least an equal time period. The 5000 lumen output ballast will be placed in the outer offices (window offices); internal offices will be supplied with the 6000 lumen output ballasts.

4.3.2 The primary aim of the IOTA Phase II contract was to provide test hardware that will demonstrate key features of the highly versatile electronic ballast.

4.3.3 IOTA's Phase II hardware work was contractually authorized by a second amendment to the Phase I contract. A third amendment authorized engineering work on a ballast that could be variably dimmed by a dial type control. The Amendment II work included hardware for step-dimming demonstration. The continuous dimming offers a different control technique -- but still provides additional power savings.

4.3.4 A fourth amendment to the contract authorized work to reduce the noise that can be generated by a high frequency device. This is generally referred to as Electrical Magnetic Interference (EMI).

4.3.5 Amendment V extended the work period and increased funding as necessary to cover an overrun. The overrun was caused by higher than expected costs on materials and parts; stretch-outs due to late deliveries, and, due to hardware fit problems.

5.0 TECHNICAL SCOPE OF WORK -- THE LBL SPECIFIED WORK TASKS

5.1 TASK VI -- PROGRAM WORK PLAN

5.1.1 This covered preparation and updating of a work plan that detailed task areas within the larger groups called out by LBL in the contract. The work plans are presented under Appendix 1.

5.2 TASK VII -- DEMONSTRATION CONSULTATION

5.2.1 This work area covered the coordination and liaison necessary to integrate program objectives, work functions, status and problems among the involved parties. It also covered attendance at meetings with LBL and PG&E to plan and discuss the demonstration program.

5.3 TASK VIIB -- BALLAST PROCUREMENT

5.3.1 This task covered manufacture of the test hardware. The total numbers and types required were (1) 435 ballasts optimized for 6000 lumen light output; (2) 230 ballasts with a lower light output (5000 lumens); and (3) 15 Emergency (local DC battery supply) System Kits.

5.3.2 This task also included descriptive instructions to facilitate test hardware installation by an electrical contractor.

5.4 TASK IX -- CERTIFICATION

5.4.1 The technical organizations whose certification would be required for general public acceptance throughout the United States are to be identified. Sample hardware should be made available if required.

5.5 TASK X -- FAILURE ANALYSIS

5.5.1 This task was set up to provide for removal of ballasts from the demonstration project to permit study after operating experience. And, it was to cover failure analysis on any ballast that failed during the demonstration program. Findings and proposed corrections are to be reported.

5.6 TASK XI -- COMMERCIALIZATION STRATEGY

5.6.1 This was to propose strategies which would serve to accelerate acceptance and utilization of the novel features of electronic ballasts by building designers and the construction industry. It also included projections of cost estimates for implementation of such strategies -- including monolithic circuits for large volume production.

5.7 TASK XII -- PRODUCT LITERATURE

5.7.1 An information package that describes the technical characteristics and novel features of energy efficient ballasts and products was also required. Those characteristics that permit improved lighting system efficiency were to be included.

5.8 TASK XIII -- CONTINUOUS DIMMING

5.8.1 This covered the engineering work needed to adapt the basic electronic circuitry to provide for continuous dimming.

5.9 TASK XIV -- EMI SUPPRESSION

5.9.1 This covered the work effort and implementing hardware to reduce Electrical Magnetic Interference.

6.0 APPROACH

6.1 GENERAL

6.1.1 Prior to the beginning of IOTA's Phase II work LBL assumed responsibility for coordination with the Pacific Gas & Electric Company to arrange for the Phase II demonstration program. This included provision of instrumentation. Therefore IOTA's role under Phase II was primarily to complete the engineering needed on the test hardware and to manufacture or procure the hardware.

6.1.2 IOTA and EXCEL Division of Beatrice Foods had entered an agreement which grants specified manufacturing and marketing rights to EXCEL prior to the LBL Phase I contract. In light of this fact EXCEL insisted and LBL concurred that the units for the Phase II demonstration should be manufactured by EXCEL. This should provide for more realism in terms of the similarity of test hardware to ultimate production hardware. IOTA agreed to this arrangement. It was specifically directed under Article VI of the Phase II contract with LBL.

6.2 FIRST PRIORITY GIVEN TO COMPLETION OF REQUIRED ENGINEERING

6.2.1 Since all ballasts other than the emergency system hardware were to be procured by subcontract to EXCEL, the first order of business was to get an engineering data package ready for transmission to EXCEL. This included completion of redesigns for needed improvements in both electrical and mechanical areas.

6.3 EMI SECOND PRIORITY

6.3.1 It became apparent in the Phase I program that there was EMI interference in excess of that encountered with standard core ballasts. Since any corrections would need to be identified as soon as possible, work on this task was pursued early in Phase II.

6.4 CONTINUOUS DIMMING NEXT PRIORITY

6.4.1 The intent for this work effort was to help assure that this energy saving feature could be demonstrated using the IOTA ballast, in the event other electronic ballast hardware was not available on the time schedule originally adopted. Early delivery to LBL was therefore desired.

6.5 EMERGENCY SYSTEM HARDWARE

6.5.1 The next area of interest from a time schedule standpoint was the completion of engineering work needed on the emergency lighting systems to permit in-house manufacture of these items.

6.6 CONFIRMATION TESTING

6.6.1 In order to verify that EXCEL production hardware performed comparably with IOTA's demonstration units, typical samples from the EXCEL first production run were performance tested at IOTA. This was the final priority in planning since the action had to follow delivery from EXCEL.

7.0 DISCUSSION OF WORK TASKS AND RESULTS

7.1 ENGINEERING CHANGES FOR EXCEL MANUFACTURED PROTOTYPES

7.1.1 Mechanical: The Phase I program revealed a number of mechanical deficiencies in terms of clearances for the housing on the units, plus electrical wiring problems relating to adequate spacing for high voltage paths on the printed circuit board. These made it necessary to redesign the metal hardware. Both the chassis and the cover were redesigned.

7.1.2 Electrical: One significant change was made in the method of powering the lamp filament. Phase I hardware had used a separate toroid type transformer for this purpose. When quantities of units were built, wide differences developed in open circuit performance conditions. Open circuit wattages with the lamps removed were excessively high and could have contributed to thermal failures. We also found a "squegging" phenomena in some units. This was caused by variations in components. The design point was not sufficiently centered. It had to be corrected to provide more margin for production tolerance variations. It was also necessary to re-optimize to boost light output on the 5000 lumen units. This was due to the fact that IOTA's early light measuring technique was not accurate for lower than standard light output levels. And, finally EMI mods required circuit board changes. For all of these foregoing reasons the printed circuit board had to be redesigned for the prototype units.

7.1.3 Model Designations: The designations adopted for the resulting prototype units were Model 54P-X and Model 64P-X to designate the 5000 and 6000 lumen units. (X designates the Serial No.)

7.2 DISCUSSION OF EMI

7.2.1 Background: In-house testing on IOTA's electronic ballasts prior to the LBL project has never previously included any significant effort to determine the extent of the EMI problem. We have conducted crude tests using hand-held radios and radios plugged into the same electrical power line connection. These have revealed a definite noise interference in between stations in the AM radio band region. Other efforts using noise meters have indicated that at distances greater than three to four feet from the lamps the EMI that is radiated was no greater than for standard magnetic type ballasts. However, we had found that there was a definite increase in noise from conducted radiation. The electrical supply lines themselves will radiate a higher than standard noise level if no filtering has been applied.

7.2.2 Conducted Noise Measurements: Under the Phase I contract IOTA arranged by subcontract with Dr. Alfred J. Hoehn, a local consulting engineer with broad experience in the RF field, to make measurements. Dr. Hoehn's laboratory equipment does not include a screen room; or, the facilities to conduct accurate outdoor testing. Therefore his work was confined to measuring conducted EMI in his laboratory.

7.2.3 Phase I Results: The baseline data revealed that there was indeed an appreciably higher level (28 db) of conducted radiation in the frequency ranges investigated with the electronic ballast compared with the magnetic ballast. However, there were also other interesting results from the baseline test with standard ballasts and lamps. For example, there was a decided noise that was randomly encountered with standard ballasts and lamps. It exceeded the uncorrected noise obtained with the Model 62 electronic ballast used as the sample. The noise is

worse with old model lamps than with new lamps. It is associated with the "hunting" of the hot spot on the filament of the lamps when powered by standard 60 cycle ballasts. This random phenomenon was not encountered with the electronic ballast. The interference level is constant from minute to minute and from test to test.

7.2.4 Modification to Reduce Conducted EMI: Under the Phase II program, with Dr. Hoehn's assistance we were able to modify the circuit with some relatively simple changes that resulted in an appreciable reduction of the noise generated by the Model 62 unit. Dr. Hoehn's final letter report summarizing findings is presented in Appendix 2.

7.2.5 Other EMI Test Results: LBL and/or PG&E have subsequently conducted tests to study the EMI with IOTA's first generation of electronic ballasts. These tests have apparently included both conducted and radiated measurements. The frequency range investigated covers radio band ranges for conducted noise that are lower than were checked by Dr. Hoehn. The net result of both tests though is to indicate that the EMI is more than with standard ballasts. Additional work must be undertaken if we are to reduce both types of EMI to levels no greater than those encountered with the standard magnetic core ballast. We are of the opinion that this can be accomplished. It must include a firm understanding and "fix" on just what the FCC requirements are to be -- if we are to avoid unnecessary cost and complexity.

7.3 EXCEL SUBCONTRACT

7.3.1 Background: In the Fall of 1976 IOTA entered into an agreement with EXCEL Division of Beatrice Foods Company. It provided funding for a prototype program on IOTA's proprietary electronic ballasts for 2-40W lamps. The two circuits that were involved were covered by

pending patent claims both of which were subsequently granted. In exchange for funding the prototype work EXCEL was offered an exclusive option for a license/purchase agreement to the circuits (with the exception of emergency lighting applications). In December of 1976 the prototype resulting from the EXCEL sponsored work was proposed for use in the LBL Phase I program. Shortly after award of the LBL Phase I contract EXCEL exercised their option pertaining to the ultimate purchase of specified rights to the two circuits. See App. 6 for EXCEL contributions.

7.3.2 The EXCEL Role: In early September 1977 prior to award of the Phase II contract it had been planned that EXCEL would undertake a "production engineering" redesign to make the IOTA prototype more suitable for volume manufacturing. However, after the contract was awarded and the first efforts were made to get an engineering definition of the starting point for EXCEL, they concluded that the time remaining before the projected delivery date for the ballasts for the demonstration test at the PG&E headquarters building was too close. There would not be enough time for a redesign with the required re-optimization and confirmation testing to assure equal performance and reliability. EXCEL therefore decided to reproduce the IOTA prototypes with the exception of some mechanical changes. These related to a different metal housing and heat sink arrangement designed to reduce manufacturing cost and improve heat-sinking capability. They also changed the layout of the printed circuit board in order to reduce production assembly time.

7.3.3 The Data Package: IOTA transmitted a preliminary data package in early October followed by a so-called final package in late October. The verbal agreement with EXCEL regarding mechanical changes was that the size and shape of the ballast that finally resulted must not be greater than a standard 2-lamp 40W fluorescent ballast. The ballast

must also be designed to be attached to the fixture (via screws) in the same manner as the core ballast. Sample units of the IOTA models were also provided. We had completed redesign of the circuit board and the mechanical housing to improve fit and electrical aspects but hardware of that design was not available at the time. Earlier models were sent followed later by 54P and 64P models.

7.3.4 EMI Mods: Dr. Hóehn's results on the EMI testing showed that an appreciable reduction could be made in the conducted noise by relatively simple changes. LBL agreed that these should be made in the demonstration units. Therefore the package was again redesigned to accommodate these changes. This resulted in the first delays, since EXCEL had to redesign their already completed printed circuit board.

7.3.5 Component Deliveries: Following the EMI design changes, components for the test program hardware were ordered by EXCEL. However, delays were encountered in delivery which stretched the earliest assemblies into February or March 1978.

7.3.6 Further Delays Due to Mechanical Fit Problems: In March of 1978 the first mechanical fit of the EXCEL produced ballast with a special heat sink type extrusion used in the PG&E fixtures revealed an unacceptable interference. To correct the problem it was necessary to redesign and manufacture new metal hardware in order to assure fit in all PG&E fixtures -- without the necessity of "make-shift" installation arrangements. IOTA was delinquent in informing EXCEL that the mechanical fit requirements of the ballasts for the PG&E fixtures were of close tolerance. This was first learned about in January 1978.

7.3.7 Hardware Delivery and Testing Plan: To avoid further schedule delays, deliveries from EXCEL were made directly to LBL and to IOTA. Units shipped to IOTA were for modification to provide for step-dimming,

and, to permit sample verification type performance testing.

7.3.8 Performance Test Results: Appendix 3 presents the summary performance data obtained with 5000 and 6000 lumen units delivered by EXCEL to IOTA for verification testing. Data shows after 10 minutes the average Model 6000 unit produces approximately 5269 lumens of light with a power consumption of 73 watts. This means that the average system efficiency is 72.2 lumens per watt. The Model 5000 unit produces 4787 lumens with a power consumption of 64 watts for a system efficiency of 74.8 lumens per watt. Tests were in free air with a lamp wall temperature of 101-7°F.

7.4 CONTINUOUS DIMMING DEMONSTRATOR

7.4.1 Background: Early in the Phase I program IOTA determined that it would be possible to provide for continuous dimming. However the expense and added complexity did not seem to be warranted. We chose to demonstrate this added power saving feature by a more economical step-dimming technique rather than continuous. However, there are occasions when continuously variable dimming may be beneficial. LBL requested that we provide a demonstrator to show this additional feature. Two methods of continuous dimming were investigated. The first involved varying input voltage to the ballast, and the second dimmed by controlling output power to the lamps. Whichever method is used it should be suitable for control of a number of fixtures by a single control unit.

7.4.2 Dimming by Varying Input Voltage: This method can best be simulated by control with a standard Variac. Efficiency in terms of lumens per watt decreases at lower light levels but remains high. Control is smooth. After lamps are started they can be dimmed down to 10 to 20% of maximum light output without losing the arc. The problem is in being able to simulate the Variac type control with a less expensive and less mechanically cumbersome device. And, an additional concern is to set the minimum

dimming voltage high enough to assure reliable starting under all temperature conditions -- with no detriment to lamp life. This limits the minimum power point to which lights can be dimmed. However, system efficacy at very low light levels is reduced because filaments must be fully activated to avoid electrode "sputtering" with consequent life-shortening effects. Realistically, dimming below this level becomes worthless, with respect to energy savings.

7.4.3 Dimming by Varying Output Power to the Lamps: This method for control was first investigated by empirical variation of output power to the lamps. This substantiated the suitability of the concept. Hardware that was mechanically and electrically suitable for output control was then designed and built.

7.4.4 Description of the System: All unique dimming hardware for each ballast was installed inside the fixture. This is to prevent interference effects between ballasts connected to a single external control. Control of several fixtures was then exercised by a variable power source which had one set of lead wires connected to the dimmer unit in each of the remote fixtures. This unit generated and distributed a low voltage direct current signal.

7.4.5 Dimmer Control Unit: The control unit must be sized for the number of fixtures involved. Since the power consumed by the dimmer unit in each fixture is well under two watts, a considerable number of fixtures can be controlled by a relatively small DC power supply. The demonstrator article used a "pot" type dial control. The function can be readily coupled with daylight sensing equipment for automatic control of artificial light as needed to compensate for varying daylight levels.

7.4.6 Demonstrator Model: IOTA built and delivered in the month of November 1977 a model which demonstrated single and multiple fixture dimming control. For simplicity and economy in achieving the purpose,

one of the fixtures in the multiple unit demonstration was used for showing the single fixture control capability. Performance data achieved with the two systems is shown in TABLE I.

TABLE I

MULTIPLE & SINGLE DIMMER DATA - LBL DEMO UNIT

Test Date	No. Units	Volts	Amps	Power	Units of Light	% Light	% Power
11/23	3	120	1.90	227.0	193.5	100.0	100.0
	3	120	1.52	190.0	166.6	86.1	83.7
	3	120	1.24	155.0	128.3	66.3	68.3
	3	120	.99	118.5	51.5	26.6	52.2
	1	120	.74	78.5	93.0	100.0	100.0
	1	120	.65	70.0	79.5	85.5	89.2
	1	120	.555	60.0	60.6	65.2	76.4
	1	120	.465	51.0	40.4	43.4	65.0

7.4.7 Data Interpretation

7.4.7.1 The first four points were with three fixtures operating and the last four were taken with only one of the fixtures regulated by a single remote control. The procedure used was to set the input watts at max (zero dimming) by means of the control and then set each subsequent point. Each point was allowed to stabilize for a minimum of 5 minutes after the zero-dimming warmup of 20 minutes.

7.4.7.2 The results from Table I have been plotted in curves that show the Change In Light & Power as a function of Input Watts. See attached Figures 1 & 2. These show that the multiple fixture system indicates that with about 25% light level the power consumption is about 50% of maximum. However, the single unit shows a slightly higher power consumption for the same percentage of light. This is due to the inter-

FIGURE 1

SINGLE FIXTURE DIMMER PERFORMANCE

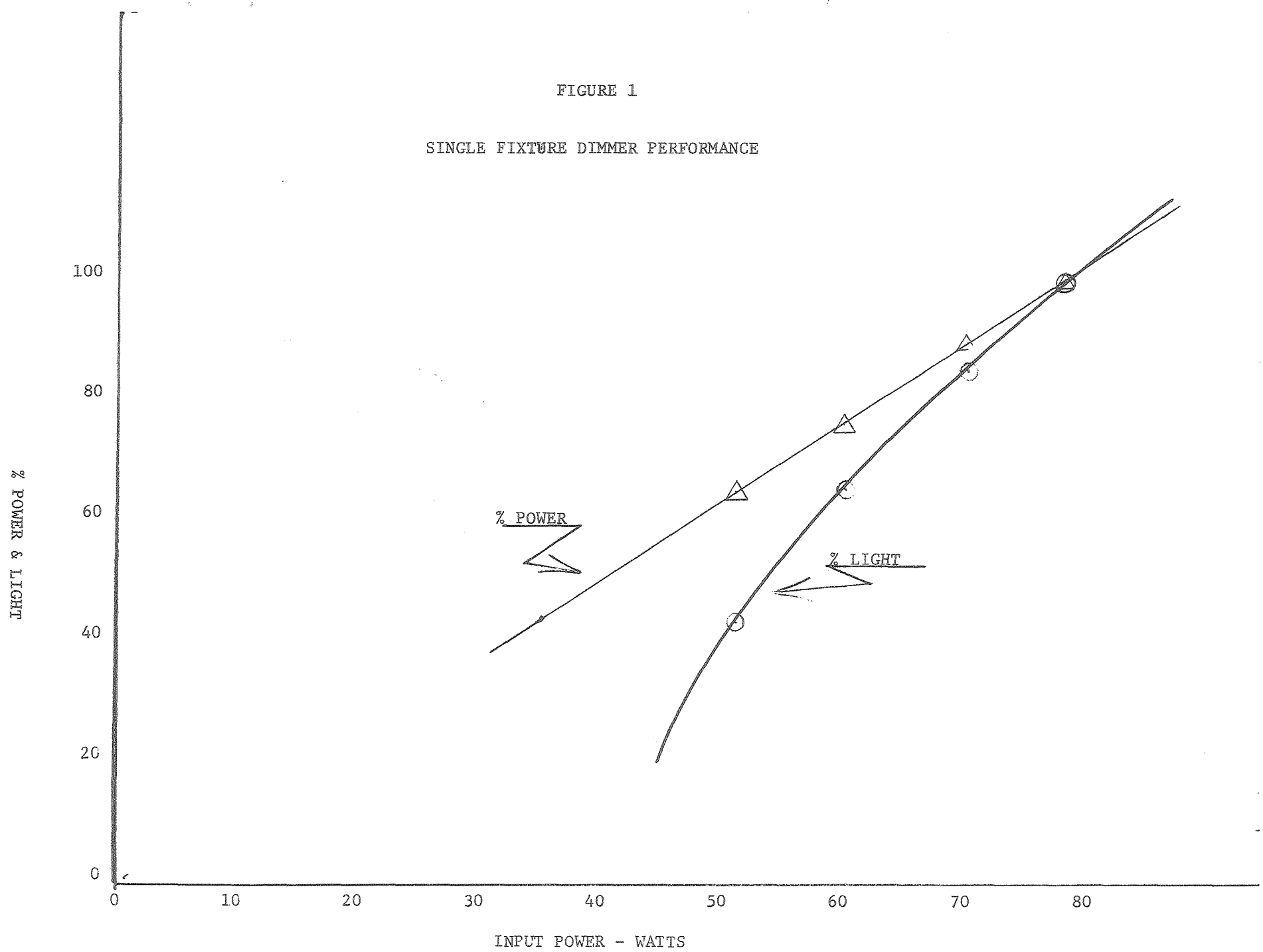

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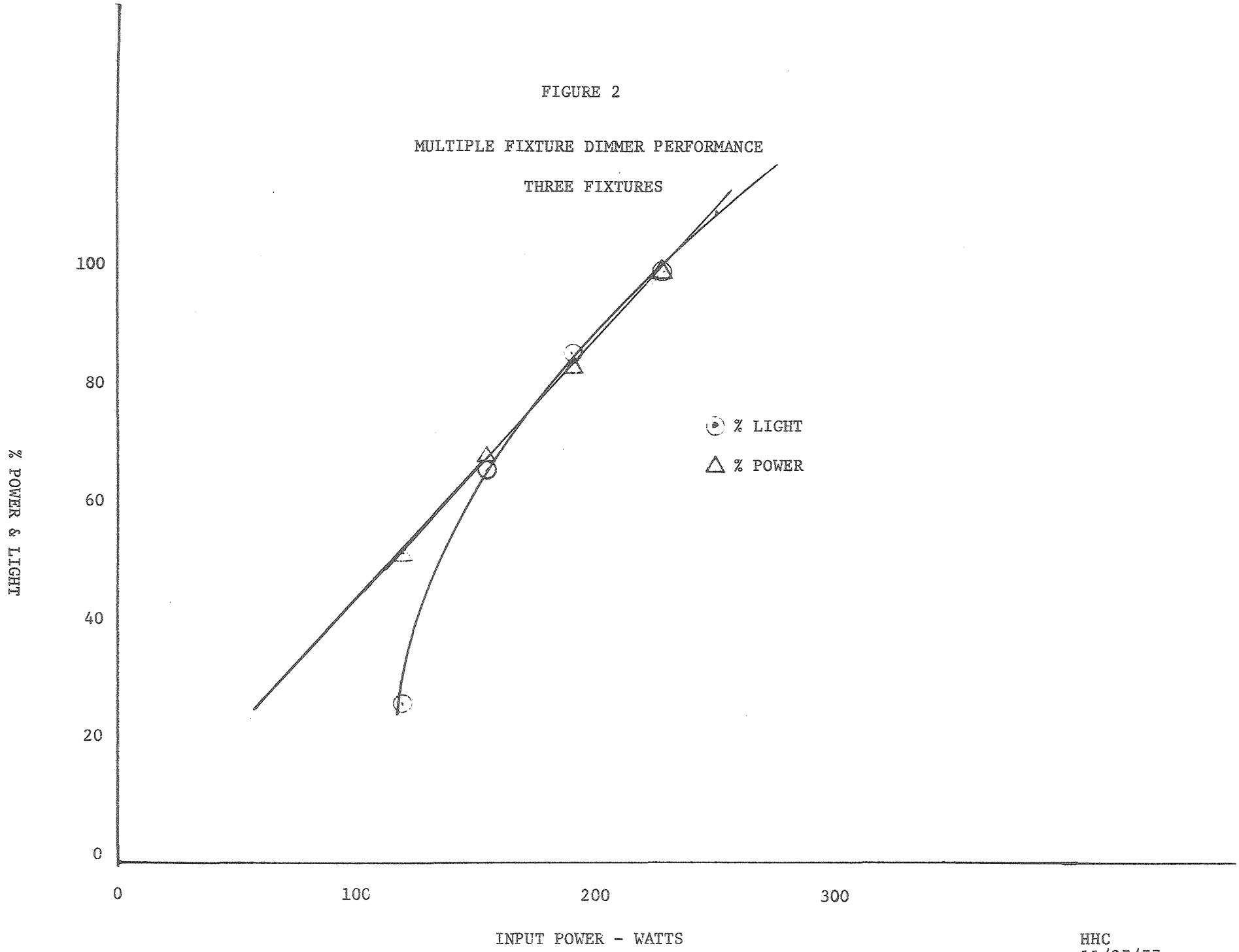
FIGURE 2

MULTIPLE FIXTURE DIMMER PERFORMANCE

THREE FIXTURES



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11/27/77

relating effects of the lamps when they are closely located. More light is produced.

