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Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

ENERGY & ENVIRONMENT DIVISION

HIGH INTENSITY DISCHARGE 400-WATT SODIUM BALLAST
PHASE I FINAL REPORT

Gerald Felper

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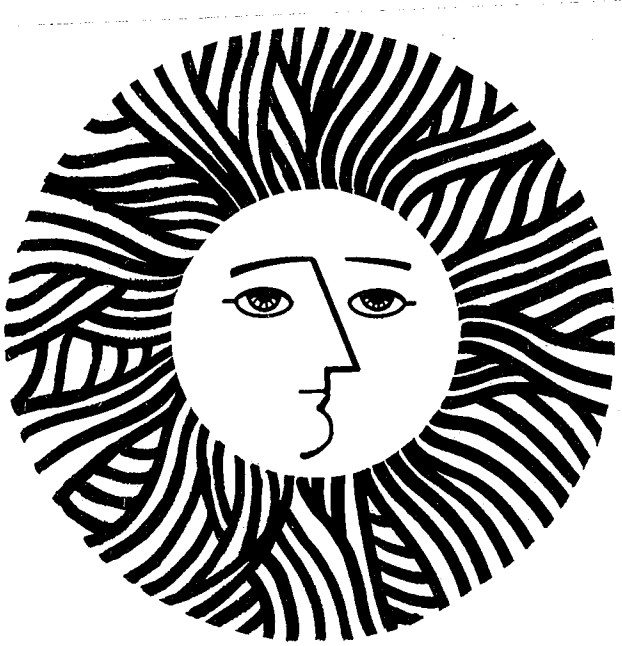

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Prepared for the U.S. Department of Energy under Contract W-7405-ENG-48

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PHASE I FINAL REPORT

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

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DATAPOWER INC.
3328 West First Street
Santa Ana, California 92703

Subcontract No. 4502210

ABSTRACT

The Department of Energy (DOE) through one of its operating contractors, Lawrence Berkeley Laboratory (LBL) of the University of California has established projects to accelerate commercial use of electronic ballasts. LBL subcontracted to Datapower to undertake a research and development program directed toward design, test and evaluation of energy efficient High Intensity Discharge (HID) Solid State 400 Watt Ballast lighting system.

This report covers Phase I of the project which was designed to modify the existing Datapower ballast to LBL configuration, measure performance characteristics, and compare efficiency with a core/coil ballast including energy loss analysis. In addition, Datapower was tasked to build six (6) prototype 400 Watt High Pressure Sodium Ballasts for verification tests by an independent test facility and follow-on performance and life tests at LBL.

TABLE OF CONTENTS

		PAGE
1.0	Program Objectives	1
2.0	Program Tasks and Contract	1
3.0	Discussion of Technical Task and Results	1
4.0	Prototype Ballasts	21
5.0	Summary	21

APPENDICES

A	Phase I Schedular Performance Report Form 534	24
B	Stress Analysis Report -- Gerhard Engineering	29
C	Test Report -- Lighting Research Laboratory	31

1.0 PROGRAM OBJECTIVES

Electronic Solid State Ballast that power fluorescent lamps at high frequencies have demonstrated energy savings and efficiency over magnetic core type ballast. The performance improvements resulting from the use of solid state ballasts in the fluorescent lamp should be obtainable if similar ballasting principles are applied to high intensity discharge (HID) lighting systems. To this end, the following applies:

Phase I of this program was designed to produce a 400 watt solid state, dimmable, ballast for driving a high pressure sodium lamp. In addition, accomplish testing to determine efficiency, dimming range, color rendering properties and reliability of this ballast. Discussion and program results are contained in the report section 4.0 of this report.

2.0 PROGRAM TASKS AND CONTRACT

Program tasks are contained in Appendix A, Schedular Performance Report, DOE Form 534.

Datapower was authorized under Amendment I to the contract to perform additional tests under Task II. They were Regulation Over Bulb Life and Light Regulation tests. A second Amendment extended the contract to May 30, 1980 for additional testing and to review the results of the independent test laboratory.

3.0 DISCUSSION OF WORK TASKS AND RESULTS

3.1 Initial Design Modifications

It was felt that the Datapower 400W HPS ballast had a few deficiencies that would have to be corrected in the LBL contract ballast. The foremost of these was that the original ballast would not sustain an end of life bulb* with nominal input line voltage. To correct this problem, the turns ratio and air gap of the ballast output transformer were merely changed.

The next problem was the output power of the original ballast that varied more than 20% for a given 20% variation in input line voltage. This was considered undesirable, so it was decided to incorporate Datapower's constant power regulation circuit in the LBL ballast control scheme. Changes in performance resulting from these design modifications will be discussed in this report.

* (140 volts at 400 watts)

3.2 Test Set-Up: Electrical

To test the electrical performance of the Datapower ballast and that of a standard core/coil ballast, the following parameters had to be accurately measured and recorded: 1) input power, 2) input voltage, 3) input current, 4) output power, and 5) input and output voltage and current waveforms. To meet these requirements, the following test equipment was used.

1) Input Power - Datapower Watt-A-Box. (See Figure 3-1)

2) Input Voltage - Data Tech Model 3101-04 rms digital voltmeter.

3) Input Current - Data Tech Model 31 true rms digital multimeter.

4) Output Power - Clarke-Hess Model 200 modulator/multiplier connected to our digital display box. (See Figure 3-2)

5) Waveforms - Tektronix Model 465 oscilloscope, Tektronix AM503 current probe/amplifier and Polaroid CR-9 Land Camera.

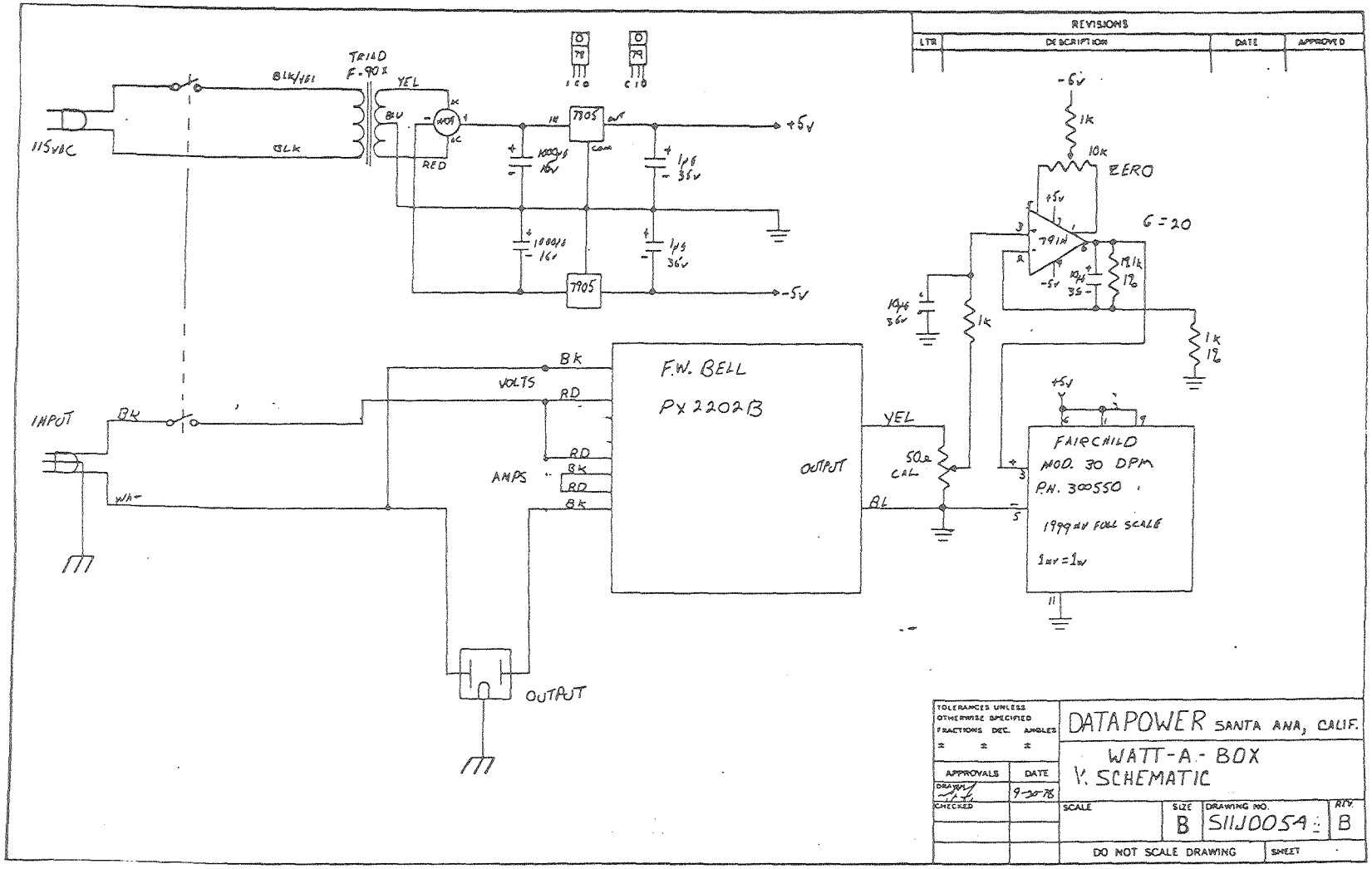
In addition, a Powerstat variable autotransformer (7.5 KVA type 1256-N) was used in conjunction with an Allkor power transformer (type E100-001) to supply an isolated variable AC voltage to the ballasts.

3.3 Test Set-Up: Photometric

The relative photometric performance of our ballast as compared to the core/coil ballast was derived from the output of a Vactec R100MB selenium photovoltaic cell. The cell was covered by a Wratten gelatin filter (Eastman Kodak Cat. 149-6355) for color correction. The cell was mounted in a small black box located approximately 30 inches from the sodium lamp. Four pieces of 5 mil thick mylar (opaque white) were taped over a slot in the front of the box. The mylar was used to attenuate the light seen by the Vactec cell so as to keep the cell in a fairly linear region of operation. Both the box with the cell and the sodium lamp are completely enclosed under test bench to keep out ambient lamp.

3.4 Test Set-Up: Thermal

The Datapower ballast was mounted in a small Hubbell HID ballast container (200-0095). The container was left detached from the lamp housing to observe the amount of heat the ballast components themselves generated. Thermocouples were mounted at various strategic places on the ballast and container and temperatures were recorded on an Esterlin Angus recorder.