7.4.7.3 The efficiency of dimming by the continuous method isless than that achieved with the step dimmer system. This was pointed out in the Phase I program. However, the continuous system would lend itself to daylight sensing and a smooth control of the artificial light needed to compensate when daylight varies. The minimum dimming position can be set at a power level that will not cause lamp damage and must be suitable for safe starting with that minimum power condition.

7.5 EMERGENCY LIGHT SYSTEMS

7.5.1 General: The circuits for IOTA's family of proprietary energy efficient electronic ballasts are basically similar. Standard alternating line current is first converted to direct current through a full-wave bridge rectifier. It is then changed back to alternating current but at high frequency. This permits the ballast to be designed to operate from either AC or DC power. Most Emergency lighting systems use battery DC power. Thus our Emergency systems can be designed to operate normally at 120VAC with 20 to 30% energy savings and then switch over automatically in the event of power failure to the battery(s). LBL's Phase II program was designed to demonstrate this advantageous feature.

7.5.2 Multiple Fixture System: The simplest way to devise an emergency system with the Phase I IOTA ballast is to modify the full-wave bridge so that two of the four diodes will carry the continuous current requirement for DC operation. With this simple modification no extra wiring or other attachments are needed. However, the battery(s) must be of sufficiently high voltage to mate with the normal voltage level at the DC portion of the circuit. For the Phase I units this voltage is in

the range of 75 to 85 volts. Thus a 72-nominal-volt battery is a good choice for a system to maintain near normal light output. The number of fixtures in each system and the duration of desired operating time then determine the amp-hour capacity requirement for the battery pack. The OSHA requirement for emergency lighting for safety purposes is that the light or lights must operate for 90 minutes in the event of power failure.

7.5.2.1 Battery System Is Versatile and Reliable: The price of standard batteries suitable for standby systems is directly associated with the voltage requirement and the volume of units in production. The most economical way to get a 72V battery is to series-connect six readily available 12V batteries. The minimum battery rating that would give reliable performance for the OSHA minimum time requirement would be a 2.0 or 2.5 amp-hour system. Such a system would power a single 2-40W lamp fixture for over two hours. The light output would be only 10% less than when the unit is operating on AC power. Most commercial buildings currently use incandescent, battery-powered emergency lights, or, an engine-driven system with selected fixtures. IOTA's multiple fixture system will permit a far more economical approach. It provides versatility in selection and location of Emergency lights. And, they would not have to have a common power source. Mechanical engine-driven systems are subject to failure. They require regular checkout and maintenance.

7.5.2.2 Charging and Control Unit: The system designed to meet LBL's requirement under the contract was conceived to involve some appreciable number of fixtures. This was to simulate a multiple unit requirement for a commercial building. We purchased Eagle Picher 15-amp-hour no service type batteries. We elected to procure the battery

charging unit from an outside source. Our specification required a dropout relay which would automatically switch the power supplying the emergency light fixtures over to the batteries when power failed. It also required a dropout voltage setting to remove the load from the batteries after the voltage had declined to a pre-selected value. This level was arbitrarily set at 65V for the nominal 72V system. We now know that this should be lowered in the future to about 60V since that is not low enough to damage the batteries. The prime reason for having it in the demonstrator hardware was to avoid ruining the batteries if the system were accidentally left on following a demonstration. The spec also required a recharging current rate of no greater than 2.0 amps tapering to a minimum standby charge rate after the batteries are restored to full charge. The charging voltage was specified at 80 to 82 volts. The subcontractor for the unit was B Industries Inc. in Phoenix, Arizona.

7.5.2.3 <u>In-House Test Setup and Procedure</u>: The ballasts for the multiple fixture system were optimized to provide a light output of approximately 5000 to 5500 lumens when operating on AC power. They were designated Model No. 1AD 120/72-2-40. Ten units were manufactured and installed in fixtures. These were mounted on a wall in two rows with five in each row, six inches apart. The first test was made with six of the series-connected 12V 15 amp-hour batteries and the ten fixtures but without the charging unit. Delays were encountered in delivery of the charging unit from B Industries. (These delays caused a sixty-day slippage in delivery of the system to LBL.) The test was to determine the performance of the batteries in a simulated power outage condition. Before taking the DC data a set of data was obtained to determine performance characteristics of the ballast when

operating on AC power. The five units for one bank of lights were measured separately from the five units in the second bank. Then all ten were operated simultaneously. We also operated one unit alone (No. 3) and two units (Nos. 3 and 8) to observe various parameters. The light measurement was made with a "paddle" one inch from the surface of the center of the lamp. TABLE II presents this data.

TABLE II

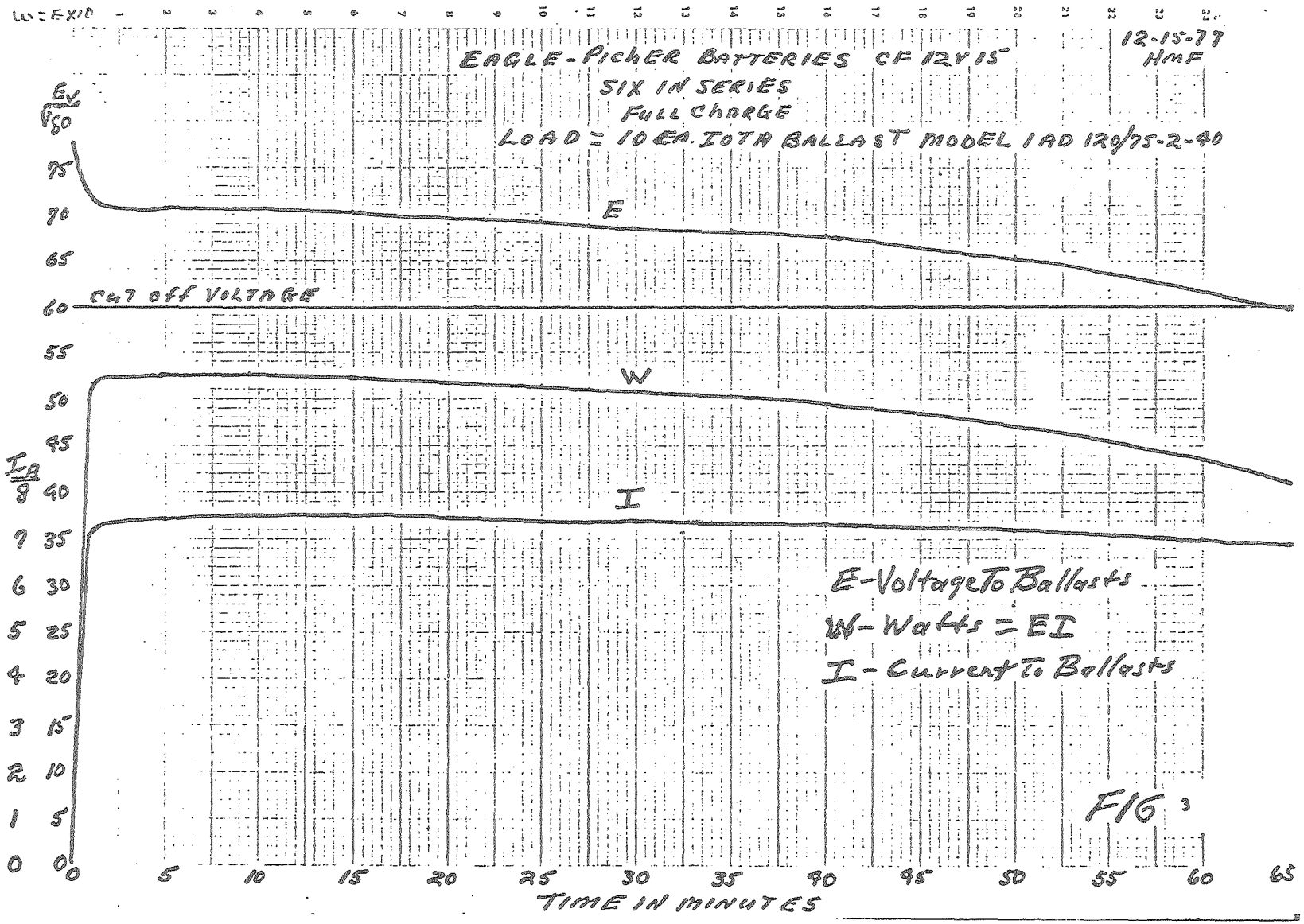
DATA WITH DUAL OPERATION BALLASTS, MODEL #1AD 120/75-240

Units Operated for 15 Minutes Before Taking Data

Ballast S.N.	Input Volts AC	Input Amps Total	Input Amps Ave	Input Watts Total	Input Watts Ave	Rel. Ave. Light	Ave. Eff.	Total Power Factor
1 Thru 5	120	3.18	.636	360	72.0	258	3.583	.943
6 Thru 10	120	3.12	.624	345	69.0	253	3.667	.921
1 Thru 10	120	6.40	.640	706	70.6	255.5	3.619	.919
No. 3 Only	120	.642	.642	72	72.0	251.5	3.493	.934
Nos. 3 & 8	120	1.26	.630	141.7	70.85	253.5	3.578	.937

7.5.2.4 Preliminary Results: Data obtained when the ten fixtures were operated from the batteries is shown in Figure 3. The test was terminated when the battery voltage declined to 60V. This occurred about 63 minutes after turn-on. This gave us an indication that the system which we wanted to demonstrate at LBL should not have this many fixtures if we were to use the 15 amp-hour batteries.

7.5.2.5 Final Test Results: A final test was run with eight fixtures using the battery charger and regulator. The batteries had been fully charged prior to the beginning of the test. The low voltage dropout relay interrupted the lamp load at the end of 88 minutes.


W = EXID
EAGLE-PICHER BATTERIES CF 12V 15
SIX IN SERIES
FULL CHARGE
LOAD = 10 EA. IOTA BALLAST MODEL IAD 120/75-2-40
12-15-77
HMF
E
CUT OFF VOLTAGE
W
I
E-Voltage To Ballasts
W-Watts = EI
I-Current To Ballasts
FIG 3
TIME IN MINUTES

The voltage was 64.8. Battery voltage and discharge current for the test are shown in Figure 4. Light was maintained at approximately 5% less than when operating on the AC system throughout the time period. With this result we concluded that the optimum number of fixtures for this particular battery/charger/regulator system was seven. It is clear however that if the voltage had been set to drop out at 60V we would have exceeded the 90 minute OSHA requirement with all eight fixtures. Data was taken during the recharge cycle to record the charge rate vs. time. This is shown in Figure 5. Charging current starts at approximately 1.8 amps and tapers to approximately 34 milliamps within a 24-hour period.

7.5.2.6 The system was delivered the latter part of March 1978.

7.5.3 Integral Emergency Light System -- Single Fixture

7.5.3.1 Background: Discussions with architects have revealed that the ideal emergency light from their viewpoint would be one that did not require remote batteries and separate wiring. They would like to have the same fluorescent lamps that provide normal light during work hours to function in an emergency. This is accomplished with the engine-driven electrical system and selected lighting fixtures -- but is not economically feasible for small facilities.

7.5.3.2 IOTA's Response: In response to this interest IOTA has adapted proprietary circuitry to make an emergency light system that uses two standard 40W lamps. All elements may be mounted within any standard fixture. The special hardware would be sold in a kit form for installation by a fixture manufacturer or by a user. It consists of two items. The first item integrates three functional elements: a 120VAC electronic ballast circuit; a 12V ballast circuit; and a 12V

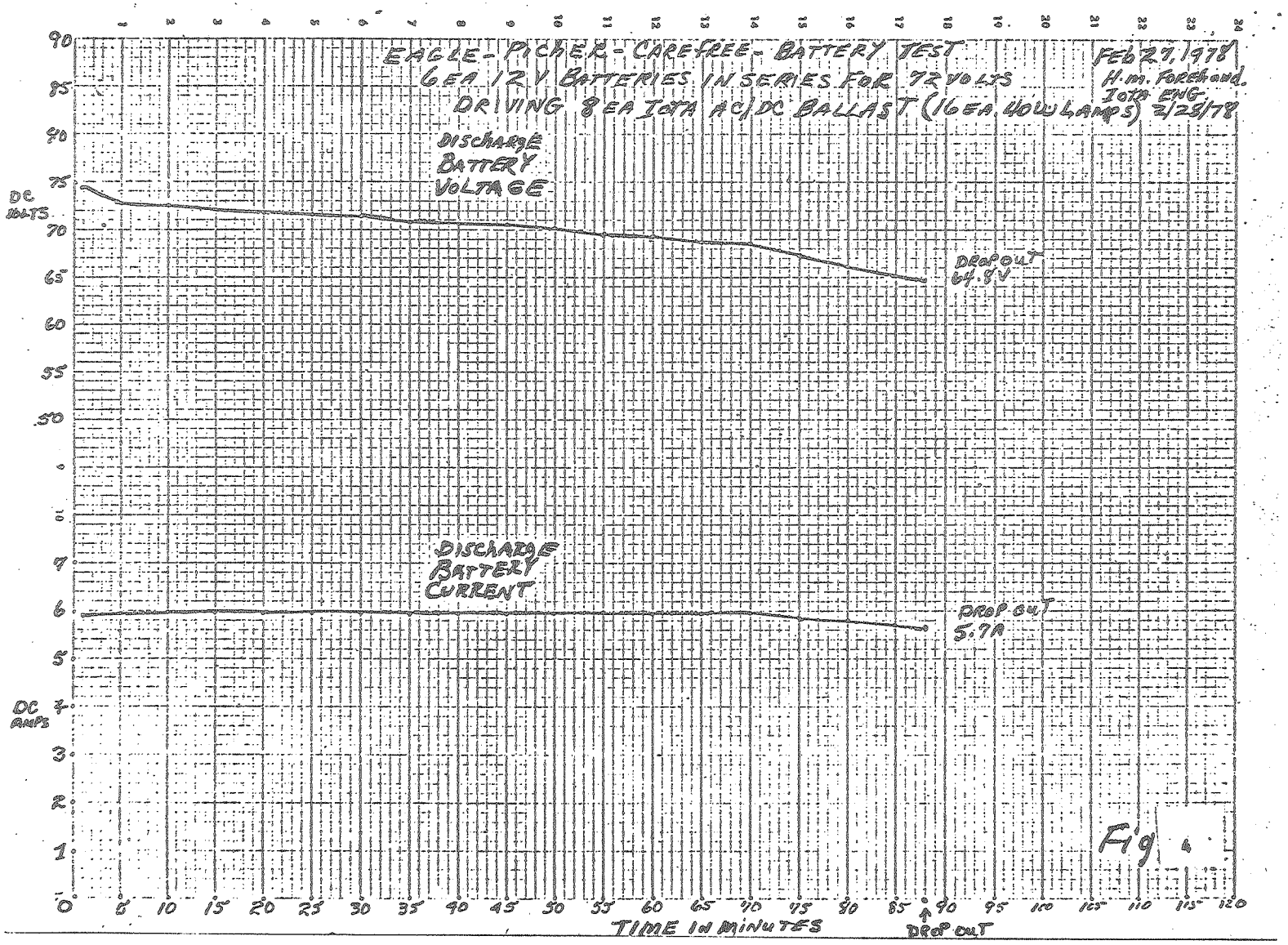
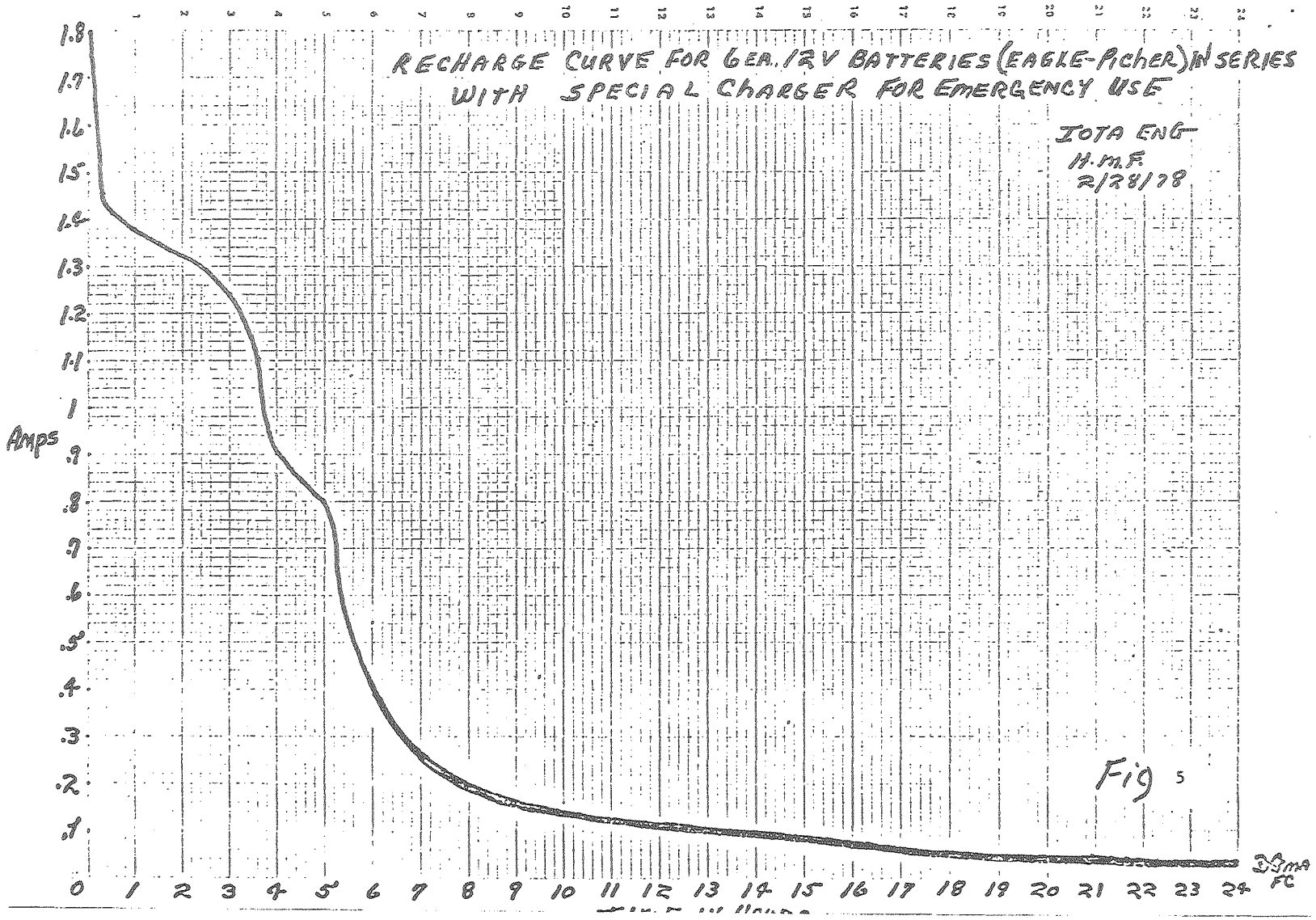

EAGLE-PICHER-CAREFREE-BATTERY TEST
6 EA 12V BATTERIES IN SERIES FOR 72 VOLTS
DRIVING 8 EA IOTA AC/DC BALLAST (16 EA 40W LAMPS)
FEB 27, 1978
H.m. Forehand
IOTA ENG
2/28/78
DISCHARGE BATTERY VOLTAGE
DROP OUT 64.8V
DC VOLTS
DISCHARGE BATTERY CURRENT
DROP OUT 5.7A
DC AMPS
TIME IN MINUTES
DROP OUT

Fig 4


RECHARGE CURVE FOR 6 EA. 12V BATTERIES (EAGLE-PICHER) IN SERIES
WITH SPECIAL CHARGER FOR EMERGENCY USE
IOTA ENG
H.M.F.
2/28/78
Amps
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Fig 5

charging unit circuit. The X-section of the electronic unit will fit within the envelope of the standard magnetic core ballast X-section, but it is longer than the standard ballast (first models approximately 16"). The second item is a battery pack containing six 2V 5-amp-hour lead acid type batteries. Both the electronic and the battery units will fit easily within the 48" length of the standard fixture housing.

7.5.3.3 First Model Testing: The first unit for the Phase II demonstration was tested to obtain complete operating data. The procedure was to operate the 2-40W lamps on 120VAC power for sufficient time to assure that the batteries were fully charged. The AC power was then turned off and the unit immediately switched to the battery system at a reduced light output. At the end of 90 minutes (the OSHA minimum requirement) the AC power was restored. Charging-cycle data was recorded till the end of the working day and at the beginning of the next day. Data from this test is presented in TABLE III.

7.5.3.4 Performance Results: The light output for normal AC operation in the above unit was optimized for approximately 5000 lumens. This light level is considered completely adequate for most requirements. Assuming the combination energy-saving system is installed in place of a standard magnetic core ballast, the energy savings during AC operation would be better than 25%. Light output during an emergency situation averages better than 25% of that normally provided by the fixture.