REVISIONS
LTR
DESCRIPTION
DATE
APPROVED
115VAC
BLK/YEL
BLK
TRIAD
F-90X
YEL
BLU
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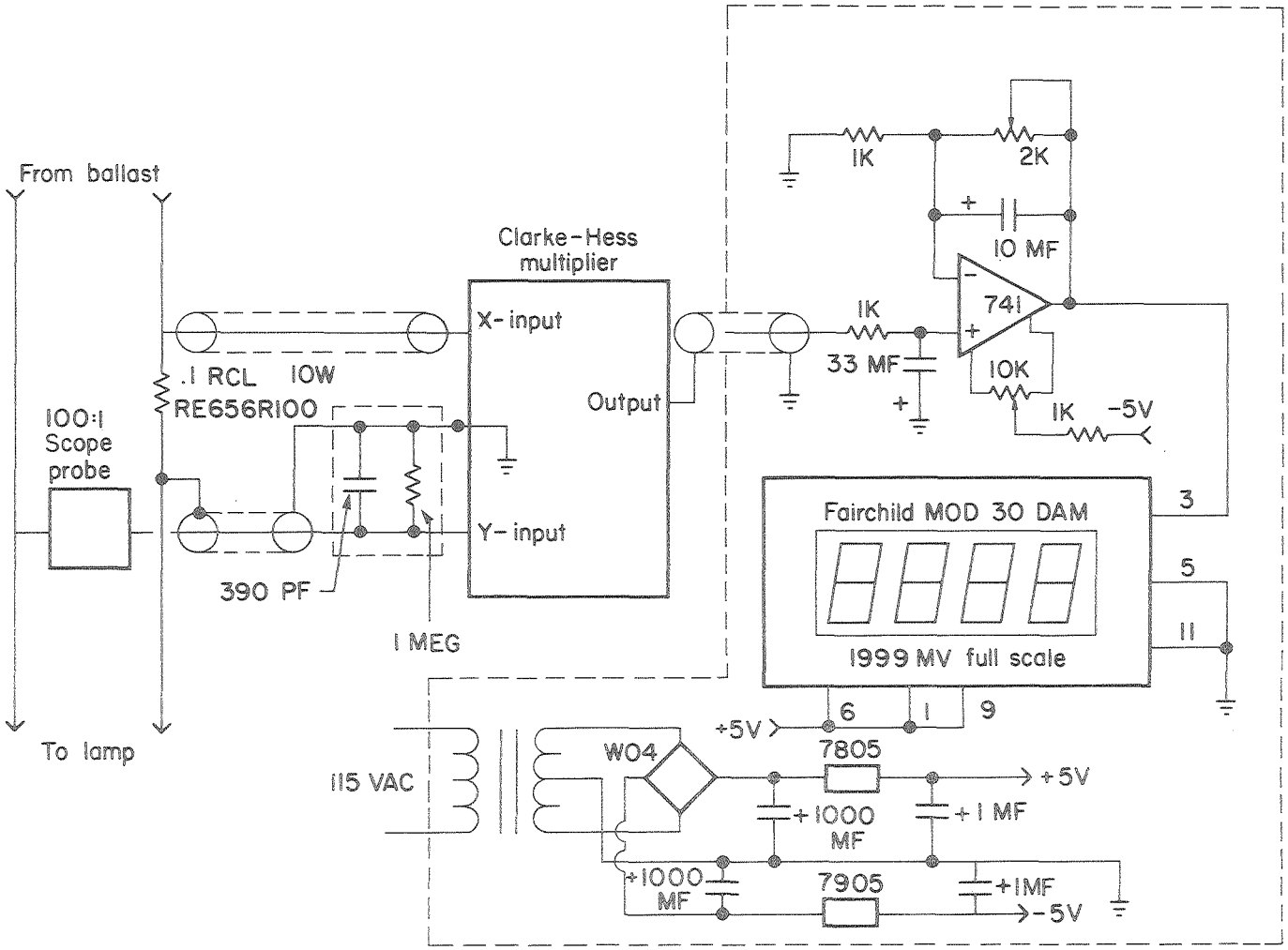
7805
+5V
-5V
1000µf 16v
1µf 35v
-6V
1k
10k
ZERO
G = 20
791H
10µf 36v
1k
1k 1%
INPUT
BK
WH
VOLTS
AMPS
RD
F.W. BELL
PX 2202B
OUTPUT
YEL
BL
50Ω CAL
FAIRCHILD
MOD. 30 DPM
P.N. 300550
1999mV FULL SCALE
1mV = 1W
OUTPUT
TOLERANCES UNLESS OTHERWISE SPECIFIED
FRACTIONS DEC. ANGLES
APPROVALS
DATE
DRAWN
9-30-78
CHECKED
DATAPOWER SANTA ANA, CALIF.
WATT-A-BOX
V. SCHEMATIC
SCALE
SIZE
B
DRAWING NO.
S11J0054
REV.
B
DO NOT SCALE DRAWING
SHEET

FIGURE 3-1

HIGH FREQUENCY WATTMETER



XBL809-1929

FIGURE 3-2

3.5 Test Considerations

To obtain accurate data to determine steady state ballast performance, the HID bulb must be allowed to reach thermal equilibrium. While warming up, the HID bulb is cooler than normal. Its impedance is lower than it would be in its steady state condition. During this time, the bulb demands more current. This causes higher ballast losses which results in lower ballast efficiency during the warm-up process. Conversely, while the bulb is being dimmed, the bulb is hotter than normal. Its impedance is higher than it would be in its steady state condition and the bulb demands less current than normal. This results in higher ballast efficiency during the dimming process. To determine the steady state efficiency of the ballast, the HID bulb should be allowed to operate at a given power level for an appropriate length of time before data is taken, i.e. five (5) minutes.

3.6 Performance Characteristics - Test Description Results

3.6.1 Power Factor

The initial test performed was to determine power factors of the Datapower Ballast (Reference Item B2 of the Schedular Performance Report). Input power voltage and current measurements were recorded for different input choke and filter capacitor combinations at varying power levels. Different "L" and "C" combinations and resulting power is shown in Table 3-1. The power factor for each measurement was computed as follows:

$$P.F. = \frac{P}{Vrms \quad Irms}$$

Power factor for the core/coil ballast was approximately .98.

For the LBL modified ballast, a 40MH choke and 140mf capacitor were selected for measurement. This combination yielded a P.F. = .74 at an output of 100 watts and P.F. = .80 at an output of 400 watts.

3.6.2 Line Regulator

The next test was made to compare Line Regulation of the Datapower Ballast and core/coil ballast (Reference SPR-B3). The line voltage and light output (photo cell current) were recorded as the line voltage was stepped at five (5) minute intervals in increments of 5% between high and low line. This data was normalized and plotted to show comparative regulations of each ballast. See Table 3-2 and Figure 3-3.

TABLE 3-1

DC CHOKE L in (mh)	Vin volts	Iin amps	Pin watts	P.F.	
89	277	.486	100	.74	
127	277	.481	100	.75	
202	277	.475	100	.76	
277	277	.477	100	.76	
89	277	2.135	450	.76	
127	277	2.077	450	.78	
202	277	1.880	448	.86	
277	277	1.829	448	.89	
NO CHOKE	277	.787	123	.56	
NO CHOKE	277	2.89	525	.66	
FOR L=126mh and C=17mf	277	.523	120	.83	Capacitor in Series with AC line
	277	.744	180	.87	
	277	.941	235	.90	
	277	1.249	325	.94	
	277	1.461	380	.94	
	277	1.697	440	.94	
	277	2.068	492	.86	

TABLE 3-2

LINE REGULATION TESTS

DATAPOWER BALLAST

Vin (volts)	Vnom	I Photo-cell(ma)	Inom
249	-10%	.749	-10.5%
263	-5%	.794	-5.1%
277	Vnom	.837	Inom
291	+5%	.877	+4.8%
305	+10%	.910	+8.7%

CORE/COIL BALLAST

Vin	Vnom	I Photo-cell (ma)	Inom
216	-10%	.786	-7.4%
228	-5%	.818	-3.7%
240	Vnom	.849	Inom
252	+5%	.881	+3.8%
264	+10%	.912	+7.4%

DATAPOWER BALLAST

WITH REGULATION CIRCUIT

Vin (volts)	Vnom	I Photo-cell (ma)	Inom
249	-10%	.868	-1.1%
263	-5%	.875	-.3%
277	Vnom	.878	Inom
291	+5%	.876	-.2%
305	+10%	.870	-.9%

NOTE: These measurements all taken at nearly full output.

GRAPH OF LIGHT INTENSITY (PHOTOCELL CURRENT) VS. LINE VOLTAGE

Line Regulation

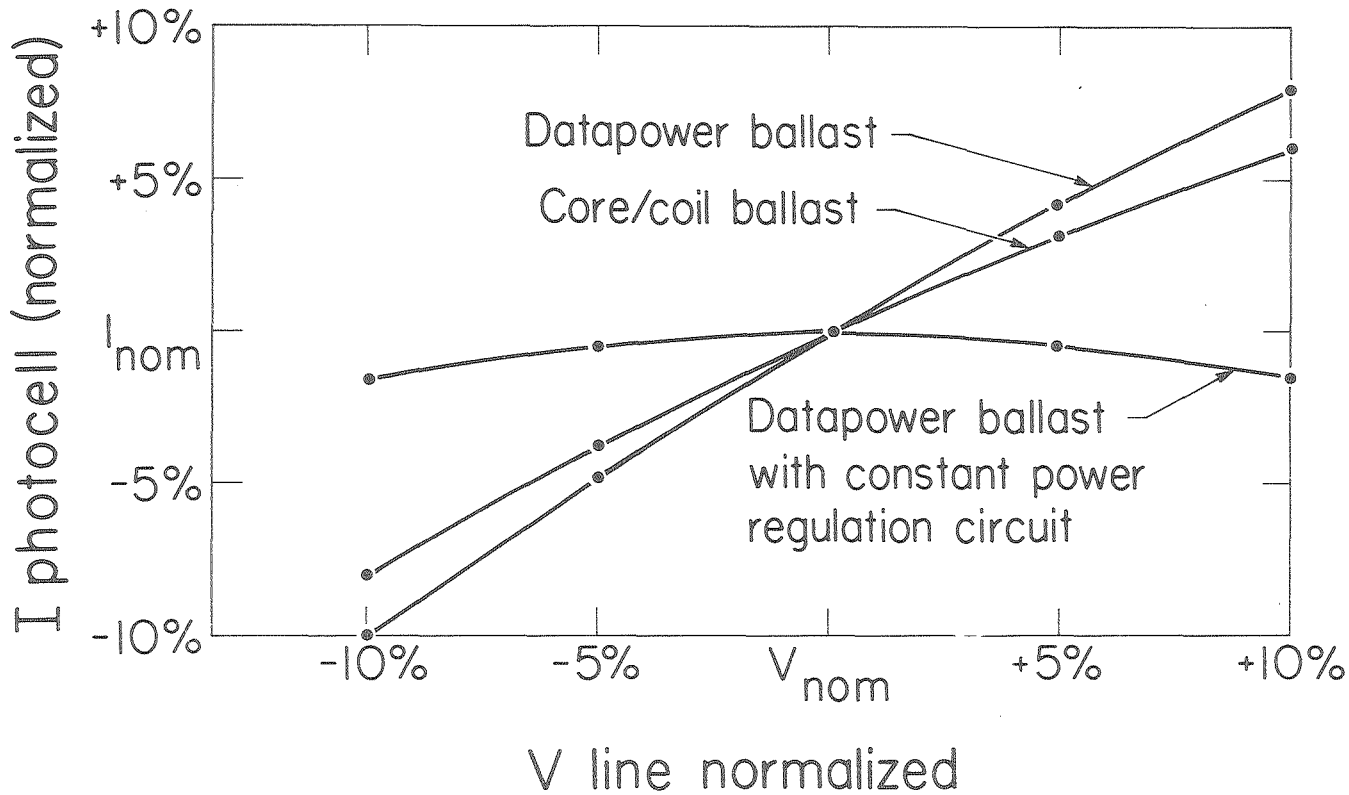


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FIGURE 3-3

Test results showed that the output power of the core/coil ballast increased linearly with line voltage. A low line to high line variation in input voltage caused a significant (15%) increase in output power.

By comparison, the output power of the Datapower ballast was held relatively constant. Its outpower power peaked at nominal line voltage and dropped off between 1% and 2% at both low and high line. A low line to high line variation caused only a 2% change in output power. Comparable regulation could be held over the entire dimming range of the Datapower ballast when properly adjusted.

3.6.3 Ballast Efficiencies

Determination of the efficiencies of both the Datapower and core/coil ballast followed.

For this test, both power and light output measurements were taken over the entire dimming range of the Datapower ballast. Input line was held at 277 volts (nominal). The same data was recorded for the core/coil ballast while its line voltage was varies over $\pm$15% of nominal voltage, i.e. 240V. See Figure 3-4, Graph of Efficiency (P out x 100%) vs. Output Power and Figure 3-5 Graph of Light Intensity (Photocell current) vs. Input Power.

It should be noted that the efficiency of the LBL contract ballast was found to be lower than the standard Datapower ballast. The efficiency was approximately 4% lower at 400 watts and about 8% lower at 100 watts. This resulted in efficiencies of approximately 84% at 400 watts and 72% at 100 watts. These lower efficiencies resulted from the combined increases in output transistor, snubber, and output transformer losses brought on by the output transformer modification.

3.6.4 Wave Shapes

Pictures recording the input and output voltage and current wave shape are shown in Figures 3-6, 3-7, and 3-8.

The thermal data was taken initially for the Datapower ballast enclosed in commercial ballast housing. No significant heating problems were noted nor anticipated since the original ballast could be run free standing in air. In regard to the LBL ballast, however, due to the lower electrical efficiency, more heat was generated which placed greater stress on the output transistors. It should be noted that the LBL ballast must be properly heat sunk to operate reliably, i.e. attach heatsink with 2 $ft.^2$ surface area. Thermal test results for Datapower Ballast are shown in Figure 3-9.

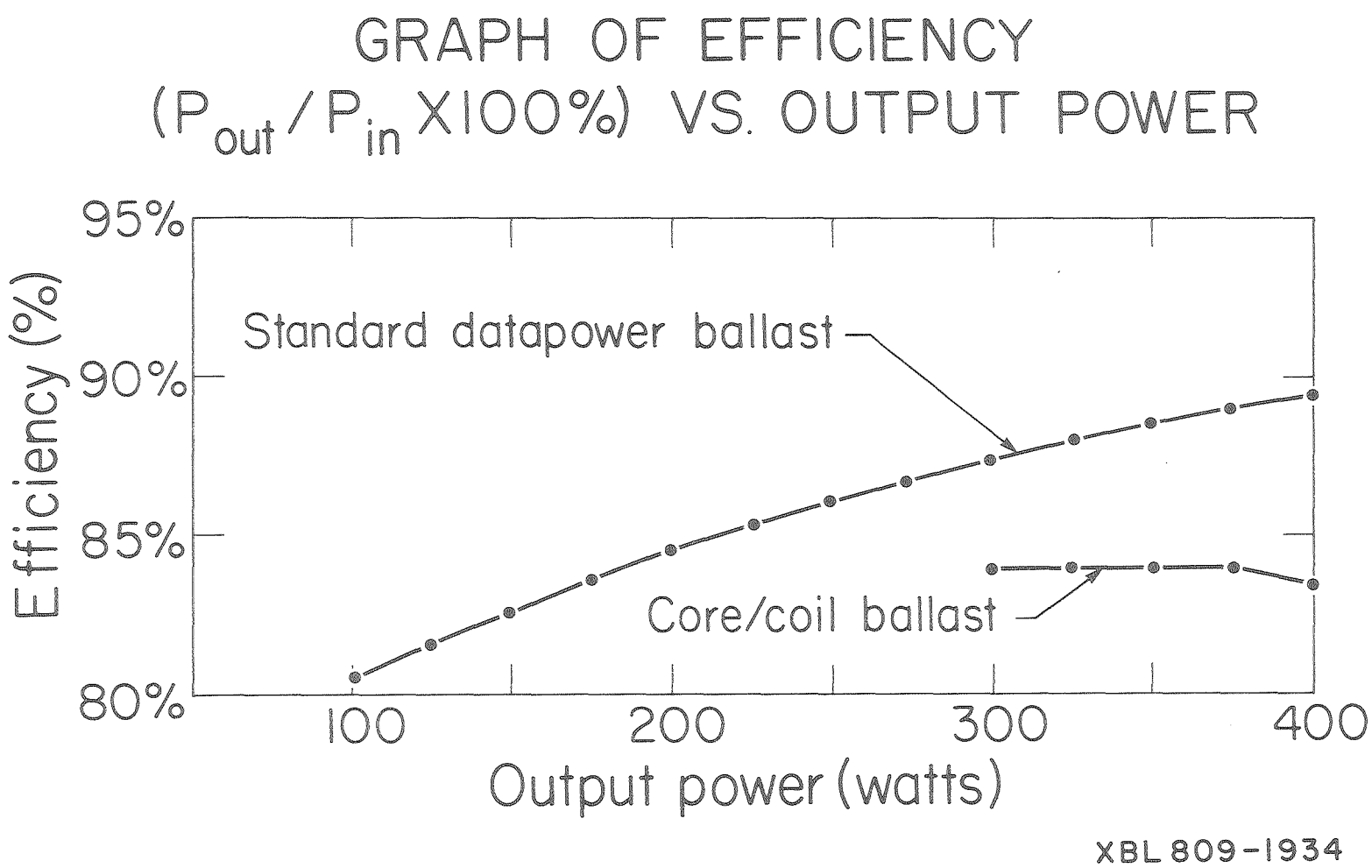
GRAPH OF EFFICIENCY
(P_{out} / P_{in} X100%) VS. OUTPUT POWER
95%
90%
85%
80%
Efficiency (%)
Standard datapower ballast
Core/coil ballast
100
200
300
400
Output power (watts)
XBL 809-1934

FIGURE 3-4

GRAPH OF LIGHT INTENSITY (PHOTOCELL CURRENT) VS. INPUT POWER

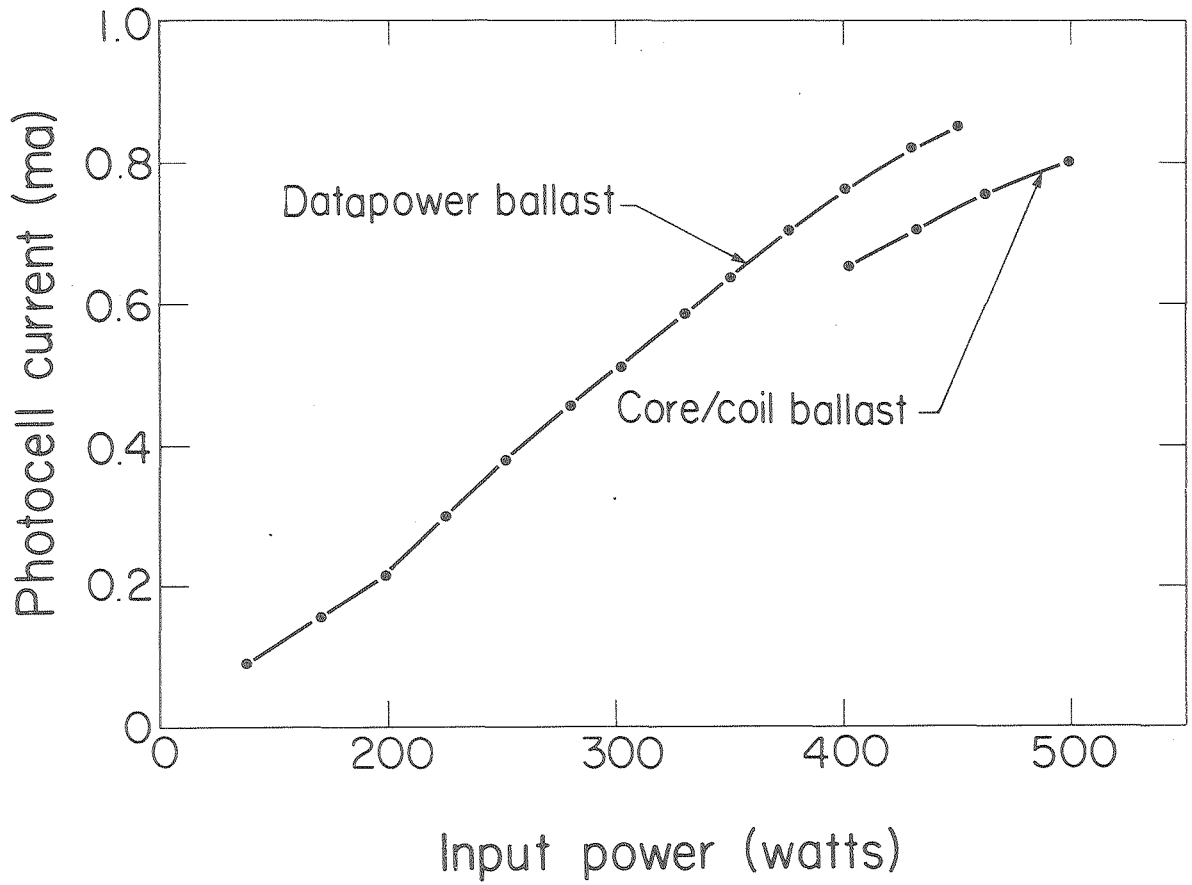

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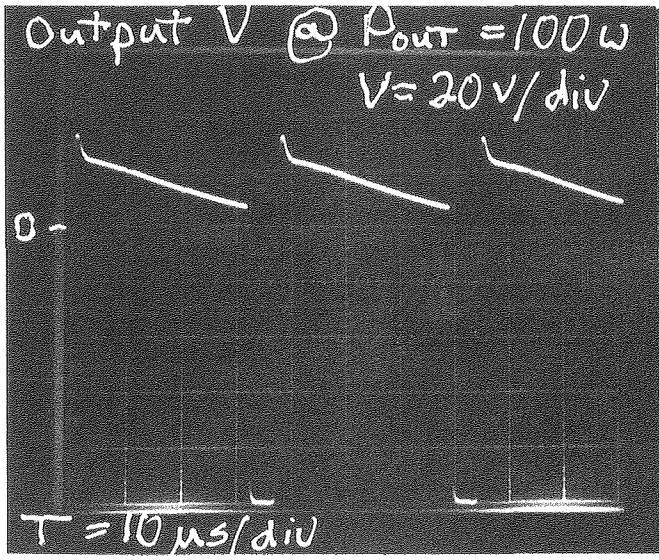
FIGURE 3-5