7.5.3.5 Data on Kits Delivered to LBL: Assembly of the five system kits delivered under the LBL contract was delayed for approximately 45 days by inability to obtain a component. After receipt the units were

TABLE III

TEST ON FIRST MODEL 1AD 120/12-2-40
INTEGRAL EMERGENCY LIGHT SYSTEM UNIT - SINGLE FIXTURE

DISCHARGING TEST

DATA ITEM									
DATE	1/15	1/16	1/16	1/16	1/16	1/16	1/16	1/16	1/16
Time (Hrs. & Min.)	15:00	09:40	09:41	09:55	10:10	10:25	10:40	10:55	11:10
Elapsed Test Time	0	0	0:01	0:15	0:30	0:45	1:00	1:15	1:30
AC Volts	120	120	0	0	0	0	0	0	0
AC Watts	69	71	0	0	0	0	0	0	0
AC Amps (RMS)	.925	.925	0	0	0	0	0	0	0
*Units of Light	260	255	85	80	80	80	75	72.5	70
DC Volts @ Battery	14.0	14.6	12.25	12.10	12.05	11.95	11.80	11.70	11.60
DC Charging Amps	+.010	+.005	---	---	---	---	---	---	---
DC Discharge Amps	---	---	-1.825	-1.775	-1.765	-1.765	-1.745	-1.730	-1.720

RE-CHARGE TEST

DATE	1/16	1/16	1/16	1/16	1/16	1/16	1/16	1/17
Time (Hrs. & Min.)	11:20	11:40	12:10	13:10	14:40	15:40	16:40	08:10
Elapsed Test Time	0:10	0:30	1:00	2:00	3:30	4:30	5:30	21:00
AC Volts	120	120	120	120	120	120	120	120
AC Watts	69	70	70	70	70.00	70.25	70.25	69.75
AC Amps (RMS)	.940	.935	.935	.935	.925	.925	.925	.9225
* Units of Light	255	255	255	255	255	255	255	260
DC Volts @ Bat.	12.25	12.40	12.50	12.65	12.75	12.80	12.90	14.96
DC Charging Amps	+.270	+.260	+.250	+.250	+.240	+.230	+.230	+.005

*Lab lights were left on during all light readings. Background reading was 15 light units when test fixture was not operated.

assembled, checked out and delivered. The operating data for the five kits is presented in TABLE IV. The charge current when the batteries were down averaged about .300 amps and then tapers down to .005 to .010A when they are fully charged.

TABLE IV

Operating on AC Current				Switch over to 12V Battery		
Unit No.	Input Volts	Input Amps	Input Watts	Approx. Light in Lumens	Amps Drain	Approx. % of Original Light
001	120	.960	61	5,000	1.80	36%
002	120	.965	62	4,910	2.00	35%
003	120	.960	60	4,910	1.90	33%
008	120	.960	60	4,910	1.90	33%
009	120	.950	60	4,820	1.95	34%

7.6 ACCELERATED START-LIFE TESTING

7.6.1 Background: As pointed out in the Phase I report, the starting characteristics of a ballast has a greater effect on lamp life than other operating parameters. Although there is a constant degradation in time with respect to light output, this is a slow process. However, if the electrodes are "sputtered" excessively during starting, life can be substantially shortened. We have therefore run continuous tests to attempt to learn as much as possible in a short calendar time about the effects on lamp life with the early model high frequency electronic ballast. In order to get any meaningful number of starts in a short calendar period, the tests were set up for three minutes ON and three minutes OFF, or, they were on six-minute cycles. The great majority of tests during the Phase II program were on three-minute timers. These tests reflect relative lamp electrode life for standard core and electronic ballasts.

7.6.2 Study of Electrodes by John H. Campbell: Mr. John Campbell, formerly with the General Electric Company Fluorescent Lamp Department for many years, is a consultant to EXCEL. As a part of our Phase II program, he was asked to examine the electrodes from a number of lamps used in the accelerated test program. This was accomplished by interrupting tests at different numbers of hours and by waiting until failures had occurred in other cases. The lamp tube was cut away leaving only the end cap and remaining portions of the electrode. These were sent to Mr. Campbell in Cleveland, where he examined them under a microscope. He examined the electrodes from nineteen standard 40W lamps. Standard ballasts were operated as "baseline control indicators" in all start test programs. Mr. Campbell's conclusions from his February 1978 report to IOTA are quoted in their entirety below:

CONCLUSIONS

"SINCE ONLY A SMALL SAMPLE OF THE LAMPS ON TEST COULD BE EXAMINED, A STATISTICAL ANALYSIS RELATING THE NUMBER OF STARTS TO LAMP LIFE AS DETERMINED BY THE OFFICIAL LIFE TEST OF 1 START PER 3 HOURS OF BURNING IS NOT INTENDED. HOWEVER, TRENDS CAN BE SHOWN AND LATER COMPARED WITH THE OFFICIAL TEST IF THE PRODUCTION BALLASTS CORRESPOND WITH THE EXPERIMENTAL MODELS.

"I BELIEVE THE TEST RESULTS AND CATHODE EXAMINATION SHOW THAT THE ELECTRONIC BALLAST OPERATING LAMPS AT HIGH FREQUENCY WILL PROVIDE A RELIABLE ENERGY SAVING LIGHTING SYSTEM WITH OUR PRESENT FLUORESCENT LAMPS. IF COUPLED WITH AN OPTIMUM LAMP DESIGNED FOR THE HIGH FREQUENCY SYSTEM, THE OVERALL EFFICIENCY CAN BE INCREASED STILL FURTHER.

Respectfully submitted,

(Signed)

JOHN H. CAMPBELL
Consulting Engineer
9430 Headlands Road
Mentor, Ohio 44060"

7.6.3 IOTA's In-House Test Results on Standard Lamps Summarized: During the Spring of 1978 an in-house test program involving twenty-two General Electric Mainlighter standard 40W lamps was conducted. A number of the ballast and lamp combinations were installed in an outside area subject to normal ambient temperature changes between day and night. These temperatures ranged from the very low 30's to the middle 80's (Degrees Fahrenheit). Other tests simulating an inside environment were run in the IOTA conference room. Here temperature variations were normal for an office type building where the heat is turned off at night. The average number of starts prior to lamp failure on the outdoor units was 13,153. The average on the inside units was 14,798. This makes an overall average of 13,975 starts before failure on a group of IOTA's latest model electronic ballasts. It compares very closely with results reported in Phase I. Eight core ballasts were used for baseline testing.

7.6.4 Results on General Electric Wattmiser II Lamps Summarized: We also conducted start-life tests with electronic ballasts using GE's relatively new model Wattmiser II lamps. These are more efficient in terms of lumens per watt than the Mainlighter lamps. They contain a different gas mixture and have slightly different starting characteristics. There were ten lamps involved with five electronic ballasts. Results showed 13,429 starts prior to failure in the outdoor environment. The indoor average was 22,833, and the overall average was 18,131. Thus it appears that the electronic ballast is equally suited to operate the new generation of high efficiency lamps as well as standard lamps. Improved test results with Wattmiser II lamps suggest that starting voltage requirements are better matched.

7.6.5 Results with Standard Lamps and Standard Ballasts Summarized: The relative number of standard baseline units has been small since standard ballast and lamp data was taken and reported during Phase I. What we have found in this time period is that the average start-life has been better during this test series than in the previous Phase I program. Prior tests indicated very comparable numbers of starts between electronic ballasts and standard ballasts. However, in this case the standard units have exceeded the electronic ballasts prior to lamp failure. One factor influencing this has been a decided difference in the ambient temperature conditions prevailing during the Phase I program as compared with this one. A second factor is that ballasts from a different manufacturer were used.

7.6.6 A total of twenty-eight electronic ballasts have been involved in accelerated start life testing at IOTA. Average number of starts on Phase I early model instant-start type ballasts was approximately 10,500. Average number of starts on the later model rapid-start units is approximately 13,500. There have been eight standard magnetic core ballasts used for baseline reference. These have yielded start lifes ranging from 12,000 averaged during Phase I to 16,000 starts during the Phase II program.

7.7 TESTS WITH A CLOSED FIXTURE

7.7.1 Temperature Effects on Lamp Operation: The light output from fluorescent lamps is affected by ambient temperature and air passage across the lamps. The manufacturer's curve of lumens vs. temperature for standard GE Mainlighter lamps and the Wattmiser II lamps clearly shows peaks that range from 90° to 105°. When bulb wall cold spot temperature exceeds this figure, lumen output falls off. The ballast mounted inside the fixture can have a distinct effect on the temperature.

of the air around the lamps -- especially in a closed fixture. The electronic ballast has less heat loss and does not contribute as much to light fall-off due to ambient temperature rise.

7.7.2 Fixture Test at IOTA: A test was conducted to measure the specific differences between a fixture with no cover and the same fixture and lamps with the cover installed. These results are quite interesting in that they show the large fall-off in light output normally encountered in a closed fixture when powered by an enclosed standard ballast. The system efficiency improvement with the electronic ballast is greater in a covered fixture than in an open one. Most office lamps are either in closed troffers, or, in fixtures with covers. The IOTA test data is shown in TABLE V.

7.7.3 Discussion of Results: IOTA ballast No. 62-7 was set to deliver a high (6000 lumen) light output. As can be seen, the light output was actually higher than that from the standard ballast even without the cover. However, the significant area of interest is the system efficiency comparison. Without the cover installed after the same operating time (155 minutes) the efficiency improvement was approximately 22%. After the cover was installed, the improvement increased. But the interesting point is that with the electronic ballast the light level actually increased when the cover was installed. Whereas it decreased with the magnetic core ballast. This means that we were likely below the optimum bulb-wall temperature point when the lamps were uncovered. The heat contribution from the electronic ballast was not enough to put the system into the fall-off region.

7.7.3.1 Optimization for Lower Output and More Savings: The Model 63-5 unit was set for a lower output level to save power but still produce as much light as the magnetic core ballast -- when the cover is installed. The data indicates that we are definitely under the

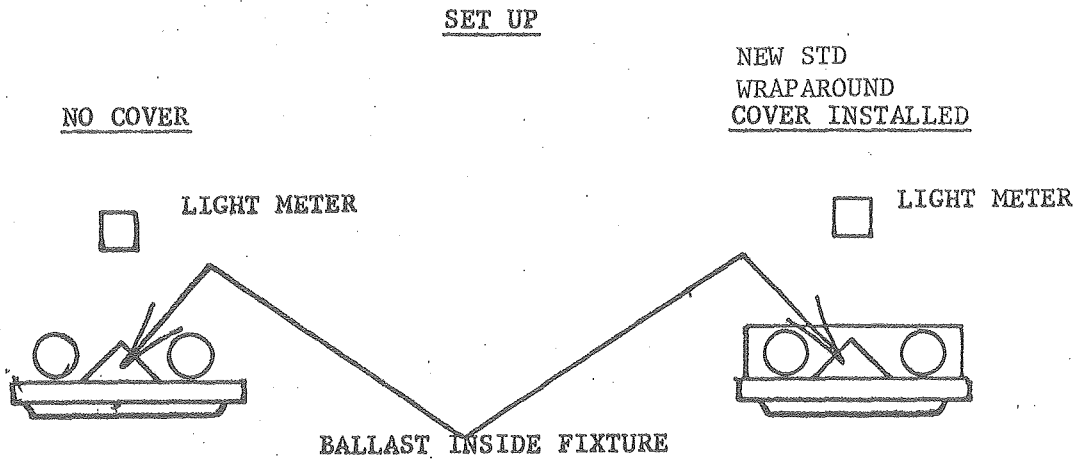
TABLE V

FIXTURE TEST DATA -- WITH & WITHOUT COVER

Test in wrap around standard fixtures--GE Mainlighter lamps and Wattsmiser II lamps. Lamps burned for 100 hours. Fixture on test bench in lab.

Test Item	Elapsed Time	Input Power Watts	Units of Light	Relative System Effic.	System Comparison	Test Condition
					Ref. Data for Standard Ballast	
Advance RQM-2540-3-TR "Kool Koil"	155'	98.25	380.0	3.8677	Baseline Data	Mainlighter Lamps No cover
	270'	90.25	367.5	4.0720	Baseline Data	Cover Installed
IOTA 62-7	155'	82.25	387.5	4.7112	+21.8%	Mainlighter Lamps No cover
" "	285'	80.00	405.0	5.0625	+24.3%	Cover installed
IOTA 62-7	130'	72.50	370.0	5.1034	+31.9%	Wattmiser II Lamps No cover
" "	314'	72.25	400.0	5.5363	+36.0%	Cover installed
IOTA 63-5	145'	74.5	355	4.7651	+23.2%	Mainlighter Lamps No cover
" "	260'	72.5	382.5	5.2759	+29.6%	Cover installed
IOTA 63-5	140'	65.5	325	4.9618	+28.3%	Wattmiser II Lamps No cover
" "	305'	67.0	380	5.6716	+39.3%	Cover installed

SET UP



optimum temperature point with the cover off, but still produce more light with the cover installed. In effect, this means that we could have reduced the light output still further, with additional power savings, and still have produced as much light with the cover installed as the standard ballast does.

7.7.3.2 More Efficient Lamps Mean Even More Savings: Tests were repeated using Wattmiser II lamps with these two ballasts. Results are very significant in terms of the system efficiency improvement. In essence, what the data says is that with an electronic ballast optimized to produce between 5000 and 5500 lumens of light, and using Wattmiser II lamps, we could produce as much light in a covered fixture for 65 to 67 watts as a magnetic ballast does at 90 watts with standard lamps. This could mean power savings in a retrofit situation of over 40%. And, of equal or greater significance, the electronic ballast will maintain light output in the high temperature environment associated with a closed ceiling type fixture. This will be very significant in terms of fewer restrictions on the designer of lighting systems.

7.8 CERTIFICATION

7.8.1 ANSI: AMERICAN NATIONAL STANDARDS INSTITUTE: Lighting hardware is used in every walk of American life. To provide some degree of standardization and interchangeability, the American National Standards Institute (ANSI) publishes standards of performance and measurement adopted by boards and committees. The committees are composed generally of representatives of users (consumers), manufacturers and government agencies concerned with the uniformity of a widely used product. Such standards have been established for fluorescent lamp ballasts and the fluorescent lamps. In order to assure performance and permit a reliable design,

architects will specify CBM ballasts. The CBM rating is regulated by a group, Certified Ballast Manufacturers, as ballast tested by the Electrical Testing Laboratories (ETL) by standards and methods approved by the ANSI Ballast Committee.

7.8.2 Underwriters Laboratories (UL): Likewise there exists an organization generally recognized as the guardian of public safety for products used by the public. This is the Underwriters Laboratories Inc. Since the proposed applications of electronic ballasts are as broad as the lighting field itself, qualification by this safety organization will be essential to commercial and industrial acceptance.

7.8.3 Certified Ballast Manufacturers (CBM): A third organization, the Certified Ballast Manufacturers, approval will enhance sales but is not likely to be an essential requirement. A committee of the ANSI organization establishes regulations for standard ballasts. The committee is largely composed of representatives of the specifically applicable industries to assure a product that will meet minimum performance standards. The specifically peculiar electronic ballast performance and testing standards will likely have to be established elsewhere. However, the committee rightfully does attempt to set minimum performance standards, and electronic ballasts should meet these standards for successful marketing.

7.8.4 Federal Communications Commission (FCC): The electronic ballast will have to meet requirements of this organization. Standard ballast powered fluorescent systems have not been subject to these requirements since they operate at line frequency. However, since our electronic ballasts are above $10KH_Z$ in frequency, we are very likely to have to obtain the approval of this agency before broad-scale public acceptance.

7.8.5 Others: There are other organizations such as the National Electrical Code group, and so forth, whose purview includes the installation of this type product. However, the foregoing listed organizations will likely be the most important ones.

7.9 FAILURE ANALYSIS

7.9.1 The original concept for the Phase II demonstration program envisioned five to six months of operation with the electronic ballast. This period was originally scheduled to fall within the time limits of the IOTA contract. Considering schedule slippages, there will be no experience with the electronic ballasts in the PG&E facility before the end of the current contract. Since the great majority of the ballasts will have been manufactured by EXCEL, it does not make sense to have IOTA between LBL and EXCEL in trying to analyze difficulties with an EXCEL product. This is especially true when one considers that EXCEL will hopefully be proceeding with a production design of their own for the next generation ballasts. Whatever is learned from the demonstration hardware should therefore be immediately available to their ongoing program. In view of this circumstance IOTA recommended and LBL concurred in eliminating IOTA's contribution to this task area -- except by special consulting help that may be requested by LBL from time to time.

7.10 COMMERCIALIZATION STRATEGY

7.10.1 EXCEL Input of Prime Importance: For the same reasons discussed in the prior task area IOTA recommended that EXCEL be requested to provide commercialization strategy information. Originally we had planned that IOTA would coordinate with EXCEL and with Dr. Don Ross, representing an architectural viewpoint and having a deep interest in the electronic ballast program. However, this requirement was also

waived for schedule and economy reasons. Obviously large volume projections in terms of unit costs and total savings should come from EXCEL. They will be producing and marketing the IOTA ballast or the follow-on item derived from the IOTA starting point circuits.

7.10.2 IOTA's Idea of Best Market Approach: IOTA's viewpoint regarding commercialization strategy is basically to aim the early penetrations at the areas which are committed or are willing to pay premium prices for energy saving products. And, to concentrate on the versatility offered by the electronic ballast that is not possible with the magnetic core type ballast. Recent introduction of the new family of energy saving standard ballasts will perhaps pave the way by defining those markets that are willing to pay more for power saving devices. The new standard energy saving ballasts and lamps are more expensive than older models. However, the first models of electronic ballasts still have to be higher priced until use of integrated circuits can help to reduce costs. The retrofit market probably offers a good starting point since the great bulk of the expense is incurred in the labor rather than in the product. In other words, when the time approaches for lamp or ballast changes, it will be economically competitive and advantageous in terms of operational costs to install electronic ballasts. Government agencies should certainly be a prime target since DOE has the mission of reducing energy consumption and should be helpful in convincing other government agencies to finance retrofit programs.

7.10.3 Stress Unique Features: Another approach strategy would be to concentrate on the unique features offered by the electronic ballast that warrant a higher initial price. This includes dimming and emergency lighting applications. After experience is gained with the early model discrete circuit products, an integrated circuit approach can be

undertaken. This will permit appreciable cost reduction. It will bring costs more nearly into line with standard ballasts.

7.10.4 Immediately Broaden the Areas of Application: One of the key areas for consideration by DOE and LBL should be to broaden the approach with the electronic ballast to include higher output lamps. There are large volumes of F96T12 lamps used in the commercial and industrial sectors. It is clear that the same advantages, first explored with the 40W lamp unit, should be brought to bear for this application. There are other reasons related to Solarvoltaic electrical system uses that also bear on this requirement. The president of the Solar Engineering Society has expressed the view that the earliest feasible application for Solarvoltaic powered electrical systems will be in the sunbelt areas of the United States. He feels that the first economically feasible areas will be for shopping centers, stores and those types of commercial establishments having large airconditioning peak loads. Such peak loading will coincide with the availability of maximum solar energy. The great majority of these establishments is illuminated with large fluorescent lamps. An electronic ballast for this application can be the mechanism for producing a better quality of light for 40% less solar-generated energy than will otherwise be required. It is estimated that the cost of a program on ballasts for high output lamps would be in the order of $250,000 and would require approximately one year's time. This would finance not only the R & D effort required but an initial production run. Additional production and marketing costs for higher volumes would probably require an equal amount of capital over the following two years.

7.11 PRODUCT LITERATURE

7.11.1 Data describing the technical characteristics and the specifications for the electronic ballasts and emergency lighting systems are included under Appendix 4. Installation instruction data is also included.

7.11.2 Four of the ballasts produced in the Phase I program were sent by LBL for verification testing to the Lighting Research Laboratory headed by Bill Jones and located in Orange, California. The circuits were of a much earlier model than the ones which were used for the Phase II demonstration program. The results are included in this report at LBL request as a validation by an outside agency of early model electronic ballast test results. LBL will subsequently ask the same agency to repeat their testing using the Phase II demonstration ballasts. Excerpts from the Bill Jones Phase I report are included as Appendix 5. The excerpts include all comments and the data sheets themselves -- other than oscillographs. Those items that are omitted related primarily to background information and calibration data and statistics.

8.0 RECOMMENDATIONS

8.1 EMI

Results of tests by IOTA and others show that EMI levels are greater for the high frequency electronic than for standard magnetic core ballasts. Much of the increase is due to the switching power supply. Work is needed to more specifically define the problem within FCC rules and to determine methods for dealing with it -- methods that are least costly in terms of performance and complexity. DOE participation, coordination and sponsorship of work in this area is recommended.

8.2 ADAPTATION FOR SOLAR POWERED ELECTRICAL SYSTEMS

The electronic ballast can be adapted for use with photovoltaic direct current electrical systems. The power required for fluorescent lighting will then be 40 to 50% less than by use of inverters and standard magnetic core ballasts. Major photovoltaic demonstration projects are already funded by DOE. It is recommended that work to adapt and qualify electronic ballasts for this requirement be funded by DOE on a priority basis.

8.3 APPLICATION OF TECHNOLOGY TO LARGE LAMPS

Approximately 20 to 30% of fluorescent lamps are in the eight foot category. But they consume two to three times that percentage in terms of the relative power used. This means that economies achieved by using electronic ballasts would be very significant. Likewise there are potential gains to be made with HID lamps. IOTA recommends that work in this area be sponsored in the immediate future.