DATAPOWER 400W SODIUM BALLAST

INPUT AND OUTPUT WAVEFORM



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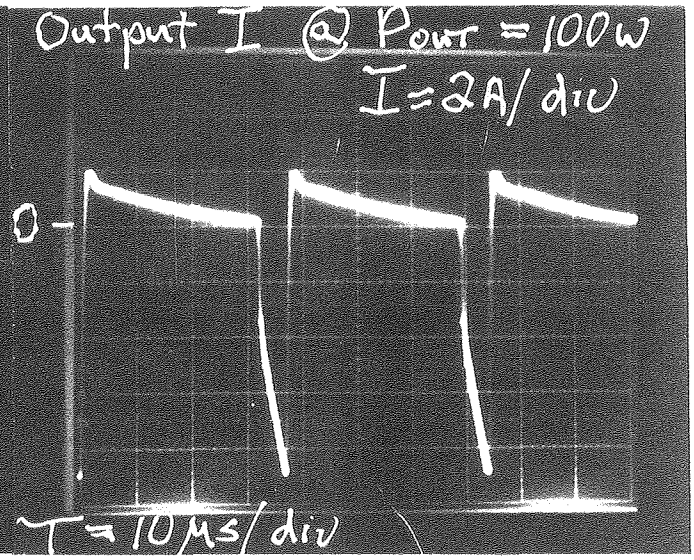

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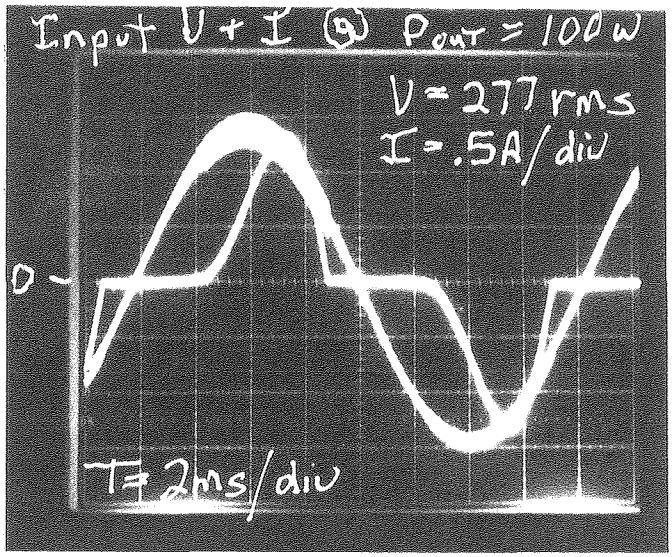

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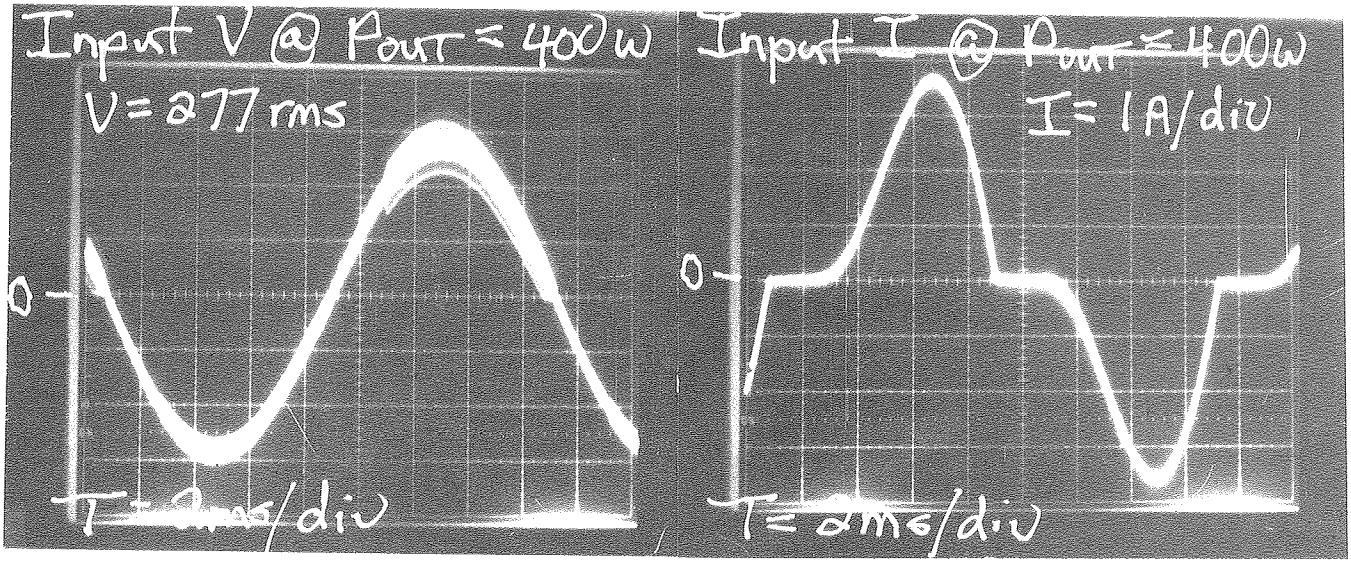
FIGURE 3-6

DATAPOWER 400W SODIUM BALLAST

INPUT AND OUTPUT WAVEFORMS



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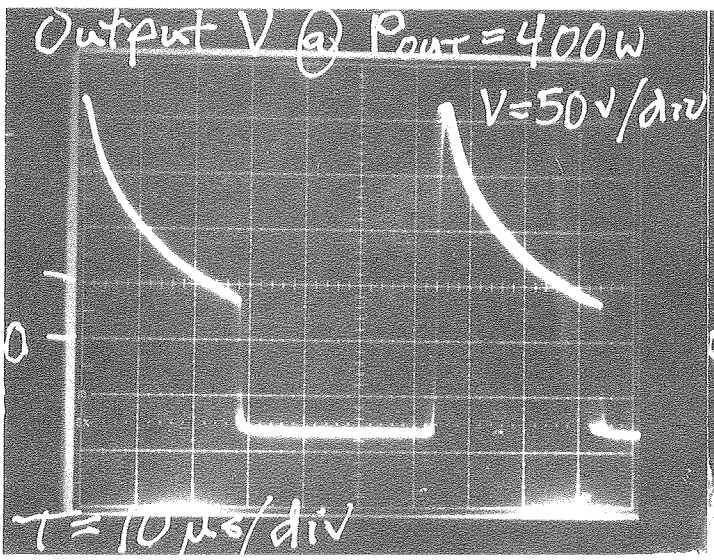

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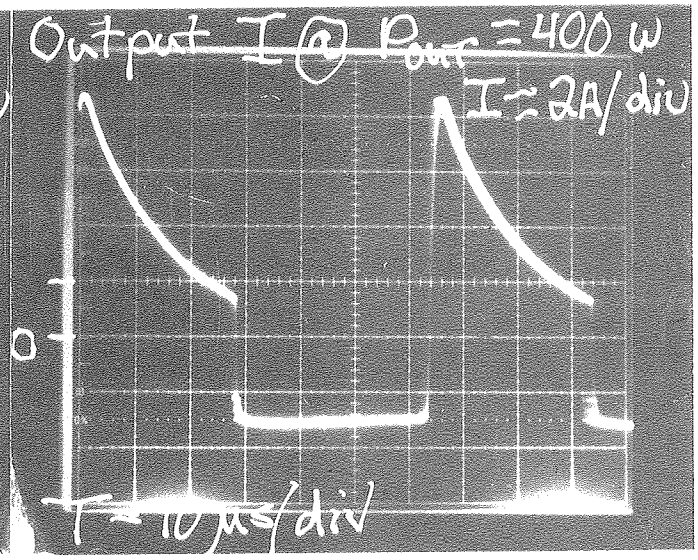

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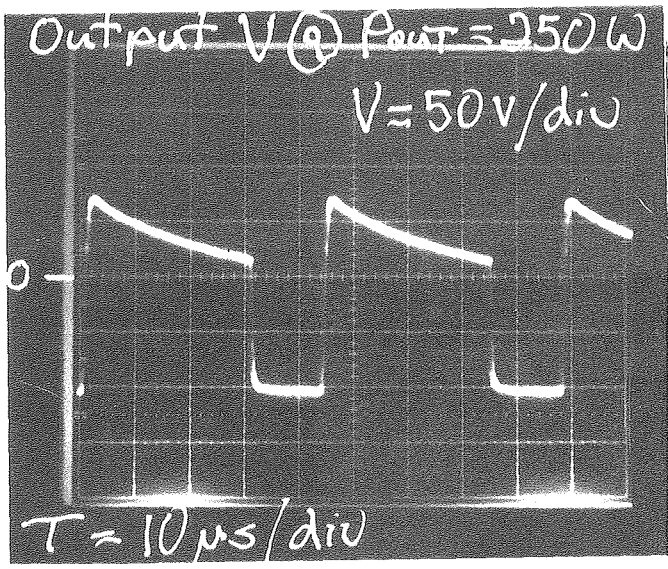
FIGURE 3-7