APPENDIX 1

PROGRAM WORK PLAN

OMB NO. 63-R1282

U.S. Energy Research and Development Administration
SCHEDULAR PERFORMANCE REPORT
(See Instructions on Reverse)

4. REPORTING PERIOD: 6/4/78 - 7/2/78

1. CONTRACT TITLE: ENERGY EFFICIENT BALLASTS FOR FLUORESCENT LIGHTING SYSTEMS

2. ADDRESSEE *(Name, Title, Address and ZIP Code)*: Dr. Berman, U of CA, Lawrence Berkeley Lab. Bldg. 90, Rm 1012, 1 Cyclotron Rd. Berkeley, CA 94720

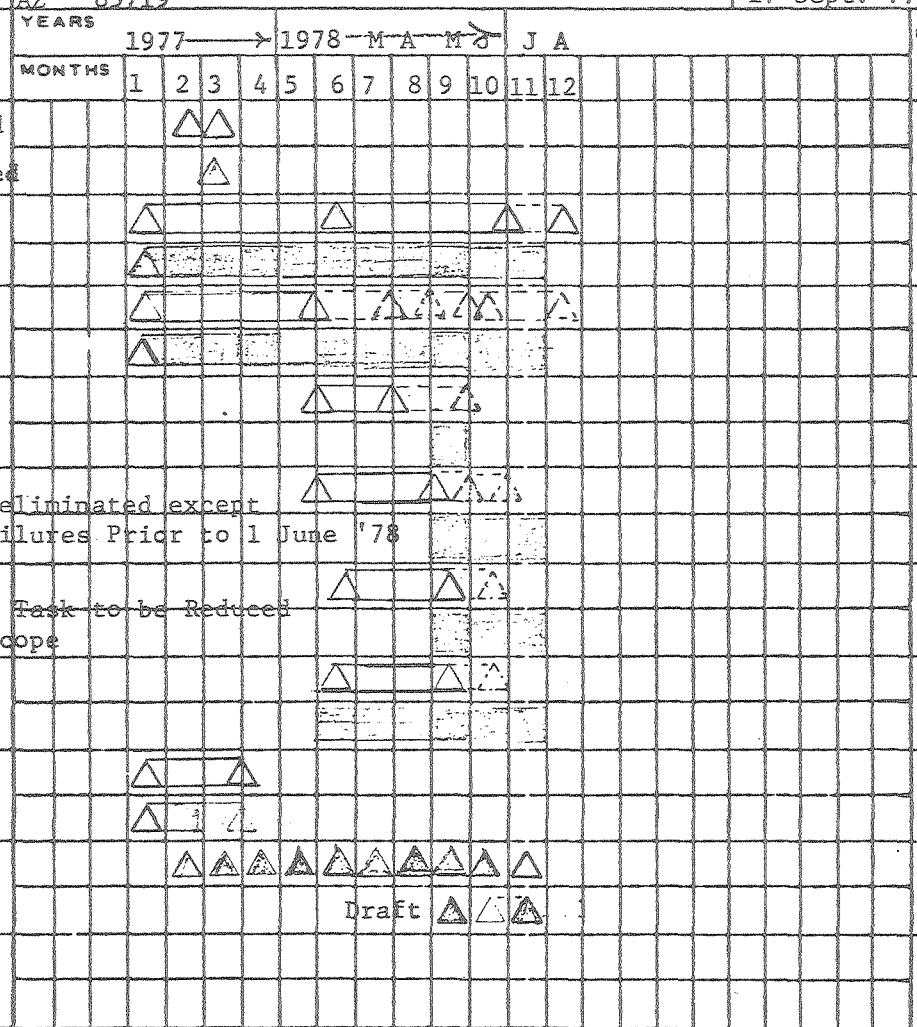
3. CONTRACT NUMBER: Subcontract 2253202 Phase II

ERDA USE ONLY — PROJECT MANAGER

5. CONTRACTOR *(Name, Address and ZIP Code)*: Iota Engineering, Inc., 1735 E. Ft. Lowell #12, Tucson, AZ 85719

6. APPROVED SCHEDULE DATE: 17 Sept. '77 - 1 Jan '77

EVALUATION DATE



8. TECHNICAL OBJECTIVE % COMPLETED

EVALUATION

LEGEND:
- ERDA Approved Schedule
- Contractor's Working Schedule

DATE: 7/18/78

9. SUBMISSION APPROVAL *(Signature of Contractor's Project Manager)*: Harry H. Clayton

No. 534

PHASE II

DETAILED PROGRAM WORK PLAN FOR IOTA ENGINEERING, INC.

		1977				1978							
	MONTHS	1	2	3	4	5	6	7	8	9	10	11	12
		S	O	N	D	J	F	M	A	M	J	J	A
..0	TASK VI - PROGRAM WORK PLAN												
1.1	Phase II Go-Ahead												
1.2	Contract Amendment #2 Received												
1.3	Work Plan Submitted												
.0	TASK VII - DEMONSTRATION CONSULTATION												
2.1	Participate Phase II Demo. Prelim. Planning												
2.2	Participate Phase II Review												
2.3	Coordination and Consultation												
.0	TASK VIII - BALLAST PROCUREMENT												
3.1	EXCEL SUBCONTRACT												
3.1.1	Contract Signed												
3.1.2	Prelim. Data Package Released to EXCEL												
3.1.3	Final Data Package on Model 54 and 64 Ballast Released												
3.1.4	Model 54 Units Delivered to IOTA												
3.1.5	Model 64 Units Delivered to IOTA												
3.1.6	Liaison and Consultation IOTA and EXCEL												
3.2	IOTA Performance Assurance Testing												
3.3	Delivery of Model 50 and 60 Units to LBL												
3.4	One-Step Dimmable Units												
3.4.1	Procure Parts and Modify 72 Model 60 Units												
3.4.2	Deliver 70 Step-Dimmable Kits to LBL												
3.5	Emergency Units												
3.5.1	Procure Parts and Fab. Single Fixture Sys. Kits												
3.5.2	Deliver 5 Single Fixture Sys. Kits												
3.5.3	Procure Parts and Fab. Multiple Fixture Sys. Kits												
3.5.4	Deliver One 7 Fixture Kit												
3.6	Description and Installation Instructions												
3.6.1	Preparation												
3.6.2	Delivery												
3.7	Electro-Magnetic Interference (EMI)												
3.7.1	Assessment of Current Problem												
3.7.2	Possible Modifications												
.0	TASK IX - CERTIFICATION This Task To Be Reduced In Scope												
4.1	Identify Required National Certification Agencies												
4.2	Deliver One of Each Model Unit for Examination by Each Agency												
4.3	Report Status of EXCEL's Progress Toward Certification												

PHASE II

DETAILED PROGRAM WORK PLAN FOR IOTA ENGINEERING, INC.

		1977				1978							
	MONTHS	1	2	3	4	5	6	7	8	9	10	11	12
		S	O	N	D	J	F	M	A	M	J	J	A
5.0	TASK X - FAILURE ANALYSIS												
5.1	Schedule Removal of Prev. Desig. Bal. After 60-90 Days This Task To Be Eliminated Except												
5.2	Performance Test Units For Failures Prior To 1 June 1978												
5.3	Dissassemble for Component Examination												
5.4	Make Components Available to EXCEL												
5.5	Report Results and Any Recommended Actions												
6.0	TASK XI - COMMERCIALIZATION STRATEGY This Task To Be Reduced In Scope												
6.1	Plan and Coordinate Outline/Framework												
6.2	Coordinate Prelim. Results from P G & E Tests												
6.3	Finalize Content and Format												
6.4	Present in Final Report												
7.0	TASK XII - PRODUCT LITERATURE												
7.1	Electronic Ballast Technical Characteristics												
7.2	Novel Features Highlighted												
7.3	Design Guidelines												
8.0	TASK XIII - CONTINUOUS DIMMING DEMO. SYS. (THIRD AMENDMENT)												
8.1	Finalization of Design Approach												
8.1.1	In-Put Control Alternative												
8.1.2	Output Control Alternative												
8.2	Procure Parts and Fabrication of Demonstrator												
8.3	Deliver Demonstrator												
9.0	REPORTS												
9.1	Monthly Progress Reports												
9.2	Draft Copy Phase II Final Report Prepared and Submitted												
9.3	Submittal of Approved Phase II Final Report												

APPENDIX 2

EMI REPORTS

By

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4 November 1977

EMI REDUCTION STUDY

on

IOTALITE MODEL 62 FLUORESCENT BALLAST

Summary

A study has been made to minimize electromagnetic interference (EMI) in the Iota Engineering Model 62 Fluorescent Lamp Ballast. With the addition of one capacitor and one small inductor (1.0 microhenry) to the circuit and rearrangement of other filter capacitors, the EMI has been reduced by an average of approximately 20 db across the broadcast band. Comparisons between the Iota ballast and a standard magnetic ballast used as a control indicate that the Iota ballast still is several db noisier in the broadcast band than the standard. Checks in a residential living room indicate, however, that EMI from the Iota unit will be suppressed when the set is tuned to a broadcast station, even on relatively weak signals. The characteristic 60 Hertz buzz is noticeable only when tuning between stations. No discernible interference was noted in any part of the FM or TV bands.

Measurement Procedure

Measurements of conducted EMI were made over the frequency range 0.540 MHz to 108 MHz on the Iota Model 62 unit and on a Catalogue No. 446-LR-TC-P ballast made by the Universal Manufacturing Corporation. The latter is typical of the magnetic ballasts now available from several manufacturers, and was used as a control or comparison standard. Initial measurements were made on both units utilizing three sets of F40CW fluorescent tubes -- one comparatively new pair (100-hour use), one pair judged to be at mid-life, and a third set approaching end of life. Ballasts and tubes were installed in the normal manner in a four-foot area-coverage-type luminaire.

Measurements were made with a Hallicrafters Model SX42 communications receiver energized through an isolating transformer. Voltage measurements were taken directly across the 117-volt AC line input to the ballasts,

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and current measurements were taken across a one-ohm series resistor inserted in the high side (black lead) of the 117-volt line. Leads were connected to the antenna input terminals of the receiver through a 1.25 microfarad capacitor in each line. Measurements were made of the audio voltage at the output jack with an electronic voltmeter, which also was isolated from the AC line supplying the ballasts.

The Iota and standard ballasts were found during the initial measurements to have significant differences only in the standard broadcast band. Therefore subsequent measurements were confined to this frequency region. Also the age of the fluorescent tube had no appreciable effect on noise from the Iota ballast and relatively little on noise from the standard ballast. An occasional exception, in the case of the standard ballast, was a very strong (10 db to 30db above ambient noise) buzz which appeared intermittently with all tubes, but particularly when the mid-life tubes were in use. This effect tended to disappear of its own accord, sometimes quickly and sometimes only after a very annoying five to fifteen minute wait. The effect is believed to be caused by arcing inside the tube at the heater surface.

This effect was not observed in connection with the Iota ballast.

EMI Reduction Philosophy and Procedure

The design philosophy for this EMI suppression task was necessarily that of the quick, economical "fix". The functional design of the unit as received is essentially determined for the present generation of ballasts, and no significant change in functional components was possible. All changes in the circuit for the purpose of reducing EMI were undertaken on the basis that they would produce minimal effect on the established functional characteristics of the unit.

The following procedures were followed in the evolution of the final suppression circuit:

Step 1 -- Removal of Original Input Filter

As received, a three capacitor (0.02 uf each), Y-configured filter was connected across the input line and to ground. Removal of this unit caused less than one db of difference in the average EMI performance across the band, although locations of interference peaks were moved within the broadcast band.

Step 2 -- RF Grounding of Common Plus Line Filter

The electronic circuits in the ballast as received were returned to an ungrounded common lead. In this study the common lead was connected to chassis through a 0.1-uf capacitor. In addition, a 0.022-uf capacitor was

connected directly across the input AC line. This procedure accomplished 20 db to 30 db of interference reduction in midband, but left the interference level at an unacceptable value at the lower frequencies.

Step 3 -- Filtering of Transistor Input

Study of the circuit indicated that a small input capacitor from base to emitter of transistor Q-1 would prevent the amplification of interference signals. (Even though the transistor functions as a switch at 23 kHz, there may be amplification of higher frequencies during the transition periods.) It was determined experimentally that the capacitor has a desirable effect at the high end of the broadcast band, but that a capacitor sufficiently large to be effective across the entire band would be detrimental to the basic circuit function and light output. The largest value of capacitance which appeared not to affect light output was 0.015 uf. A value of 0.01 uf might be used without serious effect on noise suppression.

Step 4 -- Installation of RF Suppressor in B+ Line

The final step involved insertion of a 1.0-microhenry choke paralleled with a 0.1-uf capacitor in the B+ line between the bridge rectifier and the filter capacitor C-1. This addition further improved high frequency response, but left the level at the lower end of the band undesirably high. Increasing the value of the input capacitor from 0.022 uf to 0.15 uf reduced interference at the lower end to a more satisfactory level.

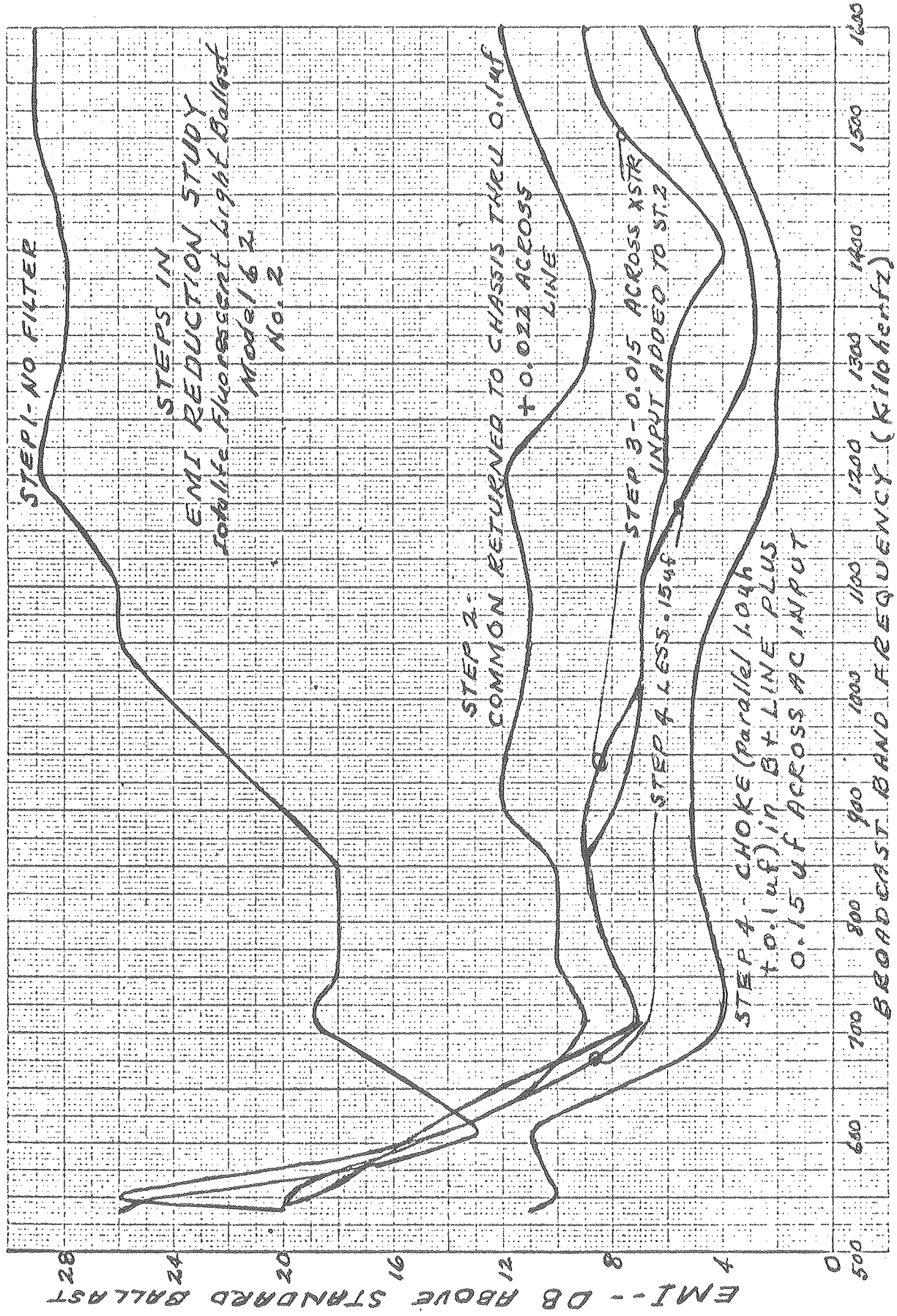
As an alternative to the larger capacitor across the input, return of the line side of the inductor-capacitor combination to the common lead through a capacitor was investigated. The rationale was that the combination with C-1 would form a pi-type filter at the output of the bridge rectifier. This approach is considerably less effective than 0.15 uf across the line, and actually is much noiser at midband.

Results

Plots of the interference characteristics of the ballast as received, and after application of the various suppression devices described above are presented on the following pages.

Further Improvement

The results of this study suggest that conducted noise from the Iotalite electronic ballast might be reduced further to within at least a decibel of the standard magnetic ballast. Reduction of the conducted interference will, in all probability, also remove most radiated interference, since the fluorescent tubes seem not to function well as antennas.


STEP 1 - NO FILTER
STEPS IN
EMI REDUCTION STUDY
Lowlite Fluorescent Light Ballast
Model 162
No. 2
STEP 2 - COMMON RETURNED TO CHASSIS THRU 0.1μf
+ 0.022 ACROSS LINE
STEP 3 - 0.015 ACROSS XSTR
INPUT ADDED TO ST. 2
STEP 4 LESS .154f
STEP 4 - CHOKE (parallel 1.04h
+ 0.1μf) in B+ LINE PLUS
0.154f ACROSS AC INPUT
BROADCAST BAND FREQUENCY (Kilohertz)
EMI -- DB ABOVE STANDARD BALLAST
0
4
8
12
16
20
24
28
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600

Little more can be done, however, simply by filtering and grounding the circuits external to the functional components. EMI control must be made an integral part of the complete circuit design. This in turn will require that the ballast designer and EMI specialist work closely together to achieve a ballast having required light output, line power factor, and safety features plus a very low electromagnetic interference level. Although the redesign probably would be minor, it will require that consideration be given to all aspects of the problem. This would include not only the circuits, but also the case, which in EMI control is really part of the circuit. The present case does very little to contain any EMI generated within it.

With proper attention to all details, it is believed that an electronic ballast can be designed which is competitive in all functional aspects with the Iotalite Model 62 and which generates no more interference than a standard magnetic ballast. With proper design, little if anything should be added to the cost of manufacture.

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28 November 1977

MEASUREMENTS ON REVISED IOTALITE CIRCUIT

Purpose

Two Iota Engineering electronic ballasts were retested on 19 and 20 November 1977. The purpose of the tests was to determine the effect on electromagnetic interference (EMI) of circuit changes incorporated to eliminate squegging of the ballast oscillator.

Results

No substantial difference was noted between these tests and those reported on 4 November 1977, although elimination of the squegging possibly made a slight improvement in EMI performance.

The Iota design with the 4 November suppression included generates 6 to 12 db more EMI than does the standard in the broadcast band. At about 2.8 MHz the two designs generate essentially equal amounts of EMI, and above 2.8 MHz the Iota ballast is less noisy. Above 30 MHz neither ballast produces significant EMI.

Measurements were very consistent on the Iota ballasts -- both between units and from day to day. As mentioned in the report of 4 November, the standard ballast and tube combination generates EMI on an intermittent basis. At times the standard may be just a few decibels above ambient at a given frequency, while at other times it may be as much as 30 db above ambient. When the standard is in the noisy condition, the Iota ballast compares favorably with it, but when the standard is quiescent, the Iota ballast seems very noisy.

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All of the suppression measures discussed in the 4 November report were re-examined, singly and in various combinations. Results indicated in the previous report were confirmed. The suppression reduces EMI from the ballast by an average 20 db.

Conclusions

The results of the 4 November tests were in general repeated. There appears to be an excellent probability that a further study of EMI reduction through a joint effort of ballast designer and EMI specialist could reduce interference across the frequency range to very acceptable levels.

Alfred J. Hoehn

AJH:ih

APPENDIX 3

PERFORMANCE DATA ON EXCEL MANUFACTURED BALLASTS

		Page
1.	NOMENCLATURE	57
2.	DIFFERENCES BETWEEN EXCEL AND IOTA UNITS	57
3.	PERFORMANCE RESULTS	57
	TABLE VI -- PERFORMANCE DATA ON EXCEL MODEL 50 UNITS AFTER 10 MIN WARMUP @ 120 VAC	58
	TABLE VII-- PERFORMANCE DATA ON EXCEL MODEL 60 UNITS AFTER 10 MIN WARMUP @ 120 VAC	59
	TABLE VIII- PERFORMANCE DATA ON EXCEL MODEL 60 UNITS WITH ONE STEP DIMMING -- SWITCHED TO DIM AFTER HIGH OUTPUT DATA TAKEN	60

PERFORMANCE DATA ON EXCEL MANUFACTURED BALLASTS

1. Nomenclature -- EXCEL has chosen to designate their 5000 lumen units as Model 50 and the 6000 lumen units as Model 60.

2. Differences between EXCEL and IOTA Units -- As previously indicated EXCEL redesigned the chassis and housing to reduce manufacturing costs on these items. Two changes were made during the course of their program. The second change which represents the units manufactured by EXCEL prior to mid-July 1978 under the IOTA subcontract, resulted in a two metal parts arrangement. Heat sinking provided for the transistor was reduced below that of the IOTA Models 54 and 64 designs. Also in the interest of economy they elected not to anodize or paint the metal black. These two changes result in higher temperatures in the unit. The other significant change was the use of a steel screw through the main transformer. IOTA has used brass or nylon. This change also has a detrimental effect on performance. IOTA understands that EXCEL units will be redesigned to correct performance reductions brought about by the foregoing changes.

3. Performance Results -- Performance data was taken on 10 Model 50 units, picked at random, and 10 of the Model 60 units that were subsequently modified for step-dimming. (See Tables VI, VII, and VIII.) This is considered to be an adequate representative sample for performance data. It shows that light output on both models is low. System performance in terms of lumens per watt is approximately five to ten per cent less than was obtained by IOTA in the Models 54 and 64 provided to LBL at an earlier date. Later model EXCEL units are expected to reflect comparable results to IOTA manufactured units.

TABLE VI

DATA ITEM	PERFORMANCE DATA ON EXCEL MODEL 50 UNITS AFTER 10 MIN WARMUP @ 120 VAC									
EXCEL BALLAST MODEL NO.	50	50	50	50	50	50	50	50	50	50
" " SERIAL NO.	58	H353	K4	54	H325	H58	H73	H52	H69	C10
INPUT VOLTS -- RMS	120	120	120	120	120	120	120	120	120	120
INPUT AMPS -- RMS	.680	.610	.573	.610	.620	.550	.593	.650	.582	.590
INPUT WATTS--STD AC WATTMETER	70.5	67.5	61.0	64.5	64.5	59.0	61.0	68.0	62.0	62.25
* OUTPUT LIGHT READING--SILICON CELL	1416	1430	1310	1374	1395	1280	1330	1420	1348	1346
** OUTPUT LIGHT READING--OVERALL	257.5	260	237.5	245.0	250.0	227.5	240	257.5	242.5	242.5
TEMPERATURE LAMP 1 @ ¢ °F	104	105	102	101	103	101	103	104	102	102
" " 2 @ ¢ °F	102	103	101	101	102	101	102	103	102	102
APPROX. LUMEN OUTPUT = LIGHT OVERALL X 19.46	5011	5060	4622	4768	4865	4427	4670	5011	4719	4719
POWER FACTOR = INPUT WATTS ÷ VOLTS X AMPS	.864	.922	.887	.881	.867	.894	.857	.871	.887	.879
SYSTEM EFFICIENCY = APPROX. LUMEN OUTPUT ÷ WATTS	71.08	74.96	75.78	73.92	75.43	75.03	76.57	73.69	76.11	75.81

AVERAGE WATTS 10 UNITS 64.03

AVERAGE LUMEN OUTPUT 4787

AVERAGE SYS EFFICIENCY 74.76

* Light by silicon cell mounted above both lamps on lab bench test station--subject to small temp. drift with time.

** Light by photo research meter with cell mounted above both lamps on test bench. Lab lights on at time of station calibration and at time of all readings. This means light readings on dim are higher than actual light produced.