DATAPOWER 400W SODIUM BALLAST

INPUT AND OUTPUT WAVEFORMS



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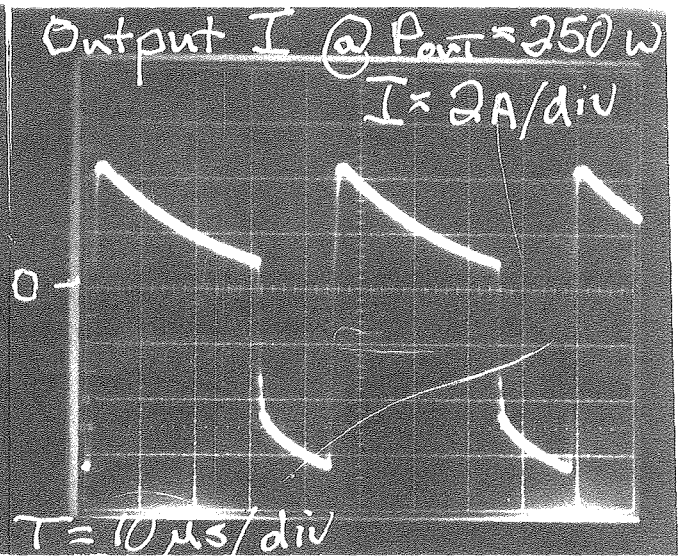

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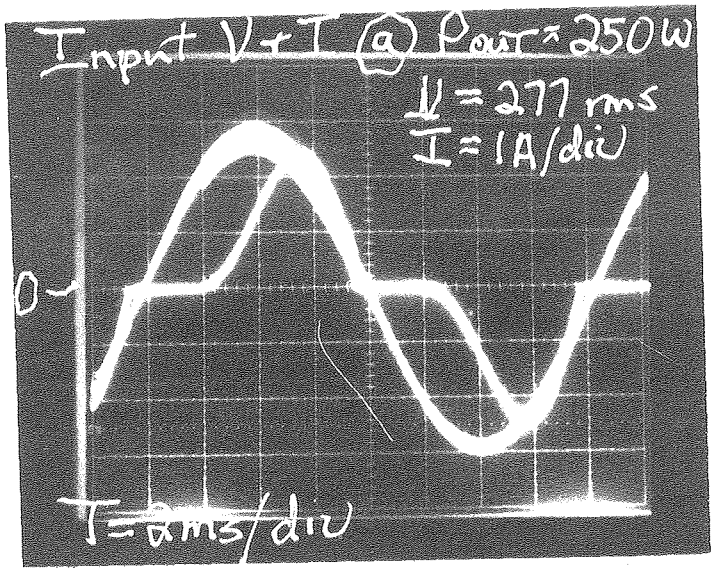

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FIGURE 3-8

Thermal Test Results

Temperature readings after 4 hours (stable)

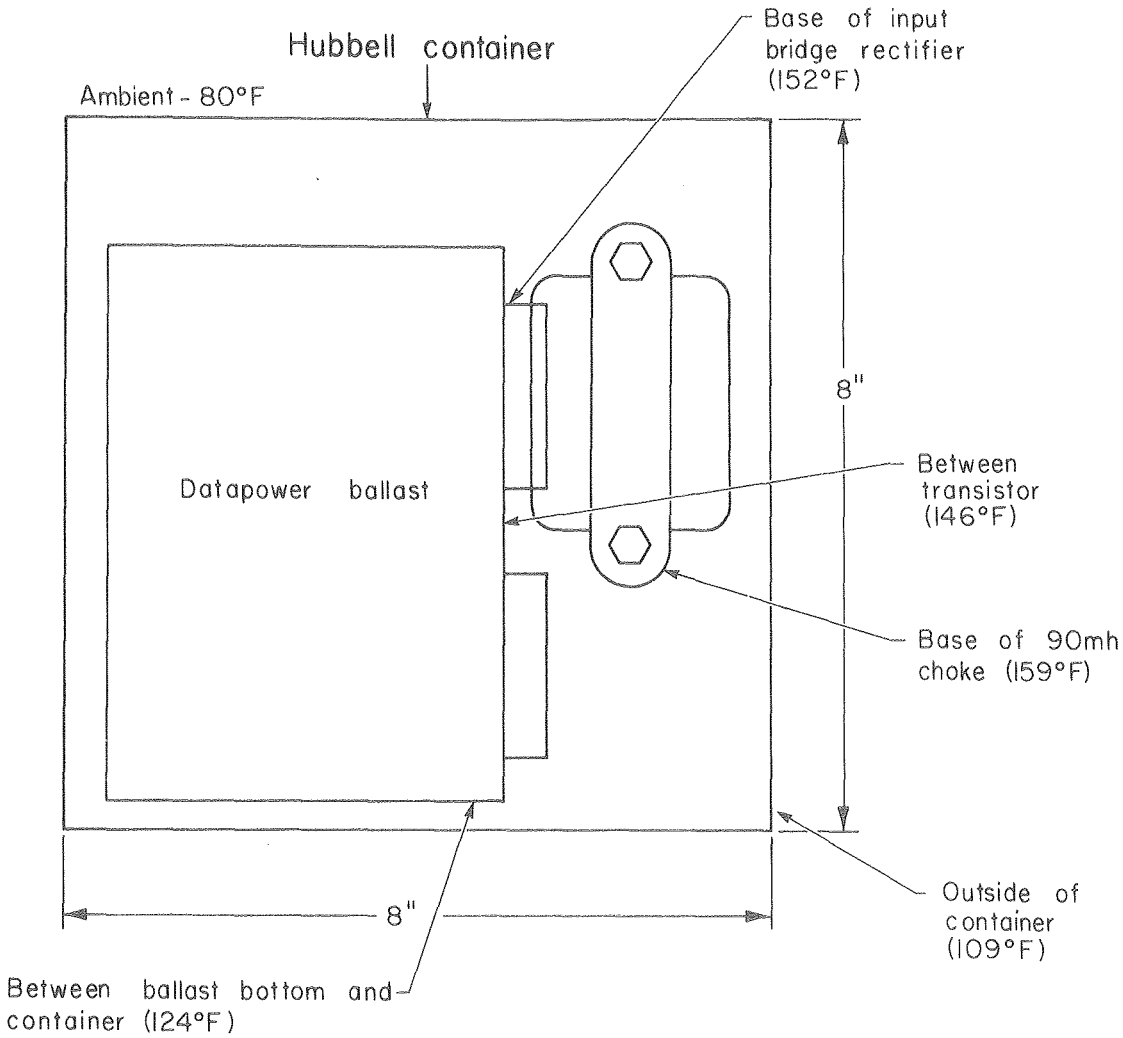

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FIGURE 3-9

3.7 Energy Loss Analysis

In this analysis, losses were derived for each major ballast component at nominal line voltage and full output power. The figures for the low frequency components were arrived at by measuring the rms voltage and/or current and making the appropriate calculation. The figures for the high frequency components were arrived at by photographing the voltage and/or current waveforms, then either estimating the area under the curve or by considering the waveforms as a series of linear approximations and applying the appropriate calculus techniques. In most cases, these figures were verified by more than one means.

The results are tabulated as follows:

High Voltage DC Supply Losses		
Input Rectifier	2.8W	
Input Choke	1.8W	
	4.6W	
Bias Supply Losses		
Bias Supply Transformer		3.0W
Output Transistor Drive Circuit		3.4W
Supply Rectifier and Control Circuit		1.1W
		7.5W
Output Transistor Losses		
Switching Losses		2 x 4.2W
Saturation Losses		2 x 4.3W
		17W
Snubber Losses		25W
Output Transformer Losses		
Copper Losses		2.6W
Core Losses		.23W
		26W
Total Ballast Losses at 400 Watts		80W

3.8 Relative Cost/Savings Comparison

For this comparison, light intensity and input power data for the Datapower ballast was taken and normalized against that of a standard core/coil ballast operating at nominal line and using the same bulb. See Table 3-3. As shown in Figure 3-10, the power savings can be seen for any given relative light intensity. The cost saving shown for the Datapower ballast are only as related to bulb and ballast power consumption. At 100% relative light intensity, the Datapower ballast together with a HPS bulb uses about 13% less power than the standard core/coil and bulb combination. At lower intensity levels, the power savings are even greater.

Savings resulting from individual applications should also be considered. Air conditioning costs will be reduced upon indoor application of the more energy efficient solid state ballast. Finally, the benefits from tighter design parameters, not having to over design to accommodate wide variations in bulb, ballast, and line parameters might also be taken into account.

3.9 Stress Analysis

The stress analysis report was accomplished by Gerhard Engineering of San Juan Capistrano, California. See Appendix B of this report.

3.10 Load Regulation (Regulation Over Bulb Life Test)

This test was made to observe output power as a function of bulb impedance. The test was run using a new bulb with low impedance. Initial ballast output power and bulb voltage were noted. A cylinder of aluminum foil was gradually moved up over the bulb length. See Figure 3-11. The radiation reflected back into the plasma caused the plasma temperature and impedance to increase. Foil cylinder was moved till bulb voltage was high enough to trigger over voltage protection circuit of ballast. Both ballast output power and bulb voltage were observed over entire range.

It was observed that ballast output power changed less than 2% over bulb voltage range from 90 to 140 volts. In addition, cognizance should be taken that this test was detrimental on certain bulbs. The quartz tube on each of the three new Norelco bulbs subjected to this process broke after a few runs. With the older Sylvania bulb, however, there did not seem to be any problems.

TABLE 3-3

RELATIVE COST/SAVINGS COMPARISON

BALLAST	Pin (watts)	Pin (relative)		I Photocell (ma)	Light Intensity (Relative)
GE Core/Coil	450	1.00		.741	1.0
DATAPOWER	124	.276		.106	.143
	153	.340		.163	.220
	182	.404		.233	.314
	209	.464		.305	.412
	236	.524		.378	.510
	262	.582		.451	.609
	289	.642		.522	.704
	317	.704		.589	.795
	343	.762		.651	.879
	369	.820		.706	.953
	396	.880		.758	1.02
	423	.940		.806	1.09
	448	.996		.855	1.15

RELATIVE COST/SAVINGS COMPARISON

The Cost of Power for a Standard Core/Coil Ballast Running 365 Days a Year,
12 Hours Per Day Computed at $.05/kW-Hour Would be $99.00/Year.
For Power Costs and Savings of Datapower Ballast, See Graph.