TABLE VII

DATA ITEM	PERFORMANCE DATA ON EXCEL MODEL 60 UNITS AFTER 10 MIN WARMUP @ 120 VAC									
EXCEL BALLAST MODEL NO.	60	60	60	60	60	60	60	60	60	60
" " SERIAL NO.	H4	H351	H217	H341	H321	L3	H255	H396	H395	H418
INPUT VOLTS -- RMS	120	120	120	120	120	120	120	120	120	120
INPUT AMPS -- RMS	.648	.670	.650	.735	.665	.668	.665	.685	.650	.735
INPUT WATTS--STD AC WATTMETER	69.0	73.5	71.0	78.25	71.5	71.0	72.0	74.25	71.0	78.25
* OUTPUT LIGHT READING--SILICON CELL	1428	1530	1498	1548	1532	1478	1507	1558	1518	1604
** OUTPUT LIGHT READING--OVERALL	252.5	265	262.5	277.5	277.5	265	270	280	272.5	285
TEMPERATURE LAMP 1 @ ℄ °F	Not Available		102	103	105	104	104	106	105	107
" " 2 @ ℄ °F	" "		102	102	103	103	103	105	104	106
APPROX. LUMEN OUTPUT = LIGHT OVERALL X 19.46	4914	5157	5108	5400	5400	5157	5254	5449	5303	5546
POWER FACTOR = INPUT WATTS ÷ VOLTS X AMPS	.887	.914	.910	.887	.896	.885	.902	.903	.910	.887
SYSTEM EFFICIENCY = APPROX. LUMEN OUTPUT ÷ WATTS	71.22	70.16	71.94	69.01	75.52	72.63	72.97	73.39	74.69	70.88

AVERAGE WATTS 10 UNITS 72.975

AVERAGE LUMEN OUTPUT 5269

AVERAGE SYS EFFICIENCY 72.20

* Light by silicon cell mounted above both lamps on lab bench test station--subject to small temp. drift with time.

** Light by photo research meter with cell mounted above both lamps on test bench. Lab lights on at time of station calibration and at time of all readings. This means light readings on dim are higher than actual light produced.

TABLE VIII

DATA ITEM	PERFORMANCE DATA ON EXCEL MODEL 60 UNITS WITH ONE STEP DIMMING -- SWITCHED TO DIM AFTER HIGH OUTPUT DATA TAKEN									
EXCEL BALLAST MODEL NO.	60	60	60	60	60	60	60	60	60	60
" " SERIAL NO.	H4	H351	H217	H341	H321	L3	H255	H396	H395	H418
INPUT VOLTS -- RMS	120	120	120	120	120	120	120	120	120	120
INPUT AMPS -- RMS	.453	.475	.470	.465	.470	.468	.465	.475	.465	.480
INPUT WATTS--STD AC WATTMETER	18.0	21.0	22.0	17.0	20.5	19.0	20.5	21.0	22.0	19.0
* OUTPUT LIGHT READING--SILICON CELL	394	490	513	358	508	420	482	503	538	443
** OUTPUT LIGHT READING--OVERALL	70.0	87.5	90.0	65.0	95.0	77.5	92.5	95.0	97.5	80.0
TEMPERATURE LAMP 1 @ ℄ °F										
" " 2 @ ℄ °F										
APPROX. LUMEN OUTPUT = LIGHT OVERALL X 19.46	1362	1703	1751	1265	1849	1508	1800	1849	1897	1557
POWER FACTOR = INPUT WATTS ÷ VOLTS X AMPS	.331	.368	.390	.301	.363	.338	.367	.368	.394	.330
SYSTEM EFFICIENCY = APPROX. LUMEN OUTPUT ÷ WATTS										

AVERAGE WATTS 10 UNITS 20.0

AVERAGE LUMEN OUTPUT 1654

AVERAGE SYS EFFICIENCY _____

* Light by silicon cell mounted above both lamps on lab bench test station--subject to small temp. drift with time.

** Light by photo research meter with cell mounted above both lamps on test bench. Lab lights on at time of station calibration and at time of all readings. This means light readings on dim are higher than actual light produced.

APPENDIX 4

PRODUCT LITERATURE

		Page
1.	DESCRIPTION AND ADVANTAGES OF IOTA's ELECTRONIC BALLASTS	62
2.	SPECIFICATIONS FOR ELECTRONIC BALLASTS FOR 2-40W RS LAMPS	64
3.	MULTIPLE FIXTURE EMERGENCY LIGHTING SYSTEM DESCRIPTION & SPEC	65
4.	INTEGRAL EMERGENCY LIGHTING SYSTEM DESCRIPTION & SPEC--SINGLE FIXTURE	66
5.	MULTIPLE FIXTURE EMERGENCY SYSTEM INSTALLATION INSTRUCTIONS	67
6.	SINGLE FIXTURE EMERGENCY SYSTEM INSTALLATION INSTRUCTIONS	68
7.	STEP-DIMMING BALLAST DESCRIPTION & INSTALLATION INSTRUCTIONS	72

DESCRIPTION AND ADVANTAGES OF ELECTRONIC BALLASTS FOR TWO 40W RAPID START FLUORESCENT LAMPS

GENERAL

The standard magnetic core ballast is basically a wire transformer that changes line voltage and controls the current as necessary to ignite and regulate the arc in one or more gas-filled fluorescent lamps. Power is delivered to the lamps at standard $60H_z$ line frequency. The electronic ballast uses solid state components and one or more relatively small transformers to accomplish the same purpose. However, the oscillating frequency of the power to the lamps is much higher than the input line frequency. IOTA's units generally vary from 25 to 35 KH_z. This new product offers many potential advantages:

1. Power Savings -- A fluorescent lamp is more efficient in producing light when the input power oscillates at high frequency. Improvements of as much as 20% have been shown with standard lamps. In addition, it is possible to obtain better electrical efficiency with solid state devices than has previously been demonstrated by standard magnetic core type ballasts. These factors combine to make possible system efficiency improvements with the IOTA 2-40W lamp ballasts ranging upward from 20%.

2. Additional Power Savings through Dimming -- The electronic ballast can be dimmed without serious degradation in system efficiency. This opens a wide range of possibilities for additional energy savings using this feature. Lighting systems can be designed where the amount of artificial light is varied as necessary to compensate for available daylight; and, to reduce lighting to that minimum level required for any specific work area or task.

3. No Flicker -- When the oscillating frequency is raised appreciably above $20KH_z$ the human eye is not able to detect the "flicker." Many people are bothered by the flicker from 60 cycle fluorescent systems.

4. No Detectable Sound -- Likewise, when the frequency is raised above the normal audible range of the human ear, the objectionable sound often associated with standard ballasts is eliminated.

5. Emergency Lighting -- The electronic ballast can be designed to operate from either alternating or direct current power. This permits adaptation for battery-powered emergency lighting without the necessity of additional hardware -- other than batteries and a charging unit.

6. Reduced Weight -- Early model electronic ballasts will weigh only about one-third as much as the standard article. Future models can probably be made with even less weight and with greatly reduced volume. This feature will lend itself to design of more aesthetically pleasing and energy efficient lighting systems in future building applications.

SPECIFICATION FOR ELECTRONIC BALLASTS
OPERATING DUAL 40-W LAMPS (RAPID START)

CHARACTERISTIC	IOTA MODEL 54 P	IOTA MODEL 64 P
Input		
AC Input RMS Voltage-Design Center	120 Volts	120 Volts
Starting & Operating Voltage Range	90-110% of Design Center	90-110% of Design Center
AC Input RMS Current-Design Center	0.650 Amps	0.750 Amps
Line Power Factor - Range	.85 - .95	.85 - .95
Output		
Frequency - Nominal	27 - 30 KHz	27 - 30 KHz
Lamp Current - Nominal	.280 Amps	.375 Amps
Lamp Voltage - 2 Lamps Nominal	218 RMS	200 RMS
Lamp Lumens - 2 Lamps Nominal	5,000	6,000
Cathode Preheat Volts - Design Center	3.8	4.0
Crest Factor	Less than 2.5	Less than 2.5
Physical		
Ballast Weight		
Ballast Dimensions		
Safety		
Protection	3 Amp In-Line Fuse	3 Amp In-Line Fuse
Thermal Switch	Nominal Setting 90°C	Nominal Setting 90°C

MULTIPLE FIXTURE EMERGENCY LIGHTING SYSTEM

General Description: This system consists basically of any number of AC/DC electronic ballasts Model No. 1 A/D 120/72-2-40, and a remote battery pack with a charging unit and switch-over control Part No. BCR 72/2.0. A Model 54 P ballast is modified to permit energy saving operation on alternating current; or alternatively, operation on DC current at a nominal 72V input. No special wiring is required. Fixtures designated for emergency lighting are on an isolated circuit, the power for which is controlled by the charging and regulator unit. The number of fixtures, operating time, and amp-hour capacity rating for the battery(s) may be traded to produce a system that will operate for the minimum 1.5 hours, or, for much longer periods.

SPECIFICATION FOR MULTIPLE FIXTURE EMERGENCY LIGHTING SYSTEM

Characteristics on AC Power (Oscillating Frequency 27-30 KH_z)	Data Item
No. and Type Fixtures	Seven or Less for 2-40W Lamps
System Input Voltage	120 VAC
System Input Current	.65 Amps per Ballast
System Input Power	68-72 Watts per Ballast
System Power Factor	.90-.94
Light Output	5000 Nominal Lumens/Fixture
Required Battery(s)	72 VDC Nominal
Battery(s) Make-up	6-12V, Series Connected
Min. Req. Capacity for OSHA 90 Minute Standard	2-Amp-Hours per Fixture
Type Charging Unit	Constant Voltage, Tapered Current
Battery Charging Voltage	79-82 VDC
Charging Current Range	.040 to 2.0 Amps
Recharging Time	Less than 24 Hrs.

Characteristics on Battery Power (Oscillating Frequency 27-30 KH_z)	
Control Method When Power Fails	Voltage Dropout Relay
Current Drain	.800 Amps/Fixture
Light Output @ 0 to 90 Min.	4800 to 4000 lumens
Battery Protection Voltage Dropout	60 VDC

INTEGRAL EMERGENCY LIGHTING SYSTEM -- SINGLE FIXTURE

General Description: This system consists basically of an electronic unit Model No. 1 A/D 120/12-2-40 and a 12 Volt battery(s) pack Part No. B6-2-5, both of which are configured for installation inside any standard 2-40W lamp fixture. The electronic unit performs three functions: first, it powers the lamps on 120H_z alternating current with power savings in the order of 25%; second, when power fails, it automatically switches the lamp load to the 12V battery; and third, it charges the battery after emergency operation and maintains a "float-level" charge thereafter.

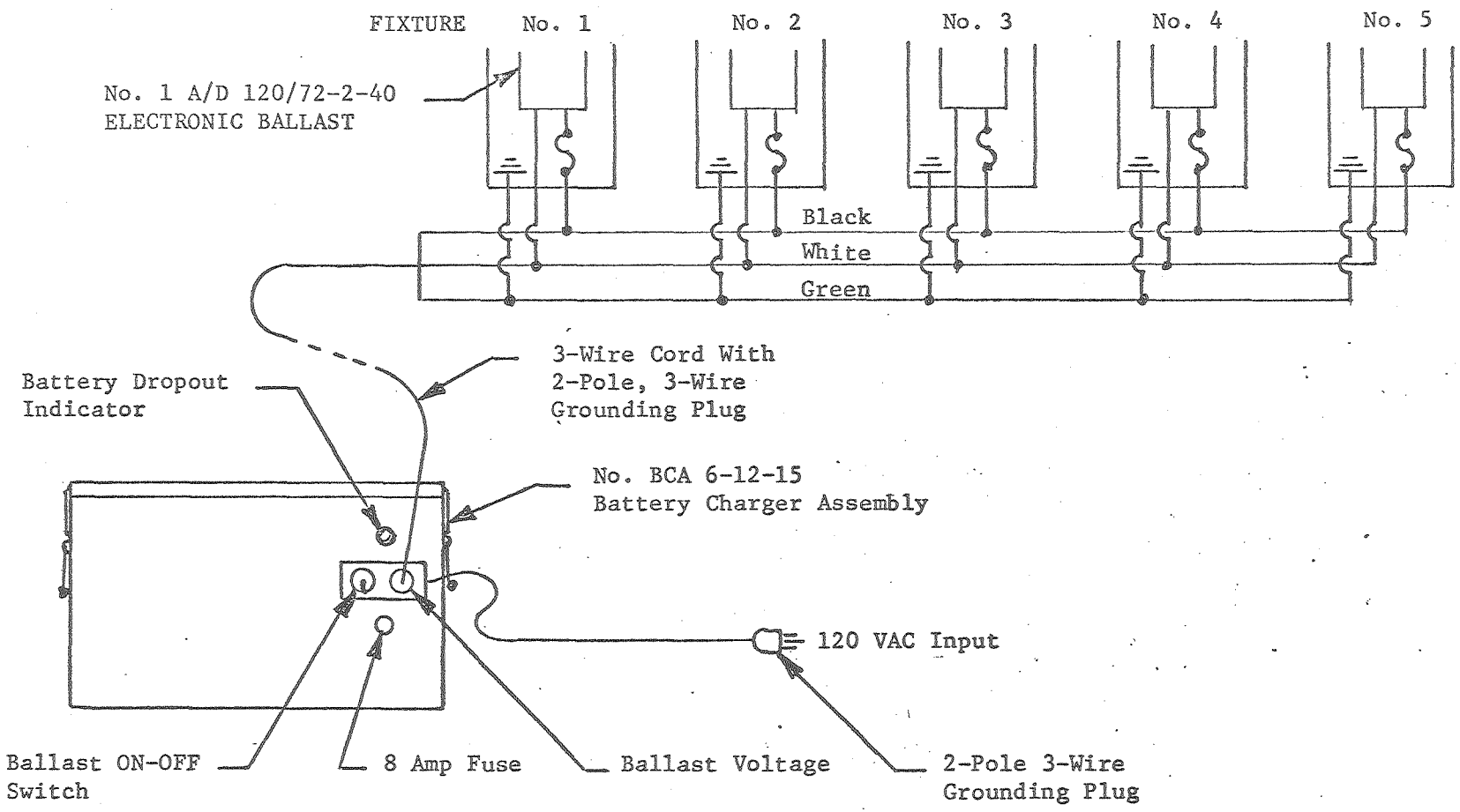
SPECIFICATION FOR INTEGRAL EMERGENCY LIGHTING SYSTEM -- SINGLE FIXTURE

Characteristics on AC Power (Oscillating Frequency 20-24 KH_z)	Data Item
Type Fixture	For 2-40W RS Lamps
System Input Voltage	120 VAC
System Input Current	.90 to .95 Amps
System Input Power	60-70 Watts
System Power Factor	.52 to .62
Light Output	5000 Nominal Lumens
Required Battery(s)	12VDC Nominal
Battery Make-up	6 - 2V, 5 AH, Series connected
Type Charging Circuit	Constant Voltage, Tapered Current
Battery Charging Voltage	13.5 to 14.5 VDC
Charging Current Range	.005 - .300 Amps
Recharging Time	Less than 24 Hours

Characteristics on Battery Power (Oscillating Frequency 17-20 KH_z)	
Control Method when Power Fails	Voltage Dropout Relay
Current Drain	1.70 to 1.90 Amps
Light Output	Over 25-35% Normal
Emergency Operation Time	Over 1.5 Hours
Battery Protection Voltage Dropout	Between 7 and 9 Volts
Starting	Capable of Starting from Battery

Wiring and Control	
No. Wires Needed for Constant Operation	Standard--Two + Fixture Ground
No. Wires Needed for Intermittent Operation	One Extra Wire
Control for Constant Operation	No Switches
Control for Intermittent Operation	Single Pole Double Throw Switch

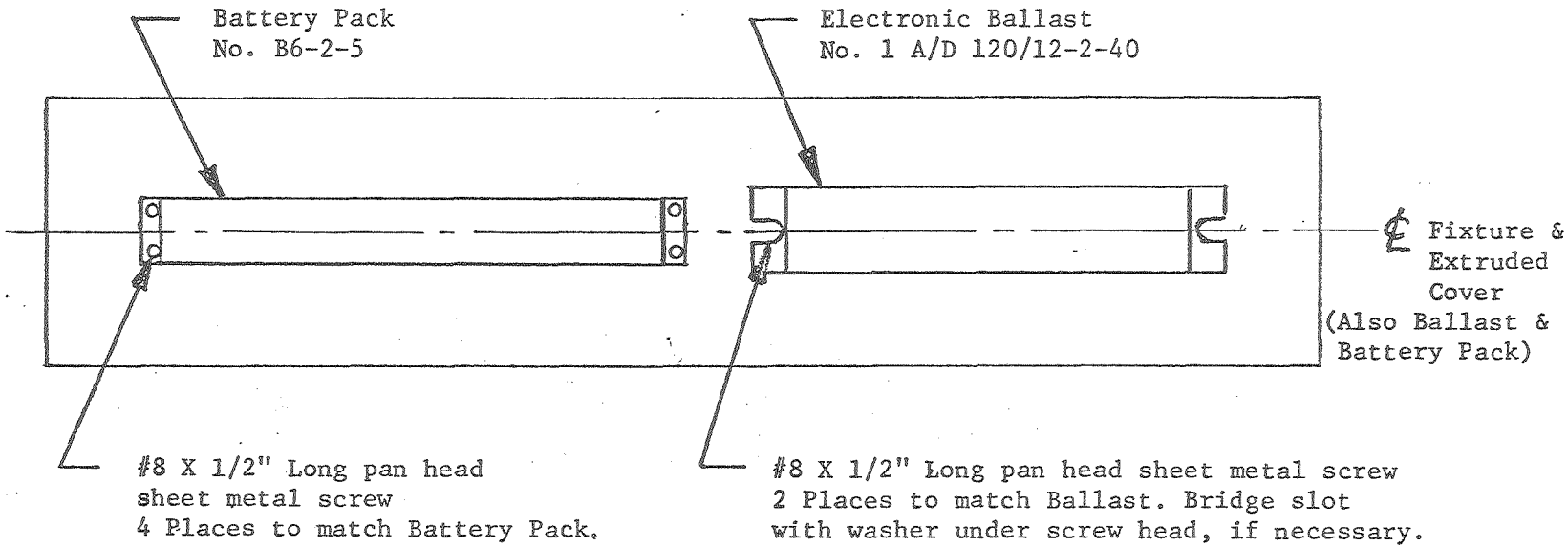
MULTIPLE FIXTURE EMERGENCY SYSTEM INSTALLATION INSTRUCTIONS



APPLICATION OF NO.1 A/D 120/72-2-40 ELECTRONIC BALLAST

WITH NO. BCA 6-12-15 BATTERY/CHARGER ASSEMBLY

IOTA Engineering, Inc.
1735 E. Ft. Lowell Rd.
Tucson, Arizona 85719



Note: Hole size in fixture panel
to suit mounting screws used.

INSTALLATION OF ELECTRONIC BALLAST NO. 1 A/D 120/12-2-40

AND BATTERY PACK NO. B6-2-5

Fig. 1

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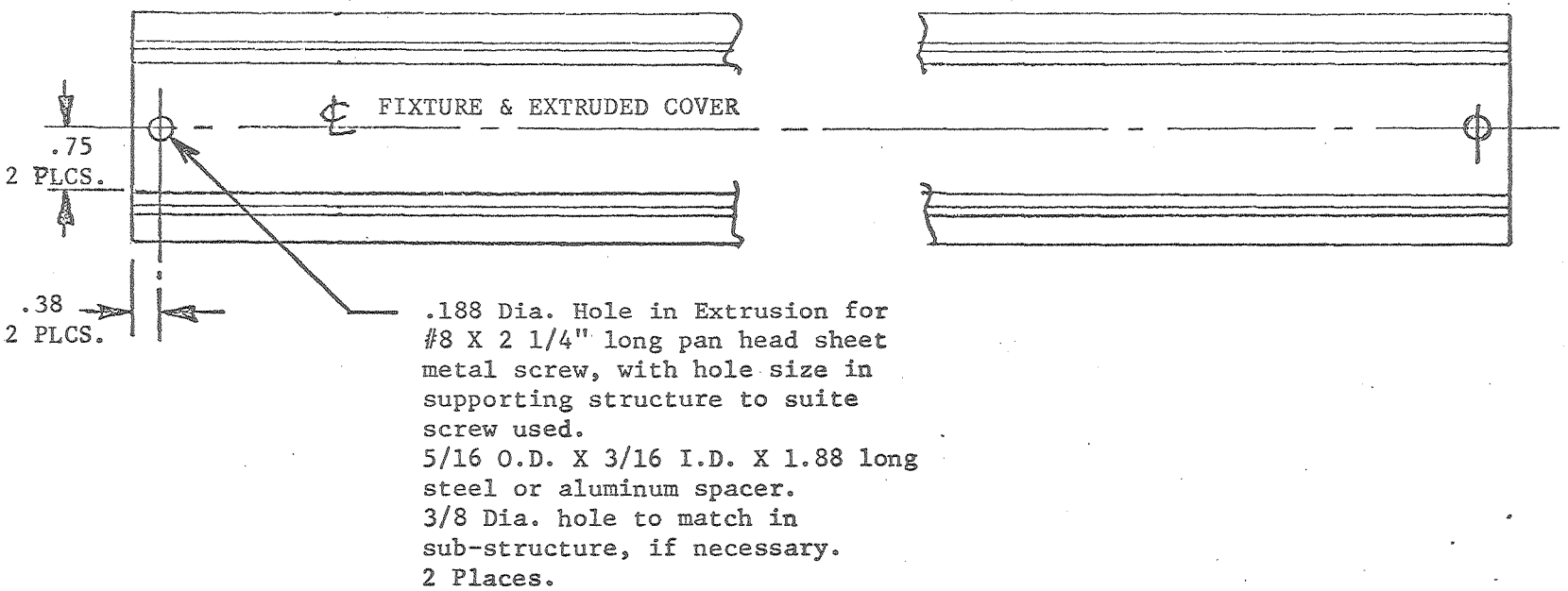
Tucson, Arizona 85719