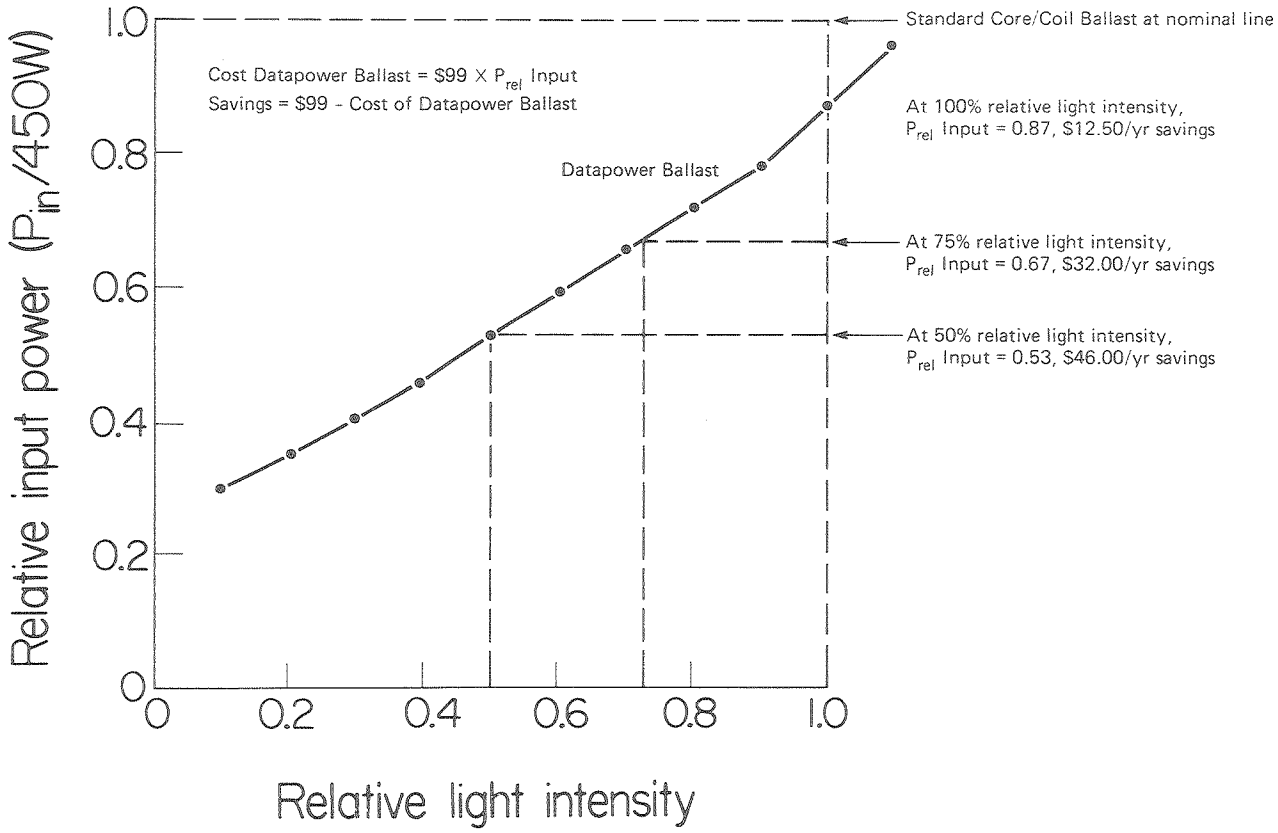

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FIGURE 3-10

Regulation Over Bulb Life Test

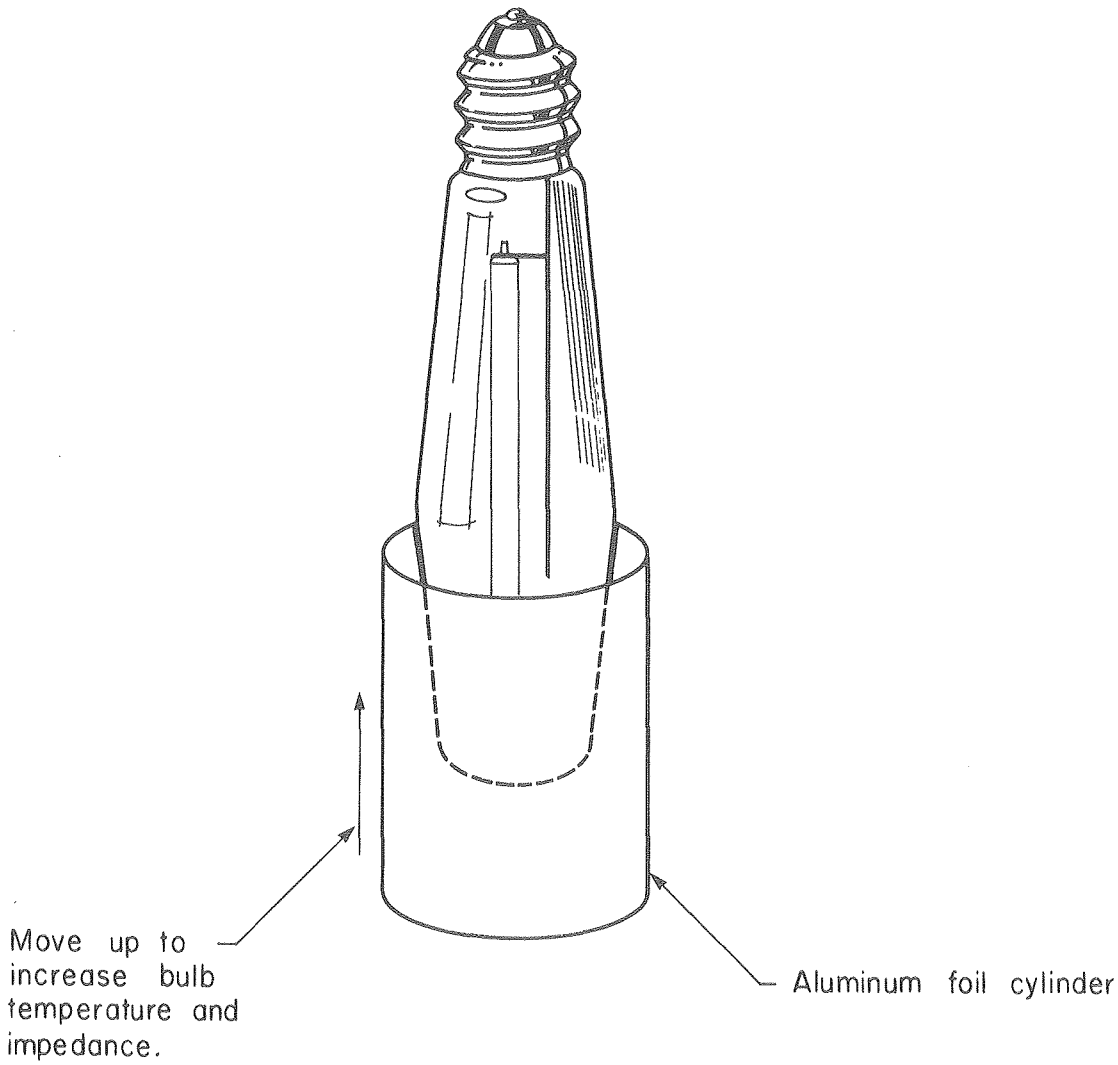

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FIGURE 3-11

3.11 Light Regulation Test

This test was made to determine the light intensity spread for different bulbs at a fixed output power. The Datapower ballast was set for 400 watts output and photocell current was recorded for each bulb. In addition, the same data was recorded for a standard core/coil ballast with a fixed input voltage.

Test results are shown in Table 3-4, Light Regulation Test, and Figure 3-12, Graph of Light Intensity vs. Individual Bulbs.

4.0 PROTOTYPE BALLASTS

Datapower built six (6) prototype ballasts. These units underwent test-evaluation and burn-in at Datapower then shipped to an independent test facility for LBL verification tests.

Appendix C is the independent test report submitted by the Lighting Research Laboratory, Orange, California.

Datapower feels that the test results are accurate except for Figure 18 which shows the lamp voltage vs. wattage. The lamp was not allowed to stabilize before the data was taken which reflects the poor regulation at low lamp voltage.

5.0 SUMMARY

Datapower's major effort during Phase I was directed toward precise definition of the performance of its 400 Watt Solid State Ballast, together with bulb interaction. Many facets of bulb/ballast operation unique to high frequencies were studied and recorded. Also, many difficulties arising in the measurement of high frequency ballast parameters were dealt with, enhancing Datapower's expertise in this area and providing a firm basis for tasks scheduled in Phase II.

Less than desired time was allocated for the modification and test of the six ballasts shipped to LBL. It was felt, however, that these units would satisfactorily demonstrate Datapower's Solid State ballast capabilities. Independent test results tend to bear this out.

During Phase I, the advantages of a 400 watt Solid State Ballast were clearly shown; specifically in the areas of increased efficiency, improved regulation, precise control of light output and power consumption. In Phase II, Datapower's effort will be directed primarily toward improving ballast design and maximizing performance to insure that the ballast meets commercial reliability standards.

TABLE 3-4

LIGHT REGULATION TEST

DATAPOWER BALLAST

BULB NO.	P BULB (Watts)	I PHOTOCELL
1	400	.870
2	400	.900
3	400	.905
4	400	.883
5	400	.892
6	400	.882
7	400	.898
8	400	.860
9	400	.902
10	400	.935

G. E. BALLAST (Core/Coil)

BULB NO.	P BULB (Watts)	I PHOTOCELL
1	402	.808
2	374	.772
3	408	.822
4	376	.765
5	368	.762
6	348	.721
7	360	.745
8	398	.798
9	372	.787
10	368	.803

For Vin = 240V

Bulbs 1-8 = Sylvania

Bulbs 9-10= Norelco

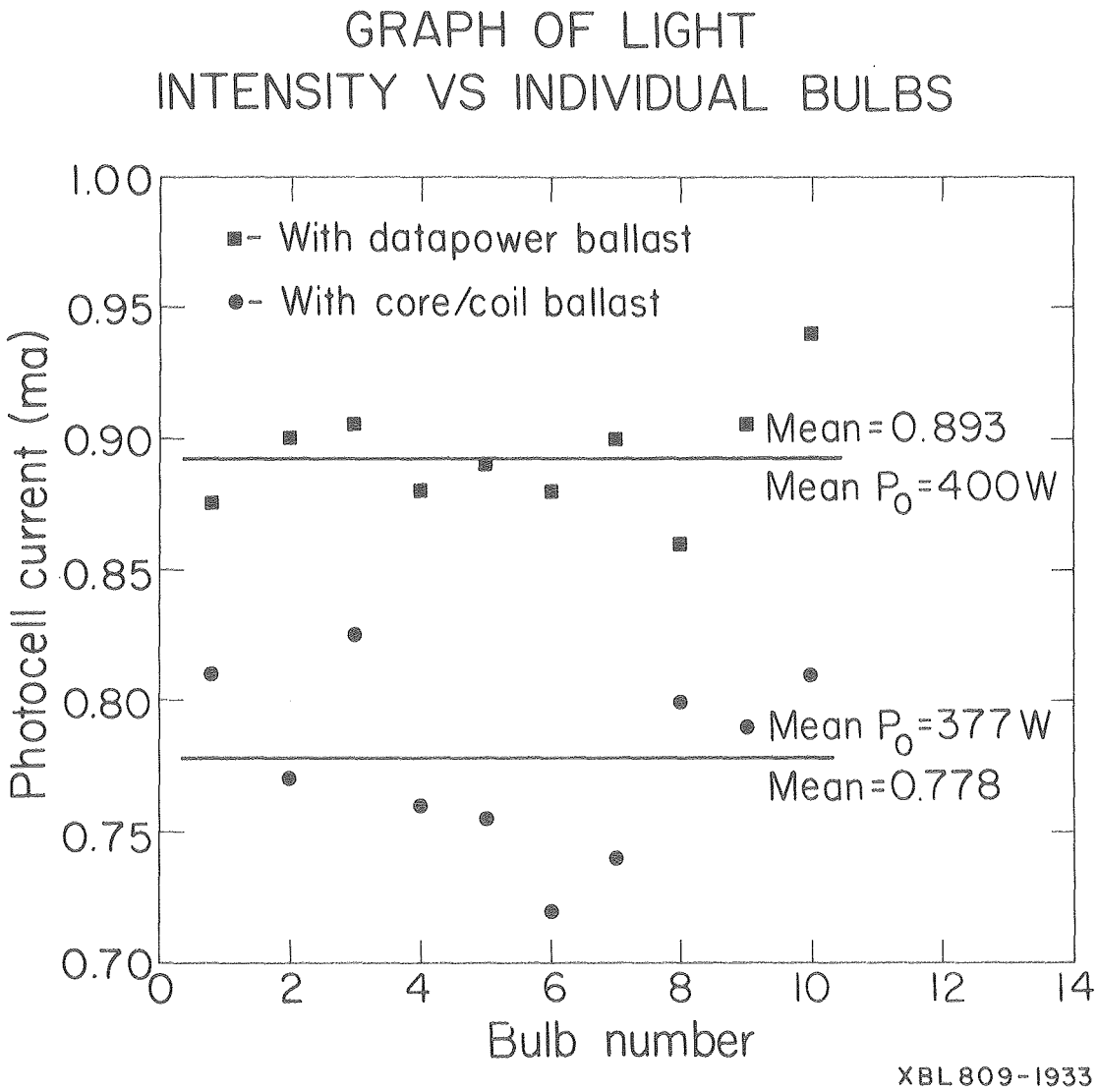

GRAPH OF LIGHT
INTENSITY VS INDIVIDUAL BULBS
■- With datapower ballast
●- With core/coil ballast
Mean=0.893
Mean P_0=400W
Mean P_0=377W
Mean=0.778
Photocell current (ma)
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0
2
4
6
8
10
12
14
Bulb number
XBL809-1933

FIGURE 3-12

APPENDIX A

PHASE I - SCHEDULAR PERFORMANCE REPORT

DEPARTMENT OF ENERGY
SCHEDULAR PERFORMANCE REPORT
(See Instructions on Reverse)

OMB NO. 61-R1.R1

6. REPORTING PERIOD: MAY 1980

1. CONTRACT TITLE: HID Solid State Ballast

2. ADDRESSEE (Name, Title, Address and ZIP Code): LBL, Berkeley, California

3. CONTRACTOR (Name, Address and ZIP Code): DATAPOWER INC.

4. CONTRACT NUMBER: 4502210

5. APPROVED SCHEDULE DATE: Amend. #1 15 Apr 1980

DOE USE ONLY
PROJECT MANAGER
EVALUATION DATE

7. REPORTING CATEGORY

YEARS: weeks 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

8. TECHNICAL OBJECTIVE % COMPLETED

EVALUATION

TASK I PROGRAM PLAN
- (A) Generate Detail Project Schedule
- (B) Define Milestones on Project Schedule 534
- (C) Define Personnel Assignments for each Task on Form 535
- (D) Define Cost Per Task on Form 533
- (E) Type Forms 533, 534, 535

TASK II PERFORMANCE CHARACTERISTICS
- (A) Modify existing prototype to LBL Configuration
- (B) Measure Performance
- B1) describe: setup, electrical tests and photometric test
- B2) Measure input power
- B3) Measure Lumen Output as a function of line voltage +10%
- B4) Compare efficiency with core/coil Ballast

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

DATE: 5-28-80

9. SUBMISSION APPROVAL (Signature of Contractor's Project Manager)

534

Page 2 of 4

DEPARTMENT OF ENERGY
SCHEDULAR PERFORMANCE REPORT
(See Instructions on Reverse)

4. REPORTING PERIOD: MAY 1980

1. CONTRACT TITLE	2. ADDRESSEE (Name, Title, Address and ZIP Code)	3. CONTRACT NUMBER	DOE USE ONLY
			PROJECT MANAGER
	5. CONTRACTOR (Name, Address and ZIP Code)	6. APPROVED SCHEDULE DATE	EVALUATION DATE

7. REPORTING CATEGORY	YEARS: weeks 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24	9. TECHNICAL OBJECTIVE % COMPLETED	EVALUATION
(B5) Record Wave Shapes of input & output voltage current			
(B6) Define required heatsinking and ambient safe operating conditions			
(C) Prepare preliminary Ballast Specification			
(C1) List Performance Targets specification			
(C2) Tabulate Performance Data			
(C3) Define suggested test procedures			
(D) Discuss Ballast Performance with regards to system performance			
TASK III ENERGY LOSS ANALYSIS Identify Energy Losses compared			
(A) To core/coil for Lamps & Ballast			
(B) Identify and discribe energy loses within the Ballast			
(C) Determine annual cost savings for Ballast			
TASK IV BUILD 6 PROTOTYPES			
(A) Assembly			

LEGEND:
DOE Approved Schedule
Contractor's Working Schedule

DATE: 5-28-80

9. SUBMISSION APPROVAL (Signature of Contractor's Project Manager)

534

DEPARTMENT OF ENERGY
SCHEDULAR PERFORMANCE REPORT
(See Instructions on Reverse)

OMB NO.

6. REPORTING PERIOD: MAY 1980

1. CONTRACT TITLE

2. ADDRESSEE (Name, Title, Address and ZIP Code)

3. CONTRACT NUMBER

DOE USE ONLY
PROJECT MANAGER

3. CONTRACTOR (Name, Address and ZIP Code)

6. APPROVED SCHEDULE DATE

EVALUATION DATE

7. REPORTING CATEGORY

YEARS — weeks 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

8. TECHNICAL OBJECTIVE % COMPLETED

EVALUATION

(B) Test 6 Prototypes

(C) Burn-in 6 Prototypes — Completed March 4, 1980

(D) Ship 6 Prototypes — Shipped to Lighting Research Lab March 6, 1980

(E) DOCUMENTATION
(E1) Mechanical Drawings

(E2) STRESS ANALYSIS

(E3) PERFORMANCE ANALYSIS

(E4) OPERATING INSTRUCTIONS — N/A

(F) Provide Liason to LBL during Test Period — Completed - Lighting Research Lab Liaison

TASK V FINAL REPORTS
(A) Prepare final report for LBL approval — 1st Draft Completed 4/21/80 Final 5-28-80

(B) Prepare proposal for Phase II — 1st Draft Completed 4/21/80 Final 5-28-80

LEGEND:
DOE Approved Schedule
Contractor's Working Schedule

DATE: 5-28-80

9. SUBMISSION APPROVAL (Signature of Contractor's Project Manager)

534

Page 4 of 4

DEPARTMENT OF ENERGY
SCHEDULAR PERFORMANCE REPORT
(See Instructions on Reverse)

1980

1. CONTRACT TITLE

2. ADDRESSEE (Name, Title, Address and ZIP Code)

3. CONTRACTOR (Name, Address and ZIP Code)

4. CONTRACT NUMBER

5. APPROVED SCHEDULE DATE

9. REPORTING CATEGORY

YEARS

weeks 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

8. TECHNICAL OBJECTIVE % COMPLETED

EVALUATION

(C) Edit and Submit Final Report

5-28-80

TASK VI
TRAVEL AND PROJECT MANAGEMENT

TASK II (e)
REGULATION OVER BULB LIFE TEST

(f)
LIGHT REGULATION TEST

NOTE: Schedule extended to February 29, 1980 per Amendment I to Sub-Contract 4502210, dated November 30, 1979., Amendment II, April 15, 1980 Schedule Extended to May 30, 1980.

LEGEND:
DOE Approved Schedule
Contractor's Working Schedule

DATE
5-28-80

6. SUBMISSION APPROVAL (Signature of Contractor's Project Manager)

APPENDIX B

STRESS ANALYSIS REPORT - GERHARD ENGINEERING

Gerhard Engineering

TO: G. FELPER

FROM: F. H. GERHARD

DATE: January 10, 1980

SUBJECT: WORST CASE ANALYSIS OF 400 WATT SODIUM BALLAST

A formal worst-case analysis is normally done on a circuit that is free from known design problems. This was not the case here.

As you know, there were still a couple of bugs in the design when I started. Consequently, I started the analysis in the areas where the difficulties were, and in addition, did some troubleshooting. Also, as frequently happens, some circuits did not tolerance out and I did some re-design in these areas.

Consequently, it was not possible to do a worst-case analysis on all of the circuits in the allotted time. The work done is documented in detail on pages 54 through 80 in Lab Notebook - G. Felper dated 1-1-80. Materials included are mathematical analysis, test results, observations and comments. Following is a summary of the work done.

The principal problem with the unit was that, depending on lamp characteristics, the lamp would either fail to warm-up or, upon approaching the end of the warm-up process, would extinguish itself. Circuit changes that helped one of these problems tended to aggravate the other.

The exact mechanisms for the two types of failures was determined through a combination of analysis and oscilloscope measurements on the bench. Design changes were made and tests run to verify them.

A thorough analysis of the shut-down circuit was made. As a result, design changes were made.

An analysis of the snubber circuit was made including calculation of the power transformer leakage inductance from experimental measurements on a prototype.

Also included in the notes are several areas that need further tolerancing and re-design before volume production can begin.

F. H. Gerhard

F. H. Gerhard

FHG:sf

31891 Paseo Terraza, San Juan Capistrano, California 92675
Business: (714) 533-3740 • Residence: (714) 493-2786

APPENDIX C

INDEPENDENT TEST REPORT

LIGHTING RESEARCH LABORATORY

LIGHTING RESEARCH LABORATORY

Design • Testing • Consulting

4-11-80 REPORT LRL 380-10

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

Attn: Mr. Rudy Verderber

Subj: Test of light output and electrical characteristics of six samples of prototype 400W HPS ballast as compared to standard core/coil ballast, as covered by LBL Purchase Order 8332202.

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.

Results: Parameters and results are tabulated in Table I.

Comment:

I. Efficacy.*

A. Lamp. Average efficacy of the lamp on the HF (High Frequency) ballasts was found to be 126.9, compared to 115.5 for the same lamp on the standard ballast. This is an increase of 10% in light output per watt. All ballasts except #1 had very nearly the same efficacy; #1 was somewhat higher.

B. System. Average overall efficacy of the HF systems was 107.7, compared to 99.5 for the standard ballast. This is an increase of 8%.