EXTRUDED COVER MODIFICATION & INSTALLATION DETAILS FOR USE WITH

ELECTRONIC BALLAST NO. 1 A/D 120/12-2-40 AND BATTERY PACK NO. B6-2-5

Fig.2

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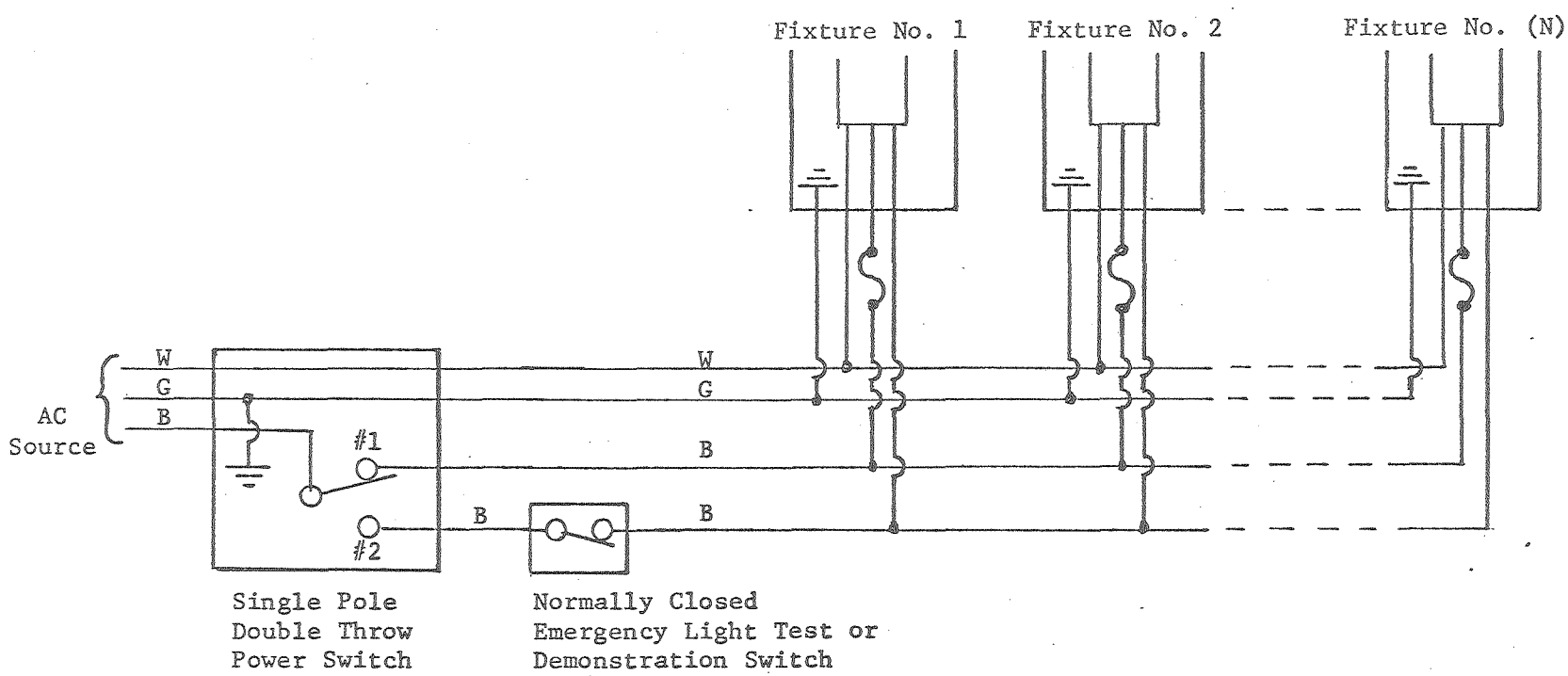
Tucson, Arizona 85719



AC POWER CONNECTION TO FIXTURES USING

NO. 1 A/D 120/12-2-40 ELECTRONIC BALLAST

Fig. 3

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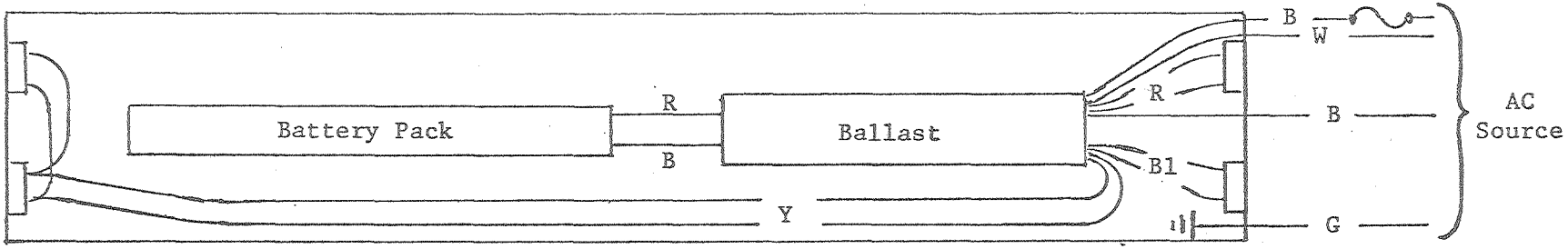
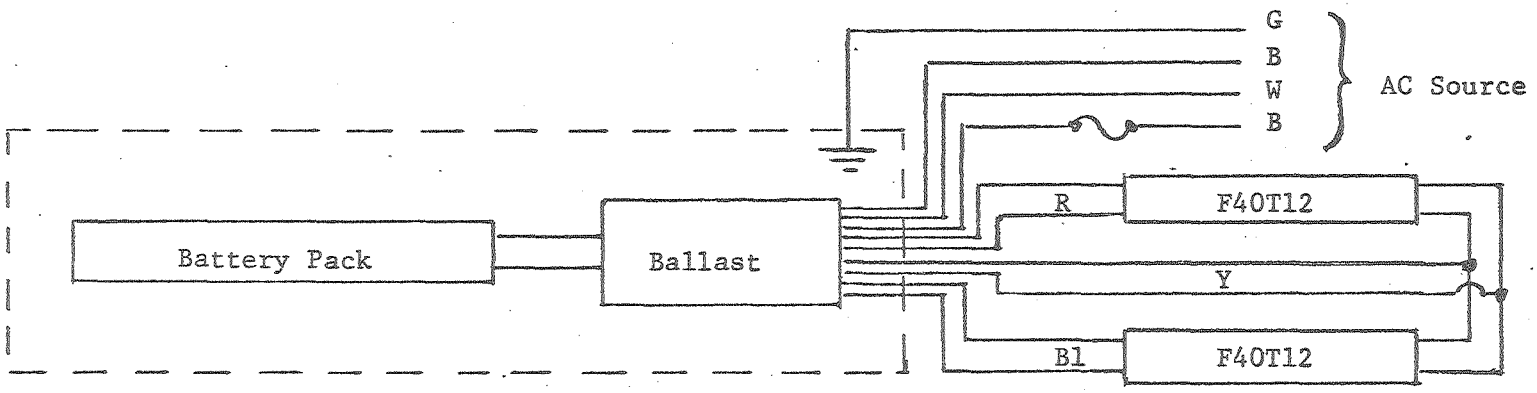
Tucson, Arizona 85719



WIRING DIAGRAM



SCHEMATIC

SCHEMATIC AND WIRING DIAGRAMS FOR FIXTURES USING

ELECTRONIC BALLAST NO.1 A/D 120/12-2-40 AND BATTERY PACK NO. B6-2-5

Fig. 4

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Tucson, Arizona 85719

STEP-DIMMING BALLAST DESCRIPTION

AND INSTALLATION INSTRUCTIONS

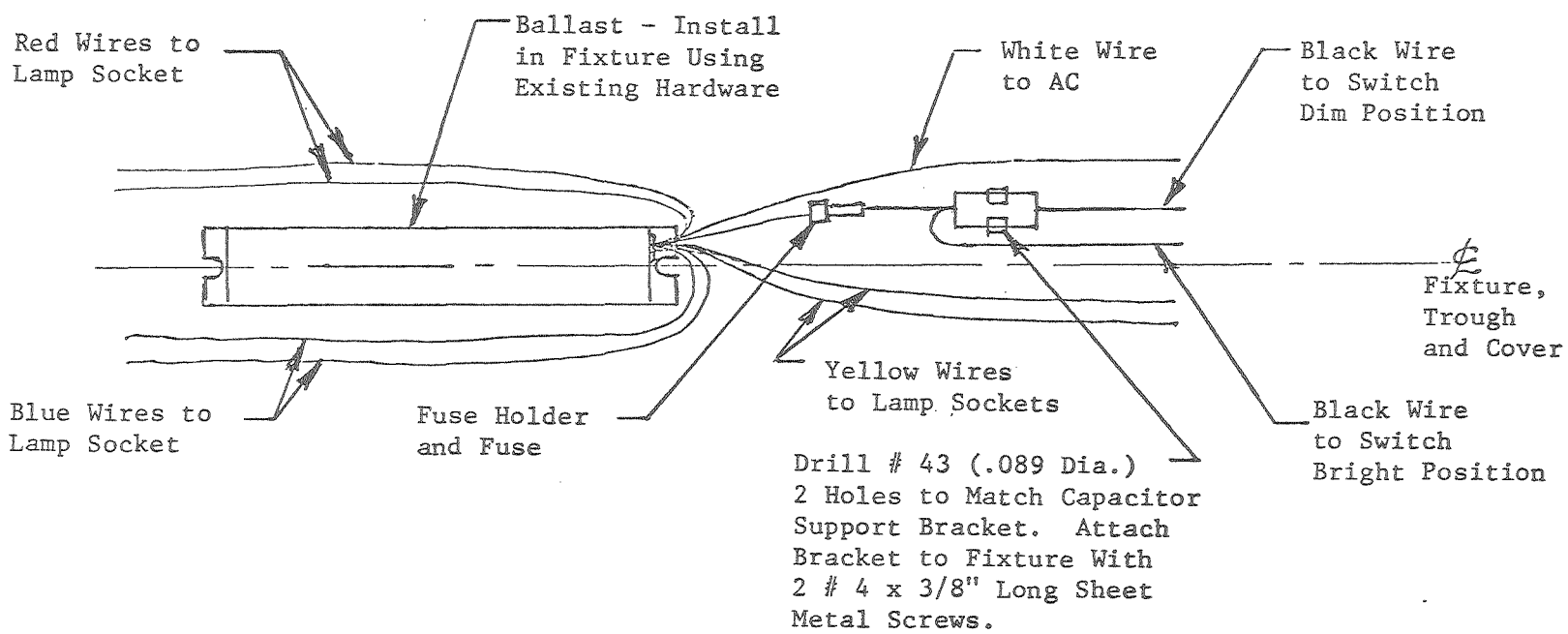
1. Attributes of Dimming -- The standard magnetic core ballast cannot be dimmed by lowering input voltage below about 90 VAC, without upsetting system performance. Whereas, the electronic ballast can be dimmed by a number of methods which have been discussed elsewhere. Dimming permits power savings by reducing light and power when less illumination is tolerable for tasks at hand. For example, it might be good to light corridors to a high illumination level during occupied hours but to greatly reduce these levels when the building is not occupied. However, safety and security lighting may be required in the corridors at all times. The ability to reduce light output from the same lamps for these circumstances permits appreciable power savings. This also permits savings when varying levels of daylight are available to an area.

2. Most Efficient Method for Dimming IOTA Ballasts -- As discussed elsewhere, IOTA has investigated and demonstrated several methods for dimming. The most efficient from a performance standpoint has consistently been control of input voltage. Continuous dimming provides aesthetic appeal but does not result in comparable system performance efficiencies, and, is more expensive than dimming by steps. Therefore, IOTA has chosen to provide step-dimming in the demonstration program.

3. Least Expensive Method to Accomplish Voltage Reduction -- The one-step dimmable ballast provided under the LBL program (70 units) was accomplished by placing an AC capacitor in series with one of the input power lines to the unit. Use of lower value capacitors results in a greater reduction in light and power than higher value units. The ones purchased for this program were rated at 10 micro-farads at 220 VAC. This results

in a power reduction of approximately 72% and a slightly larger percentage reduction in light output. Specific performance data on 10 EXCEL manufactured Model 60 units have been presented under Appendix 3.

4. Installation Instructions -- The wiring diagram instructions for installation of the IOTA one-step dimming ballast are given on the following page.



INSTALLATION INFORMATION

EXCEL ELECTRONIC BALLAST

WITH CAPACITOR DIMMING

APPENDIX 5

Excerpts From

LIGHTING RESEARCH LABORATORY REPORT

on

PHASE I

ELECTRONIC BALLASTS

LIGHTING RESEARCH LABORATORY

Design • Testing • Consulting

8-8-77 REPORT 677-5
p. 1 of 25

To: Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

Attn: Mr. R. R. Verderber

Subj: Test of light output and electrical characteristics of eight samples of commercial 2/40W 60 Hz ballasts and four samples of Iota Engr. Inc. 2/40W High Frequency ballasts, as covered by UC Purchase Order 2889502, Sections A, B, C & F, and Change Order No. 1

Procedure: All tests were performed in accordance with IES or other applicable standards, where appropriate. Test procedures not in accordance with published standards are described in the Report. Where appropriate, absolute or relative accuracy figures are given for each test.

Results: Test elements and results are tabulated in Table I and Table II and in the Kaelite report.

Comment: Comment is keyed to classifications under "Scope" in subject Purchase Order and C.O. (Change Order) No. 1.

I. Efficacy.

A. Free air tests. The average free-air efficacy for the standard 120v 60Hz ballast is 64.2 LPW. The "high-efficiency" 60-Hz unit averages 67.4, an increase of 5% over the standard unit. Average for the three low-output Iota units is 71.3, an increase of 11% over the standard and 6% over the high-efficiency unit. The single sample of the high-output Iota has an efficacy of 75.1, an increase of 17% over the standard unit and 11% over the high-efficiency unit.

Based on free-air tests, which are indicative of performance in industrial, suspended commercial, and bare-lamp units, the expected improvement in economy of operation with the Iota ballast is of the order of 6 - 11% over the most efficient currently available 60-Hz ballast.

P O Box 6193, Orange, CA 92667 (714) 771-1312

B. Calorimeter tests.

1. Four lamp units. It is apparent that the temperature buildup in four-lamp recessed units produces a substantial drop in lamp output. The decline for the standard ballast (#1 and #2) is from 11988 to 9825 lumens, or 18%. The drop in output is accompanied by a drop in wattage, so that the drop in efficacy is only 7%. The same drops are obtained with the high-efficiency 60 Hz ballast (#6 and #8), showing that it is due to the lamp temperature.

With the Iota low-output unit, the light output drops only 2.6%, and the loss in efficacy is only 1.4%. The net result is an efficacy of 69.7% for this unit, compared to 58.6% and 62.5% for standard and high-efficiency 60Hz units respectively. The Iota unit therefore operates at an increase of 19% over the standard unit and 12% over the high-efficiency unit, or roughly double the improvements in free air. This improvement is apparently due to the lower temperature and current loading.

2. Two lamp units (CO#1 Sec 1): These show, as might be expected, considerably less loss of light output due to temperature. The high-efficiency 60 Hz unit drops from 5920 to 5487 lumens, a loss of 7%. As a result, the advantage of the Iota unit over this unit should be expected to be less than that with four lamps and more similar to that for free air. This is indeed the case, the advantage for the low output Iota (#A) being 5%. The high-output Iota (#B) shows a drop in efficacy of only 2.1% for this condition, having a total advantage over the high-efficiency 60Hz unit of 11%.

C. It is therefore seen that the ability of the Iota unit to hold its efficiency in the usual recessed-troffer installation is a highly significant factor in today's market, since four-lamp 2 X 4 troffers are probably the largest-selling commercial unit. Its advantage in free air or in 2-lamp 2 X 4 units, however, is considerably less marked.

II. Regulation. Regulation for the 60-Hz units is consistent in the 5 to 7 percent range. This is normal for a standard electromagnetic ballast. The Iota unit also shows reasonable regulation consistency at a level of around 8 to 11 percent. While greater than the 60-Hz units, this is still an acceptable range, and the difference would not be noticeable in practice.

III. Starting Characteristics.

A. Starting time. This is a variable characteristic, strongly dependent upon supply voltage, but subject to considerable variation from start to start under the same conditions. It should be noted that the Iota units start, at rated voltage, in about half the time of the standard ballast. Since this approaches the "instant-start" condition, which in 60-Hz ballasts has deleterious effects on the cathodes of the lamps, the possibility exists that, particularly at overvoltage, this fast starting may be damaging to the lamps and affect their life.

B. Peak starting current. In addition to differences between ballasts, this factor is strongly influenced by the portion of the cycle in which the switch is closed. It is necessary to examine numerous starts and to pick the most severe case, and there is no guarantee that this is actually the absolute worst. The conclusions which may be drawn from these tests are:

1. Peak starting current tends to be higher as voltage input is increased.
2. Peak currents for the Iota unit are in general 1/2 to 1/3 of those for 60-Hz ballasts
3. All peaks are below 5 amperes.

C. Low-temperature starting. The minimum voltage required to start the lamp within 10 seconds was used as a criterion of low-temperature starting. The 60-Hz units were quite consistent at about 80% of rated voltage for the 120-volt units; and 85% of rated for the 277 volt. The Iota units under the same condition started at about 55% of rated input voltage, which indicates that low-temperature starting should not produce any problems.

D. Cathode-circuit voltage. The magnitude of the voltage applied to the cathode in the Iota ballast is similar to that for the 60-Hz unit. After the lamp has fired, this drops to a lower level, which is advantageous both from the standpoint of lamp life and for increased energy conservation.

IV. Open circuit voltage. The Iota units in general had an open circuit voltage of about 184% of that for the 60-Hz units. This is probably primarily responsible for the excellent low-temperature starting performance reported in IIIC, but also for the fast starting reported in IIIA.

V. Crest Factor. Within a given ballast type, crest factor as determined by oscilloscope trace examination was constant for rated voltage conditions, being 1.5 for the 60-Hz ballasts and 1.76 for the Iota. Neither of these is an extreme value. Furthermore, it is not certain that the deleterious effects of high crest factor apply to this source and circuit as they do in HID (high-intensity-discharge) systems. The largest effect is likely to be the effect of the waveshape on power factor.

VI. Power Factor. Power factor measurements have an intrinsically lower accuracy than measurements of E, I and P, for two reasons:

1. A highly distorted current wave may have strong higher order harmonics. The meter used is compensated to 800 cycles, but the accuracy of an 800-cycle component is ± 3%. Any higher-order harmonics will not be reflected properly in the current reading, although the voltage reading will be accurate, since the input voltage wave is essentially sinusoidal. This can have the effect of calculating a higher power factor by an amount depending on the harmonic content of the current wave.

2. Since power factor is calculated by dividing power by voltage x current, with both P and EI subject to an accuracy of 0.75%, the expected accuracy of the complex product of these tolerances is approximately ± 1%.

Particularly in the case of the Iota ballasts, therefore, the power factor may be somewhat lower than the measurements indicate. Since all readings are above 90%, this should not be at all critical.

VII. Noise. The 60-Hz ballasts tested were quite consistent in noise level, with an average of 35 dbA. If we assign this level the rated noise level for these units (A), the low-output Iota units, A, C and D, will average 20 dbA, or 15 dbA quieter than an A rated ballast, or three sound levels quieter than A. In any case, the ballasts are essentially inaudible. The high-output Iota (#B) measures 26 dbA, or about two sound levels below A.

CO#1 Sec 2: The noise spectra of Iota #A and #D were examined to spot any important frequency components in the 20 - 30 KC range. Since the sound level meter's response drops off rapidly above 15 KC, it was not possible to determine the magnitude, but the only significant frequency component in this range for either ballast was approximately 23KC. Reference to Fig. 15 will show that this frequency is not pronounced in the waveform.

VIII. Flicker. Flicker is measured by the determination of Flicker Index, which takes waveform into effect and is considered more reliable as an index of perceptual flicker than is Percent Flicker. While the base secondary frequency is around 35 KC, the secondary voltage and therefore the light output varies at a 120 Hz rate (see Fig. 10 & 13). It is therefore possible to compare flicker indices for the 60-Hz and Iota units, since basic repetition rates are the same. The index for the Iota unit is .055, which is superior to the same lamp on 60 Hz, whose index is .065.

IX. Stroboscopic effect. The magnitude of stroboscopic effect, which is apparent with moving objects, is dependent upon the perceived brightness of the object seen at times of greatest and least illumination. It is therefore more nearly related to the maximum and minimum values of light output within a cycle, and is better described by Percent Flicker. Here, % Flicker is 17.9% for the lamp on the Iota ballast and 30.4% on the standard ballast. Therefore, strobe will be less noticeable on the Iota ballast.

XI. Spectral Energy Distribution. SED curves were run for the same lamp on a 60-Hz ballast and on the Iota 22PCT2. Results are given in the Kaelite report. The spread of the x and y coefficients is less than the tolerance allowed in the standard color tolerance for the lamp. The difference in color between the lamp on a standard ballast and on the Iota is, therefore, insignificant.

It should be noted that the response rate of the chart and pen recording the SED curves is not quite capable of rendering the mercury lines in the spectrum. This does not affect the accuracy of the x and y coefficients, since the spectral output is fed directly into the computer and is not taken from the chart.

CERTIFIED FOR LRL:

Bill F. Jones, P. E.
Consulting Illumination Engineer

TABLE I FREE-AIR OPERATION

LINE	ITEM				
1	Ballast	18PCT3#A	22PCT2#B	18PCT4#C	18PCT8#D
2	Lamps	4,5	4,5	4,5	9,10
3	Volts	120	120	120	120
4	Amps	.551	.732	.552	.578
5	Watts	64.0	80.3	62.3	65.8
6	Power Factor	.97	.91	.94	.95
7	Lumens	4514	6031	4588	4736
8	Efficacy, LPW	70.5	75.1	73.6	70.9
9	Regulation, 90%	-10.7%	-8.6%	-10.5%	-10.9%
	" 110%	+9.8%	+8.0%	+9.7%	+4.7%
10	Starting Time, 90%	1.0	0.7	0.8	0.6
	100%	0.8	0.5	0.6	0.5
	110%	0.6	0.4	0.5	0.4
11	Peak Start I, 90%	1.0	1.0	1.0	1.0
	100%	1.8	2.5	1.0	1.0
	110%	2.4	1.0	1.0	1.0
12	Open Circ. Voltage	464	509	469	492
13	Crest Factor	1.76	1.76	1.76	1.76
14	Cathode Ckt Volt:				
	Yel Start	2.4	2.2	2.4	2.3
	Oper.	1.6	1.5	1.6	1.5
	Red Start	2.6	2.7	2.6	2.6
	Oper.	1.8	1.8	1.8	1.8
	Blu Start	2.2	1.9	2.2	2.2
	Oper.	1.5	1.3	1.5	1.5
15	Flicker Index	.055	.055	.055	.055
	Percent Flicker	17.9	17.9	17.9	17.9
16	Secondary Freq.	35.7KHz	30.5KHz	34.2KHz	34.2KHz
17	Lamp Temp.	35	38	35	35
18	Ballast Temp.	43	43	43	43
19	Min. Start E @ 50°	70	65	70	65
20	Rel. Noise Level	20	26	20	20

TABLE I FREE-AIR OPERATION

LINE	ITEM	RQM2S40#1	RQM2S40#2	RQM2S40#3	RQM2S40#4
1	Ballast	RQM2S40#1	RQM2S40#2	RQM2S40#3	RQM2S40#4
2	Lamps	9,10	4,5	4,5	4,5
3	Volts	120	120	120	120
4	Amps	.804	.793	.795	.797
5	Watts	95.5	94.0	94.2	94.4
6	Power Factor	.99	.99	.99	.99
7	Lumens	5920	6068	6105	6179
8	Efficacy, LPW	62.0	64.6	64.8	65.4
9	Regulation, 90%	-7.5%	-7.3%	-7.3%	-7.2%
	" 110%	+7.5%	+6.1%	+6.1%	+6.0%
10	Starting Time, 90%	4.0	3.5	4.0	1.4
	100%	1.5	1.3	1.4	1.2
	110%	1.0	1.0	0.8	0.9
11	Peak Start I, 90%	4.0	3.0	2.0	3.0
	100%	4.5	4.0	1.0	3.0
	110%	5.0	4.5	2.0	4.5
12	Open Circ. Voltage	261	259	263	265
13	Crest Factor	1.5	1.5	1.5	1.5
14	Cathode Ckt Volt:				
	Yel Start	2.8	2.8	2.9	2.7
	Oper.	2.7	2.7	2.7	2.7
	Red Start	2.8	2.8	2.7	2.8
	Oper.	2.6	2.7	2.6	2.6
	Blu Start	2.8	2.8	2.8	2.7
	Oper.	2.9	2.9	2.9	2.8
15	Flicker Index	.065	.065	.065	.065
	Percent Flicker	30.4	30.4	30.4	30.4
16	Secondary Freq.	60 Hz	60 Hz	60 Hz	60 Hz
17	Lamp Temp.	38	38	38	38
18	Ballast Temp.	-	-	-	-
19	Min. Start E @ 50°	95	95	95	95
20	Rel. Noise Level,	34	36	32	32

TABLE I FREE-AIR OPERATION

LINE	ITEM				
1	Ballast	V2S40-1#5	V2S40-1#6	V2S40-1#7	V2S40-1#8
2	Lamps	4,5	9,10	9,10	9,10
3	Volts	277	277	277	277
4	Amps	.318	.326	.337	.327
5	Watts	86.5	88.4	92.0	88.7
6	Power Factor	.98	.98	.98	.98
7	Lumens	5957	5920	6068	5994
8	Efficacy, LPW	68.9	67.0	66.0	67.6
9	Regulation, 90%	-6.8%	-5.6%	-6.7%	-6.8%
	" 110%	+5.6%	+5.6%	+6.7%	+6.2%
10	Starting Time, 90%	2.7	2.8	5.0	3.5
	100%	1.5	1.4	1.5	1.6
	110%	1.0	1.0	1.5	1.5
11	Peak Start I, 90%	3.0	4.6	5.3	4.0
	100%	5.0	5.8	5.8	5.2
	110%	6.0	3.6	3.5	7.3
12	Open Circ. Voltage	252	252	255	254
13	Crest Factor	1.5	1.5	1.5	1.5
14	Cathode Ckt Volt:				
	Yel Start	2.6	2.8	2.9	2.7
	Oper.	2.6	2.7	2.7	2.7
	Red Start	2.7	2.8	2.8	2.8
	Oper.	2.6	2.7	2.7	2.7
	Blu Start	2.8	2.8	2.7	2.8
	Oper.	2.8	2.9	2.8	2.9
15	Flicker Index	.065	.065	.065	.065
	Percent Flicker	30.4	30.4	30.4	30.4
16	Secondary Freq.	60 Hz	60 Hz	60 Hz	60 Hz
17	Lamp Temp.	38	38	38	38
18	Ballast Temp.	-	-	-	-
19	Min. Start E @ 50°	240	240	220	240
20	Rel. Noise Level	36	36	35	36

Notes to Table I:

Free-Air Conditions: Lamps mounted for free-still-air circulation, with air temperature maintained at 77°F (25°C)

Line	Note
1	120V 60Hz ballasts selected for equal lumens per watt w/same within 0.3%. Ballasts used were Advance Transformer RQM2S40-3.277V 60 Hz ballasts selected for equal lumens per watt with same lamps within ± 1.2%, larger tolerance being due to limited stock available for selection. Ballasts used were Advance Transformer V-2S40-1 "high efficiency" type. High-frequency ballasts were as furnished by client, Iota Model 18PCT and 22PCT, numbers as shown in table; and consisting of units adjusted for low light output (#A, C and D), and for high output(#B).
2	Lamps selected for equal light output within 1% on same ballast, matched for equal candlepower at 90°. See Note 7.
3	Voltage accuracy ± 0.5%. See Fig. 1 for waveform
4	Current accuracy ± 0.5%, @ 60 Hz, compensated to 800 Hz. Accuracy of 800 Hz harmonic ± 3%. See Fig. 2 & 3.
5	Wattage accuracy ± 0.75%
6	Power factor = Watts/Volt-Amps, approx. accuracy ± 1%. See Comment part VI.
7	Measured by monitoring 90° CP of lamps @ 20 ft. Calibrated by complete photometry of lamps on both 60 Hz and HF ballasts to establish lumen/cp ratio under both sets of conditions. Accuracy: Absolute - ± 5%; Relative - ± 2%; Lumen/candlepower ratio equal within 0.7%.
8	Lumens per watt. See Comment part I.
9	Steady-state regulation, percent change in light output at 90% and 110% rated voltage, compared to that at 100% rated voltage, after complete stabilization. See Fig. 4, 5, 6, & 7 for line current waveforms. See Comment part II.
10	Approximate time required to start lamp, seconds, at 90%, 100% and 110% of rated voltage, lamps warm but fully deionized. See fig. 8 & 9. See Comment part IIIA.
11	Peak current drawn at start/peak current during normal operation. For actual peak current, multiply by steady-state current x crest factor. These values are approximate only. See Comment part IIIB. See Fig. 8, 9.
12	RMS volts, no load on ballast, measured red to blue leads, rated voltage on primary.
13	Measured on oscilloscope calibrated for direct-reading in amperes. Crest factor = peak current/rms current. See Fig. 2, 3.

Notes to Table I cont'd.

Line	Note
14	Operating voltages directly measured; starting voltage measured by ratio of start to operating from oscilloscope determination. See Fig. 11 and Comment part IIID.
15	Flicker index = $\frac{\text{Total light output above average level}}{\text{Total Light Output}}$ for one cycle of variation. Percent flicker = $\frac{\text{Max. Light Out} - \text{Min. Light Out}}{\text{Max. Light Out} + \text{Min. Light Out}}$ for one cycle of variation See IES Handbook 5th Ed p. 8-27, and Fig. 12, 13.
16	Measured by calibrated oscilloscope sweep. Accuracy $\pm$ 5%
17	Lamp temperature in $^{\circ}$C measured by thermocouple affixed to bulb wall at point selected to reflect average lamp temperature. Figures should be considered relative.
18	Measured at hot spot on ballast
19	Minimum line voltage required to start lamps within 10 seconds under still-air ambient conditions at 50°F (10°C).
20	dbA reading for ballast installed on mounting plate in sound-isolating box. Figures are relative only, using 60 cycle ballasts (A sound rating) as reference. See Comment part VIII and Fig. 14, 15.

TABLE II CALORIMETER OPERATION

LINE	ITEM			
1	Ballast & Lamp	18PCT3#A-4,5	18PCT3#A-4,5	22PCT2#B-4,5
2	Combination		18PCT8#D-9,10	
3	Volts	120	120	120
4	Amps	.557	1.10	.727
5	Watts	64.9	129.4	78.9
6	Power Factor	.97	.98	.90
7	Lumens	4522	9013	5796
8	Efficacy, LPW	69.7	69.7	73.5
9	Regulation, 90%	-10.7%	-10.5%	-7.9%
	110%	+9.8%	+6.5%	+7.9%
10	Starting Time, 90%	1.0	1.0	0.9
	100%	0.8	0.7	0.7
	110%	0.6	0.6	0.5
11	Peak Start I, 90%	1.0	1.0	2.0
	100%	1.8	1.5	1.2
	110%	2.4	2.2	1.0
12	Temperatures, °C			
	A. Ambient	24.5	25	25
	B. Plenum	30.5	35.5	29
	C. Lamp Comp.	37	48	38
	D. Ballast Comp.	36.5	46	35
	E. Lamp	33	51	47
	F. Ballast	56	64.5	58.5

TABLE II CALORIMETER OPERATION

LINE	ITEM			
1	Ballast & Lamp	RQM#1-9,10	V2S#6-9,10	V2S#6-9,10
2	Combination	RQM#2-4,5	V2S#8-4,5	
3	Volts	120	277	277
4	Amps	1.41	.573	.303
5	Watts	167.6	156.4	82.6
6	Power Factor	.99	.98	.98
7	Lumens	9825	9773	5487
8	Efficacy, LPW	58.6	62.5	66.4
9	Regulation, 90%	-7.4%	-6.4%	-6.1%
	110%	+6.9%	+5.5%	+5.3%
10	Starting Time, 90%	3.7	3.2	2.5
	100%	1.5	1.7	1.8
	110%	1.0	0.9	1.0
11	Peak Start I, 90%	4.0	2.5	4.2
	100%	4.5	3.5	5.0
	110%	4.5	5.0	5.1
12	Temperatures, °C			
	A. Ambient	25	24.5	25
	B. Plenum	36	35	31.5
	C. Lamp Comp.	51	49.5	40
	D. Ballast Comp.	48	46	34.5
	E. Lamp	55	54	48
	F. Ballast	-	-	-

Notes to Table II:

Calorimeter Conditions: Lamps and ballasts mounted in recessed troffer installed in ADC test calorimeter to simulate normal recessed installation, with plenum volume per luminaire = 60 cu. ft. Tests conducted under stable conditions with minimum 4-hour warmup.

Line	Note
1	Since performance of recessed units on 60 Hz ballasts is variable with lamp loading, tests were performed on both two and four lamp combinations, and on individual samplings of low-output (18PCT) and high-output (22PCT) high frequency ballasts.
3-6	See Notes to Table I
7	Calibration transferred from free-air tests and monitored by illumination measurement below luminaire, using a drop diffusing panel in the luminaire to integrate the light output of the lamps. Calibrations cross-checked on each test to verify accuracy and found to hold within ± 1%.
8-11	See Notes to Table I
12	Temperatures measured by thermocouples and temperature bridge, accuracy ± 0.5°C. Thermocouples located as follows: A. 12" below face of unit, shielded from radiation B. Ave of 4 thermocouple readings, located at center of each of 4 walls of calorimeter inside plenum C. Thermocouple suspended at lamp level in lamp compartment between outer and inner lamps D. Thermocouple suspended in center of ballast compartment. E. Thermocouple fastened to lamp in same manner as free air tests (see line 17, Notes to Table I). F. Thermocouple fastened to hot spot on ballast.

Kaelite
CORPORATION
9372 HILLVIEW ROAD • ANAHEIM, CALIFORNIA • 92804 • PHONE 714/776-5400

CERTIFIED TEST REPORT Sheet 1 of 4

No. 770908

Performed for Lighting Research Laboratory Date 7/14/77

Purchase Order No. Verbal - W. Jones

Item Tested:
Description Fluorescent Fixtures with ballasts noted P/N --- S/N --

Test Requirement: To determine the spectral distribution and chromaticity coordinates of the light produced by two Westinghouse F40CW Preheat Rapid Start lamps when operated with an Iotalite Model 22PCT-2 electronic ballast and a Universal catalog #446-LR-TC-P ballast. The tests shall be conducted at 120.0 volts, 60 cps.

Procedure: The equipment for determining spectral distribution and chromaticity coordinates was a Beckman Model DK-1A Spectrophotometer equipped with a Davidson & Hemmendinger Model 132-DE Tristimulus Integrator (Item 2.1). This equipment had previously been calibrated using an NBS supplied color temperature standard (Item 3.4) in conjunction with a barium sulfate disc and verified accurate to within ±.001 for both x and y in regions approximating the Planckian black body locus.

The two fluorescent lamps noted above were placed in a fixture which contained the Iotalite ballast and operated at 120.0 ±0.5 volts A.C., 60 cps which was monitored by Item 1.1. The light generated was allowed to reflect from the barium sulfate disc into the spectrophotometer. After a 20 minute warmup, a spectral scan was completed and x and y were computed accordingly.

The fluorescent lamps were then placed in the fixture containing the Universal ballast and orientated in the same manner. After a similar 20 minute warmup, the test was repeated.

Certified by George H. Kaelin Date 7/14/77

CERTIFIED TEST REPORT

No. 770908

Results: The following chromaticity data was obtained:

Ballast	x	y
Iotalite Model 22PCT-2	.3717	.3941
Universal 446-LR-TC-P	.3764	.3906

The spectral charts obtained are included herein.

REPORT NO. 770908

The items checked below were utilized in the performance of the subject test or calibration.

1. Electrical Measuring Equipment

		Description	Limits	Accuracy	Calib Freq.
X	1	United Systems Corp. Model 269 S/N 1052 Precision Digital Multimeter	1000V	0.02% DC 0.10% AC	6 Mos
	2	Keithley Model 155, S/N 27027 Null Detector - Microvoltmeter	1000V	1%	6 Mos
	3	United Systems Corp. Model 277-9 S/N 4192 DC Milliampere Meter	199.9 ma	0.10%	6 Mos
	4	Weston Model 901, S/N 25013 Ampere Meter	20 A	0.25%	6 Mos

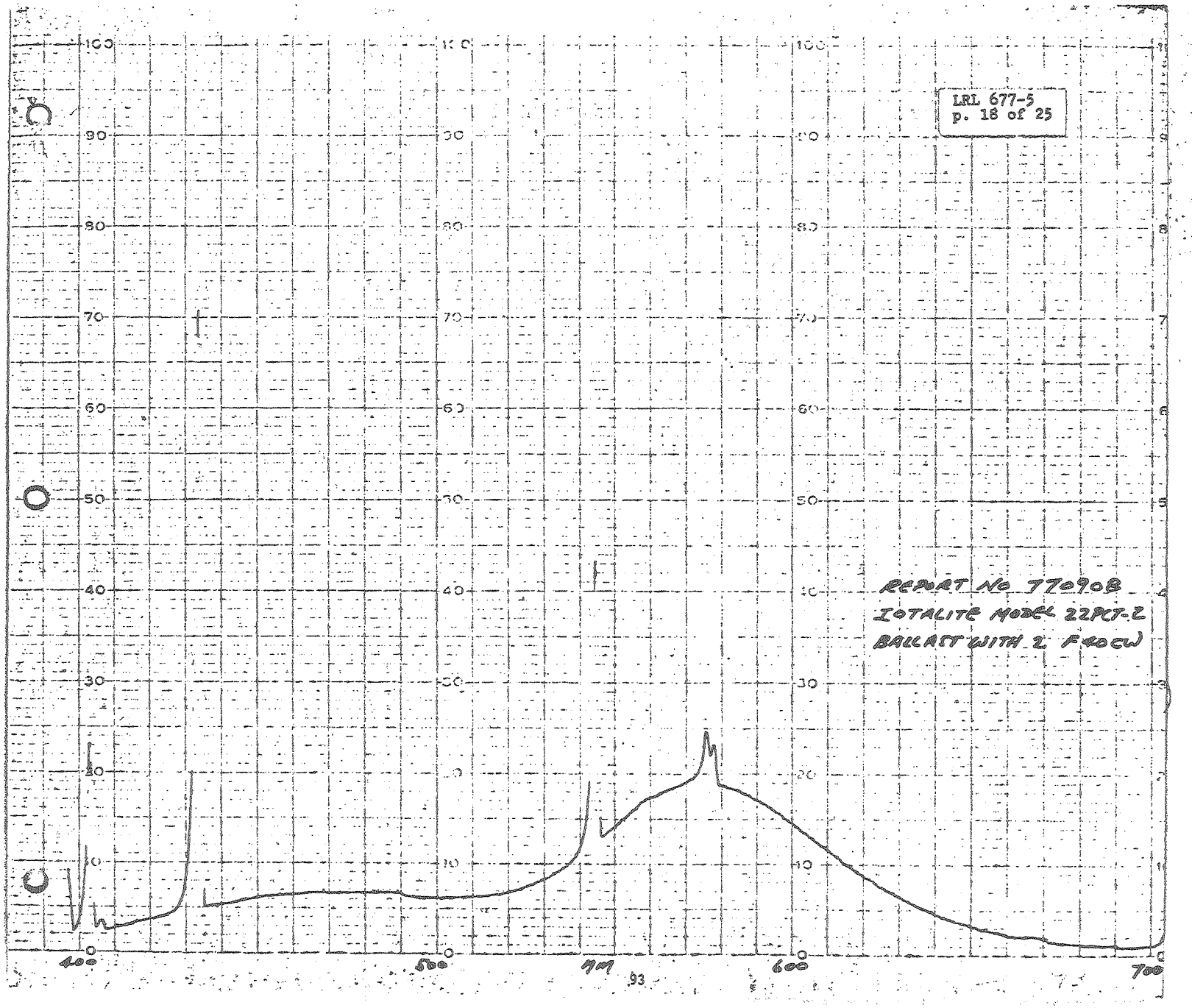
2. Photometric Test Equipment

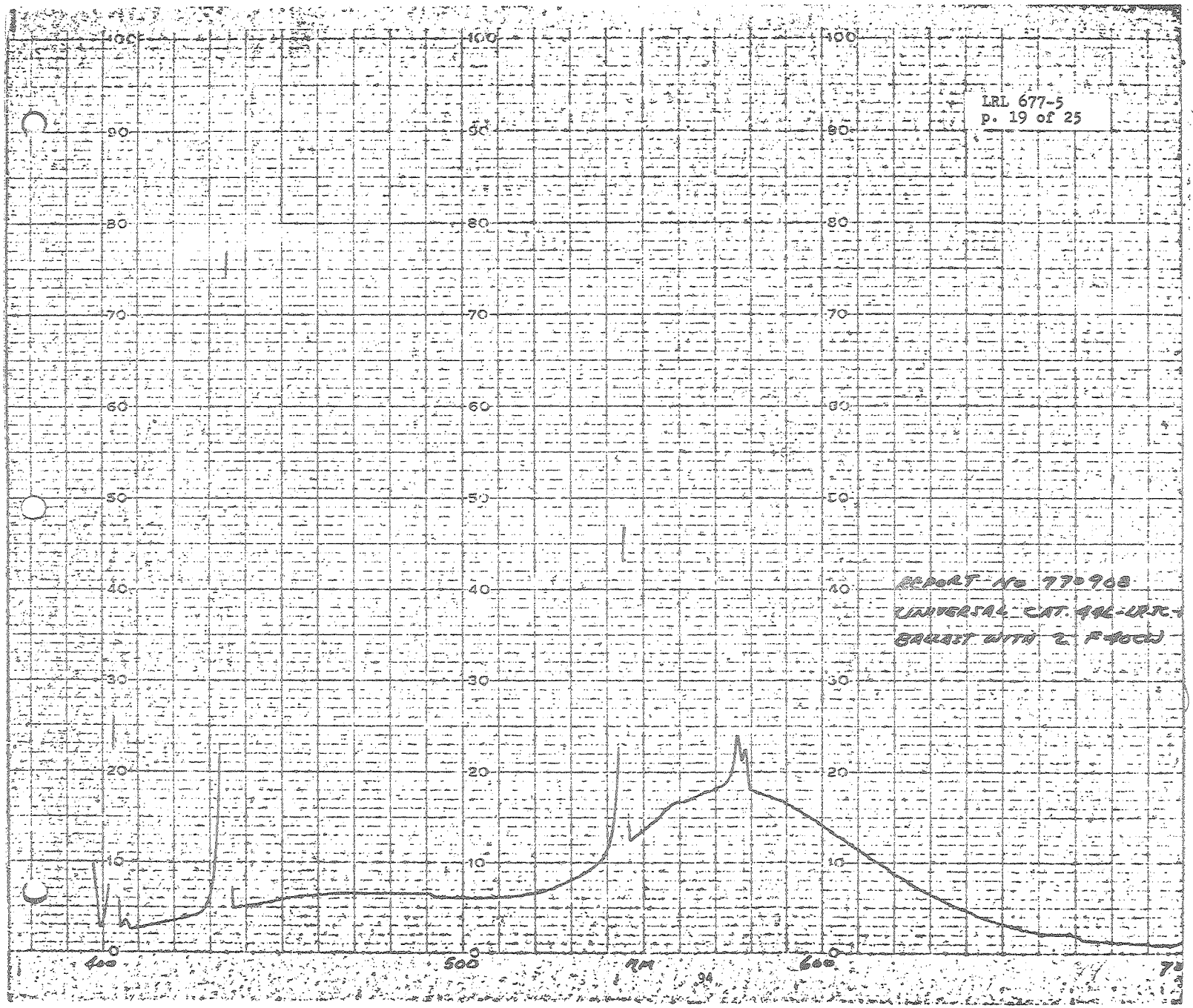
		Description	Limits	Accuracy	Calib Freq.
X	1	Recording Spectrophotometer, Beckman Model DK-1A, S/N CP-5304 with Davidson & Hemmendinger Model 132-DE Tristimulus Integrator	200 to 1000 mm	± .003	6 Mos
	2	Photo Research Corp. Model 1980 CDB S/N D 1054 Microcandela Meter	$1x10^{-6}$ to $1x10^{6}$ Ft.C.	2%	12 Mo
	3	Photo Research Corp. Model 1980A-OP S/N C607 Pritchard Photometer	$1x10^{-6}$ to $1x10^{6}$ Ft.L.	2%	12 Mo
	4	Photo Research Corp. Model 15025 UB S/N 2317 Spectra Spot Photometer	$1x10^{-3}$ to $1x10^{3}$ Ft.L.	5%	12 Mo
	5	Eppley Laboratories Inc. Circular Bi-Silver Thermopile, S/N 12852	.25 to 3.5 microns	1%	12 Mo
	6	J. F. Davy Co. Model 420C, S/N 021 Flash Photometer	50 Ft.C. seconds	2%	12 Mo
	7	Bausch & Lomb Model 33-86-76 S/N 301 High Intensity Monochrometer	150-850 mm	2.5 mm	12 Mo
	8	Gardner Laboratory Inc. Model GG-9040, S/N 5843 60° Glossmeter with Gloss Stds. 60-5843-B & 60-5843-W	0 to 100	±2%	Ea. U

REPORT NO. 770908

3. Illumination Standards

		Description	Limits	Accuracy	Calib Freq.
__	1	NBS supplied 100 Watt Candlepower Standard #NBS 9477 NBS Test 210473-1	85 cp	2%	6 Hrs
__	2	NBS supplied 500 Watt Candlepower Standard #NBS 7388 NBS Test 192674	667 cp	± .75%	6 Hrs
__	3	NBS supplied 500 Watt Candlepower Standard #NBS 7398 NBS Test 192674	656 cp	± .75%	6 Hrs
X	4	NBS supplied 500 Watt Color Temp. Standard #NBS 9912 NBS Test 210473-2	2854°K	± 9°K	6 Hrs
__	5	NBS supplied 500 Watt Color Temp. Standard #NBS 8053 NBS Test 192673	2000 thru 3000°K	± 8°K	6 Hrs
__	6	Eppley supplied Standard of Total Radiation #E-7405 Test No. 30465	85×10^{-6} w/cm^2	2%	6 Hrs
__	7	NBS traceable 100 Watt Candlepower Standard #7401	180 cp	3%	6 Hrs
__	8	NBS traceable 100 Watt Candlepower Standard #7402	180 cp	3%	6 Hrs
__	9	NBS traceable 100 Watt Color Temp. Standard #7403	2854°K	12°K	6 Hrs
__	10	NBS traceable 500 Watt Candlepower Standard #7407	700 cp	3%	6 Hrs
__	11	NBS supplied 2" Flashed Master Opal Transmission Standard NBS Test 212.11-12/68	.481	± .10%	---
__	12	NBS traceable 2" Flashed Opal Transmission Standard #101	.512	1%	---
__	13	NBS traceable 3" Flashed Opal Transmission Standard #107	.460	1%	---
__	14	Eastman Barium Sulfate Reflectance Standard	100%	1%	---
__	15	NBS supplied Miniature Lamp Standard of Luminous Flux #NBS 9536	.5 MSCp	1%	Ea. Use
__	16	NBS supplied Miniature Lamp Standard of Luminous Flux #NBS 9550	.5 MSCp	1%	Ea. Use


LRL 677-5
p. 18 of 25
REPORT NO 770908
IOTALITE MODEL 22PCT-2
BALLAST WITH 2 F40CW
400
500
600
700


REPORT-No 770908
UNIVERSAL CAT. 44K-UPR-
BALLAST WITH 2 F-400W
100
90
80
70
60
50
40
30
20
10
0
400
500
nm
600
700

Instrumentation:

Voltage:	Input	SRC Model VAW, ± 0.5%, 0-800 Hz	
	Secondary	Fluke 8000, ± 1.0% + 2 counts	
Current:	Input	SRC Model VAW, ± 0.5%, 0-800 Hz	
Watts:	Input	SRC Model VAW, ± 0.75%	
Lumens:		Photoresearch P-1000, Abs. ± 4%	
		Rel. ± 1%	
Temperature:		Leeds-Northrup 8692 Temp. Pot.,	± 0.5°C
		Frese Thermometer, 0-220F	± 0.2°F
Frequency:		Tektronix 912 Oscilloscope	± 5%
Sound Level		General Radio 1551C	± 1 db
Waveforms		Tektronix 912 Oscilloscope	-

CAPTIONS FOR FIGURES

1. Input voltage waveform for all tests, and input current waveform for rated voltage, 120V 60 Hz ballast.
2. Line current waveform for 60 Hz ballast, rated E.
3. Line current waveform for Iota ballast, rated E.
4. Line current waveform for 60 Hz ballast, 90% rated E
5. Line current waveform for 60 Hz ballast, 110% rated E
6. Line current waveform for Iota ballast, 90% rated E
7. Line current waveform for Iota ballast, 110% rated E
8. Peak current and starting time traces for 60 Hz ballast
9. Peak current and starting time traces for Iota ballast
10. Voltage envelope of secondary high-voltage, Iota ballast, sweep rate 2 ms/div.
11. Starting and operating current traces for Iota ballast, cathode circuit
12. Variation in light output, 60-Hz ballast, sweep rate 2 ms/div
13. Variation in light output, Iota ballast, sweep rate 2 ms/div
14. Noise waveform, 60-Hz ballast, 1 ms/div sweep rate
15. Noise waveform, Iota ballast, 1 ms/div sweep rate, to same scale as Fig. 14.

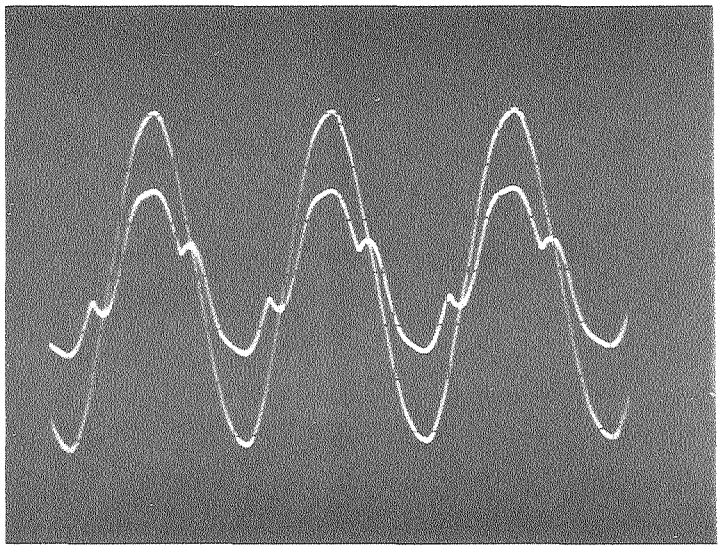


Fig. 1

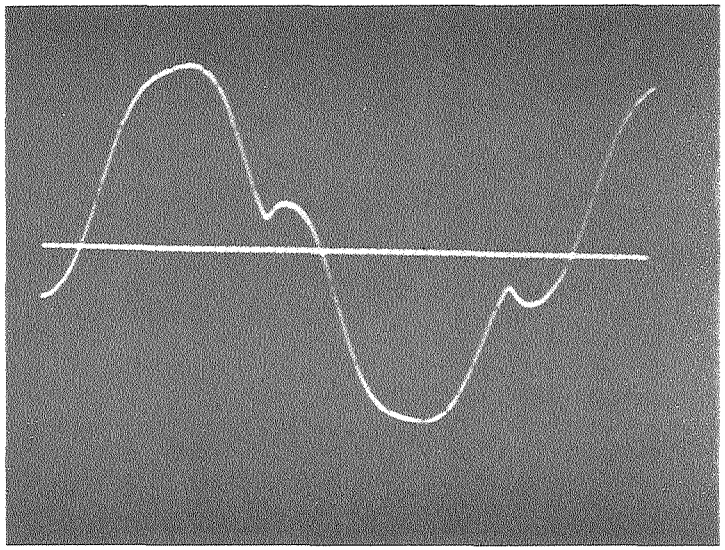


Fig. 2

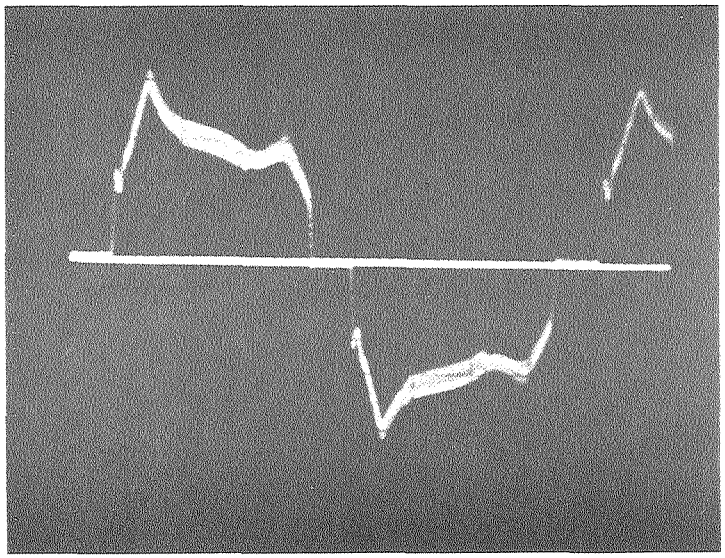


Fig. 3

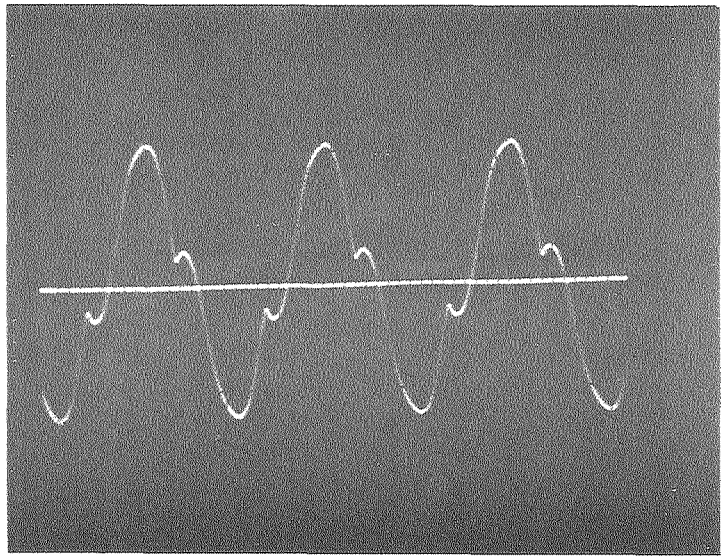


Fig. 4

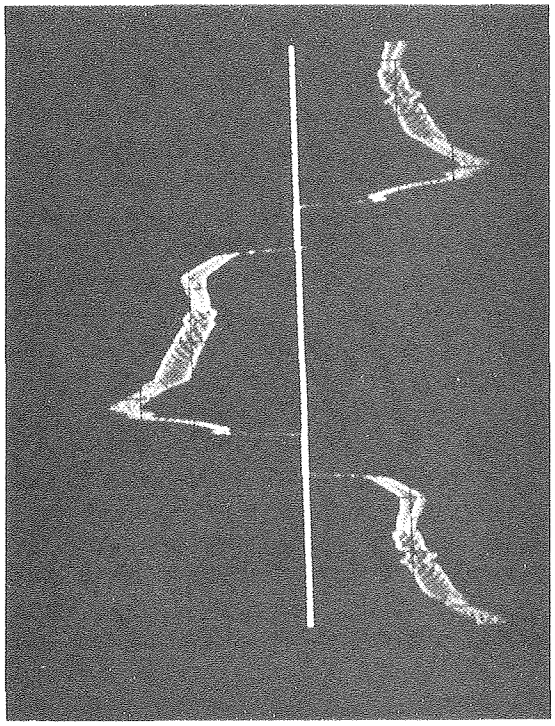


Fig. 6

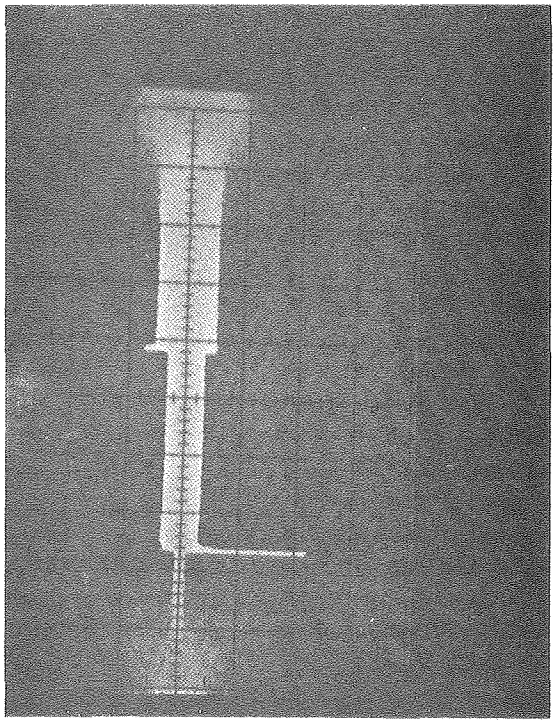


Fig. 8

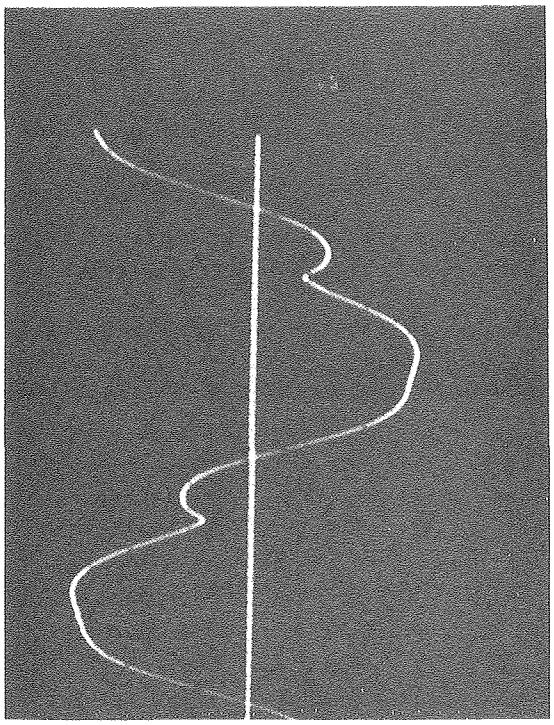
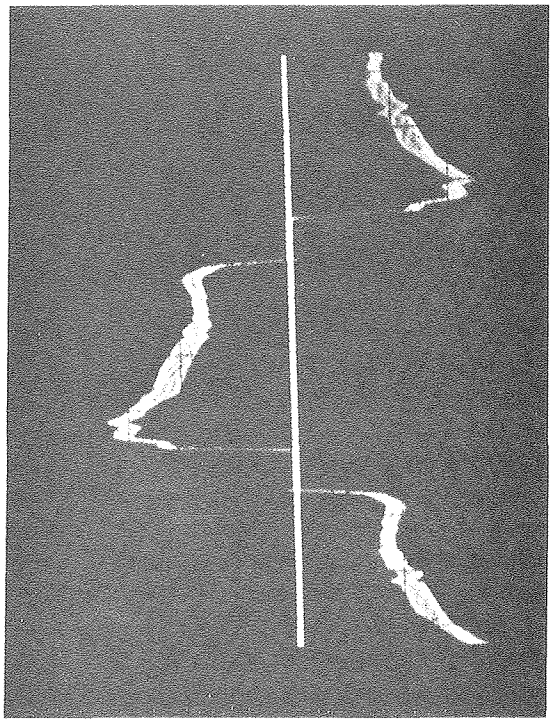


Fig. 5



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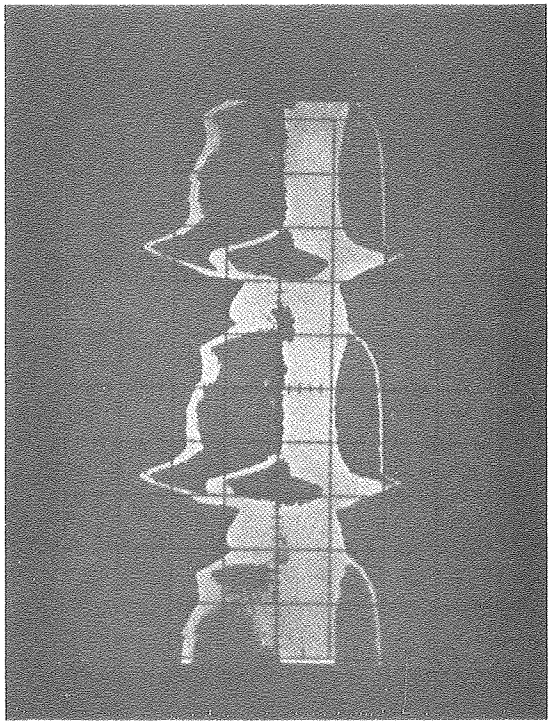

Fig. 10

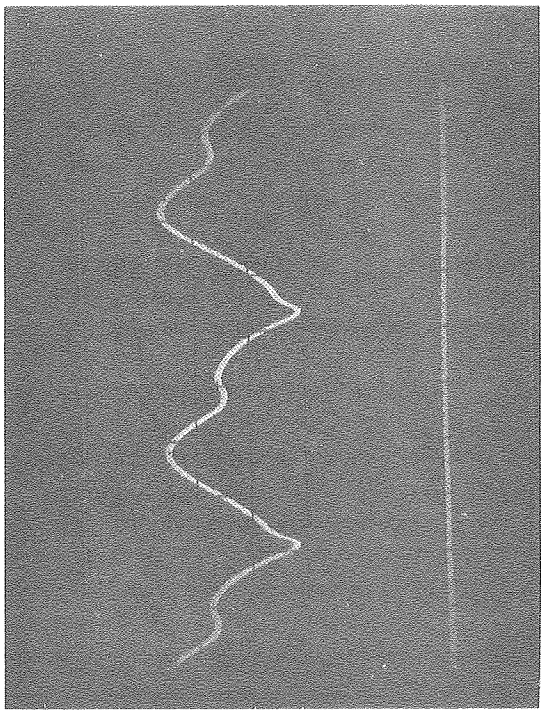

Fig. 12

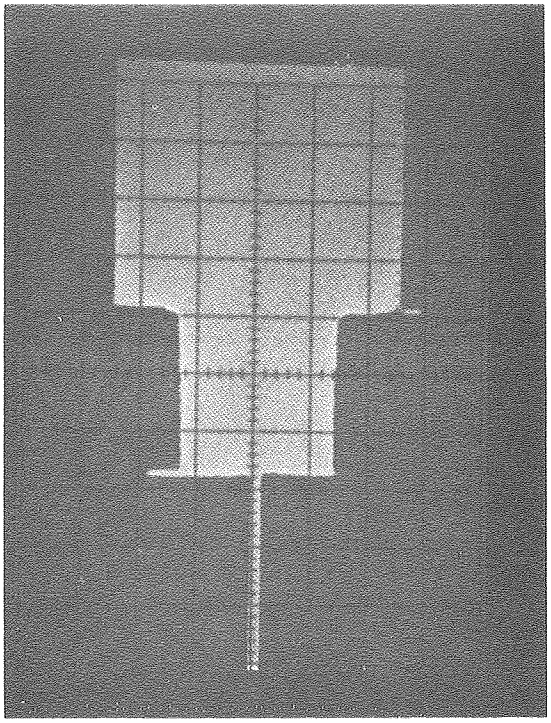

Fig. 9

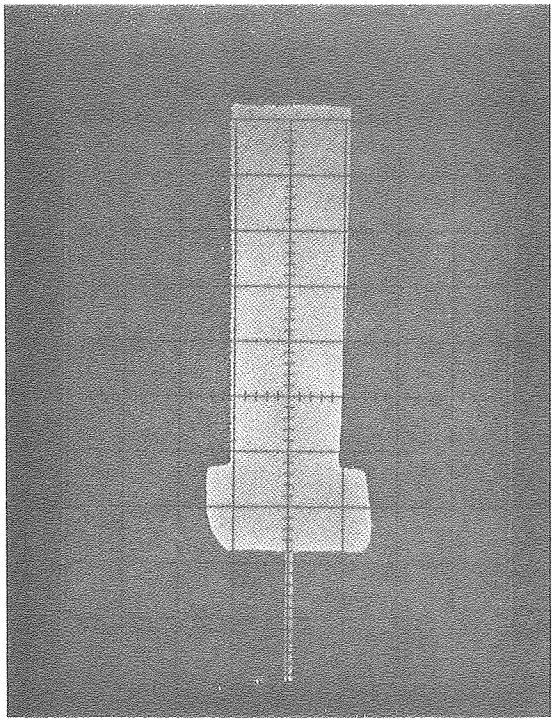

Fig. 11

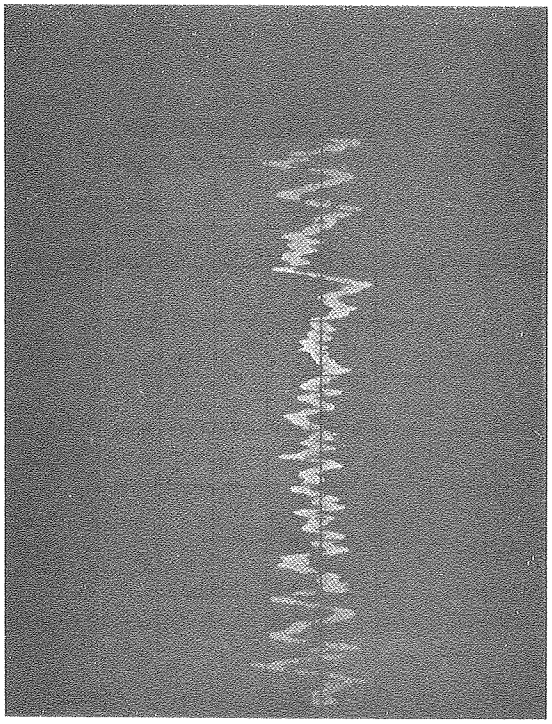

Fig. 14

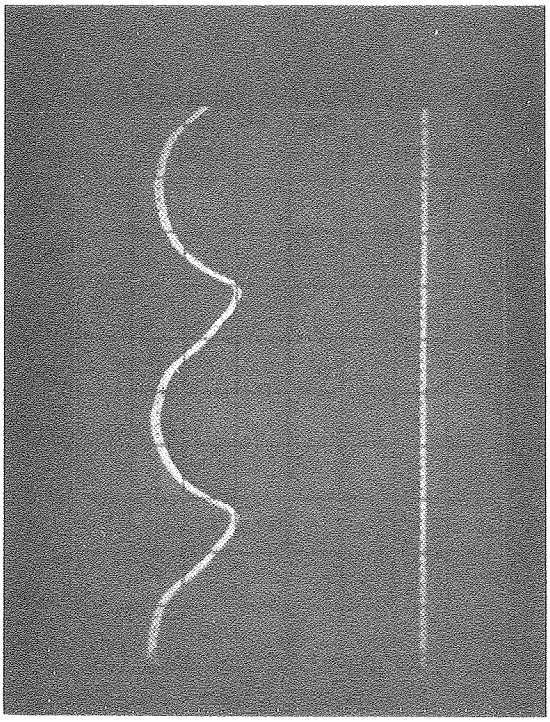

Fig. 13

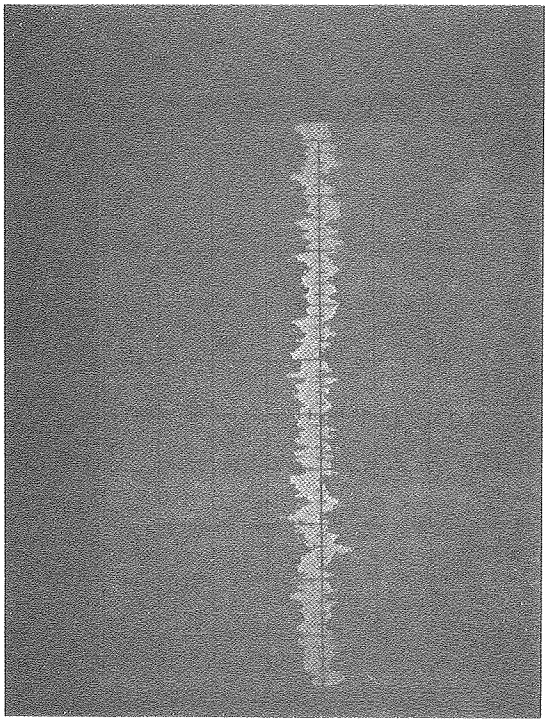

Fig. 15

APPENDIX 6

EXCEL CONTRIBUTION

Under the terms of the IOTA contract with LBL the firm that will manufacture and market the IOTA 5000 and 6000 lumen ballasts, EXCEL Electronics Systems Division of Beatrice Foods Co., agreed at inception of the program to contribute at least $50,000 to the overall objective of the DOE sponsored program during Phase II. This was "to accelerate the commercialization of energy efficient electronic ballasts." The documentation of this EXCEL funded contribution will be submitted when received and will then become a part of this Appendix.

It should be noted that in addition to their funding of extensive market research, production planning, and the equipment of a preliminary production facility, EXCEL has reported that they have absorbed costs for the manufacture of the demonstration ballasts that were in excess of those allowed under the IOTA fixed price subcontract.

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

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