II. Power Factor.

A. Lamp. Power factor of the lamp alone was found to be .97 on the average, compared to .83 for the standard ballast. At 22Khz the lamp acts as essentially a pure resistance, and the voltage and current waveshapes are practically identical and in phase. See Figs. 10,11, & 12. On the standard ballast, the lamp voltage is almost a square wave, and the current wave approaches triangular shape. Power factor therefore is lower due to the harmonic content, although the waves are in phase. See Figs. 4,5, & 6.

* Based on absolute output. See Line 21 for efficacy based on rated lumen output.

P.O. BOX 6193 • Orange, California 92667 • (714) 771-1312

LRL assumes no responsibility for information furnished by others and utilized in this report. Where assumptions must be made they are based on our best knowledge and judgment, but are not guaranteed.

II. Power Factor

B. System. Power factor for HF system was an average of .77 compared to .94 for the standard ballast. A highly peaked current waveform with a duty cycle of about 50% results in a low power factor due to high harmonic content not present in the voltage wave. The 60Hz fundamental of the current wave is about 20 degrees out of phase with the voltage, lagging, so contributes little to the low power factor. See Figs 7,8, & 9. The standard ballast current waveform is only slightly distorted, and voltage and current waves are almost in phase, accounting for the high power factor. See Figs. 1, 2, & 3.

III. Regulation

Light output regulation on the standard ballast is +11.7% at 110% rated voltage, and -13% at 90% rated voltage. The HF ballasts peak at reated voltage and fall off on either side, so regulation is negative in both cases, and extremely good. Average is -2% at 110% and -0.9% at 90%. On units #4 and #7, an internal relay switched off and on at 110% voltage, making it impossible to get a reliable determination of regulation.

IV. Minimum Starting Voltage

Minimum starting voltage for all units was 250V or more, with one unit requiring an overvoltage of 8 volts before it would start. For satisfactory performance, minimum starting voltage should be at least 20% below rated voltage.

V. Dimming

While not requested as a part of the test, an investigation of the dimming characteristics was carried out on one unit. The unit dims smoothly from full output down to 4% of full output. System power factor holds fairly constant over the dimming range, dropping to .71 at the low end. Efficacy drops gradually for the first half of the range, then more rapidly to a low of 17.6 LPW at the low end. Note from the secondary voltage and current waveforms (Figs. 13 and 14) that power to the lamp is reduced by shortening the conduction period, until at the low end the duty cycle is about 12%. It requires about 5½ minutes for the unit to go from the lowest output to 90% of maximum, and about 4 minutes for the unit to go from maximum to 10% of maximum.

VI. Flicker and Strobe

The standard ballast shows a flicker index of 25.7, and a percent flicker of 69.5%. See Fig. 15. The HF ballast shows a flicker index below .01, and a percent flicker of 1.5%. See Fig. 16. As a result, there is no perceptible strobe.

VII. Voltage/Power Lamp Traverse

Two ballasts were selected on the basis of different voltage operating points and were induced to traverse the voltage/power trapezoid. Lower values were obtained by recording during warm-up; upper values by heating the lamp with a surrounding, white interior can. See Fig. 17. The lamp voltage was raised to 125 volts, and the test terminated at that point, since the curves had leveled out so that the lamp power was not diminishing. Note that the leveling out takes place just above the normal

operating point, indicating that the lamp is being operated close to its maximum efficacy. See Fig. 18

VIII. Frequency

Operating frequency for all of the HF units was approximately 22Khz in the secondary.

IX. General Comment

A. A very high level of RFI was noted feeding back through the lines. Although the unit was operated from a low-Z source, the voltage wave showed considerable "hash". See Fig. 7. A closeup look at the "hash" showed that it consisted of primarily 22Khz oscillations on the voltage trace, and was confined to the region around the negative maximum voltage.

B. The units warm up very slowly, requiring between 15 and 30 minutes to reach full output.

C. By and large the units are fairly quite, although #2 was equipped with a very noisy choke.

D. Three ballasts failed during the test program. #1 failed after the test completion; #4 by arcing internally; and #5 after the cold-start test.

E. The units require about 7 - 10 seconds to fire the lamp. Shortly thereafter an internal relay operates.

F. Comparative light output results between the standard and the HF ballasts will be influenced by the conditions of test. In the presence of flux reflected from the surround to the lamp, the light output drops off. This effect is not the same for the lamp on standard and on HF ballasts, so the results will be different if the lamps are tested in a photometric sphere as compared to free-air tests. Until and unless a standardized test method is indicated, I would suggest that lamps not be stabilized in a sphere for measurement therein.

G. Ratings and results. The lamp used showed an output on the standard ballast of 45056 lumens at 390 watts. This would scale to an output of 46211 lumens at 400 watts, which is 92.4% of rating. Since this correlation is not unusual, it was decided to give the figures in line 21 as the best results to use for correlation with standard catalog data. Any base may be used, and tabulated results allow conversion to any such base.

CERTIFIED FOR LRL:

Bill F. Jones

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

TABLE I

OPERATING PARAMETERS IN FREE AIR

LINE	ITEM	STD	#1	#2	#3	#4	#6	#7
1	Ballast	STD	#1	#2	#3	#4	#6	#7
2	Primary:							
3	Voltage	240	277	277	277	277	277	277
4	Amps	2.0	2.08	2.16	2.14	2.08	1.97	2.10
5	Watts	453	446	464	455	442	422	450
6	Power Factor	.94	.77	.78	.77	.77	.77	.77
7	Light Output	45056	47595	50094	49505	47411	45684	48182
8	Efficacy, LPW	99.5	106.7	108.0	108.8	107.3	108.3	107.0
9	Relative (1)	-	107	108	109	108	109	108
10	Regulation: 90%	-13.0	-0.6	-0.8	-0.9	-0.5	-1.8	-0.8
11	110%	+11.7	-4.7	-1.0	-1.6	(3)	-1.3	(3)
12	Min. Start Volt.	176	-	265	285	250	250	-
13	Secondary:							
14	Voltage	99	88.1	107.4	99.2	93.8	93.9	93.0
15	Amps	4.73	4.27	3.77	4.05	4.11	4.00	4.24
16	Watts	390	359	399	392	374	366	384
17	Power Factor	.83	.95	.98	.98	.97	.97	.97
18	Efficacy, LPW	115.5	132.6	125.5	126.3	126.8	124.8	125.5
19	Relative (1)	-	115	109	109	110	108	109
20	Ballast Loss, Watts	63	87	65	63	68	56	66
21	Rated Efficacy (2)	110	118	120	121	119	120	119

Notes:

1. Relative to lamp performance on standard ballast
2. Assuming rated output from lamp on standard ballast
3. Internal relay switches off and on at 305 v, making regulation measurement unreliable

Test Conditions: Lamp mounted in free still air, air temperature 77°F, dark surround. No appreciable flux reflected to lamp.

Line	Note
1	Standard ballast is core/coil ballast, General Electric 17G3002. High Frequency (HF) ballasts 6 samples of prototype furnished by Datapower.
2	All primary measurements made on SR Model VAW volt-amp-wattmeter, accuracy for voltage and current ± 0.5%; watts ± 0.75%, response flat to 800 Hz.
3.	Voltage held constant to ± 0.5 volt.
6	Power Factor = Watts/(Volts x amps).
7	Light output absolute, measured by complete photometry of lamp referred to 90° candlepower reading and checked for std. vs. HF operation by integrating sphere. Accuracy: Absolute ± 5%; Relative ± 2%.
8	Lumens per watt. See Comment part I.
9	See Note 1 at bottom of Table 1
10	Steady-state regulation @ 90% and 110% of rated voltage.
12	See Comment Part IV.
13	All secondary measurements made on Clarke-Hess Model 255 Digital Wattmeter, Accuracy ± 0.4%, Range 0 - 300Khz. Meter checked against SR @ 60Hz, and by light output of incandescent lamp at 22Khz, and found within 1% gross, 60Hz/22Khz.
17	See line 6
18	See line 8
19	See Note 1 at bottom of Table 1
20	Ballast loss = (Input watts - lamp watts)
21	This line assumes that lamp is producing rated output, and compares performance on the HF ballasts as though that were the case. The resulting LPW efficacies listed may then be compared with catalog information on core/coil ballasts.

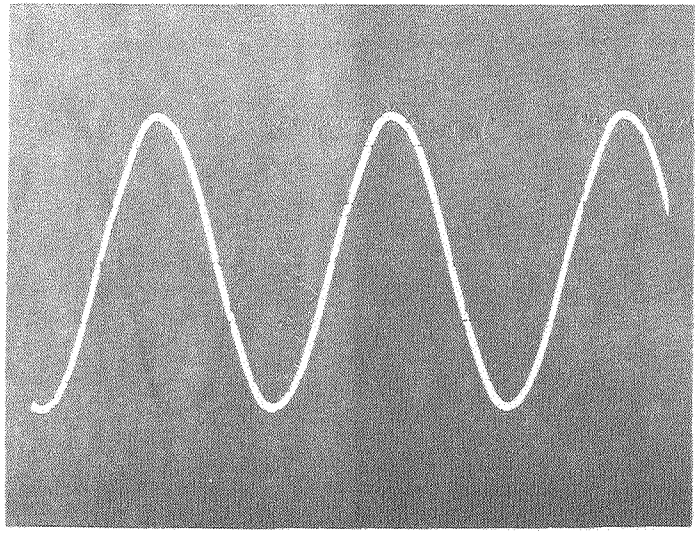


FIG. 1 XBB 8010-11582

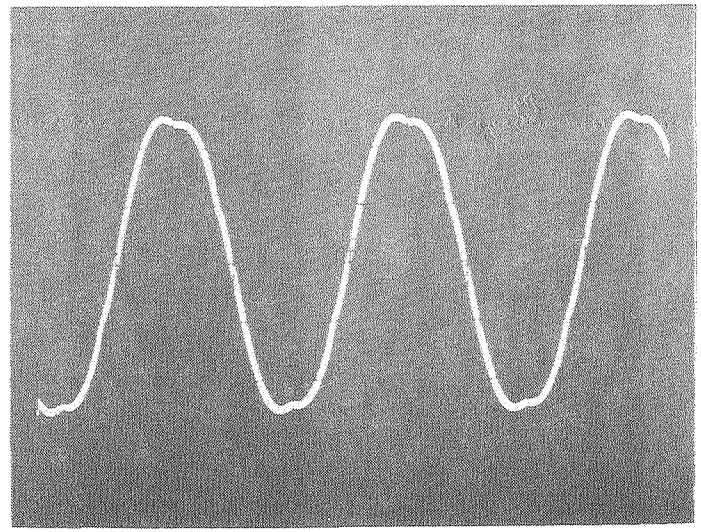


FIG. 2 XBB 8010-11583

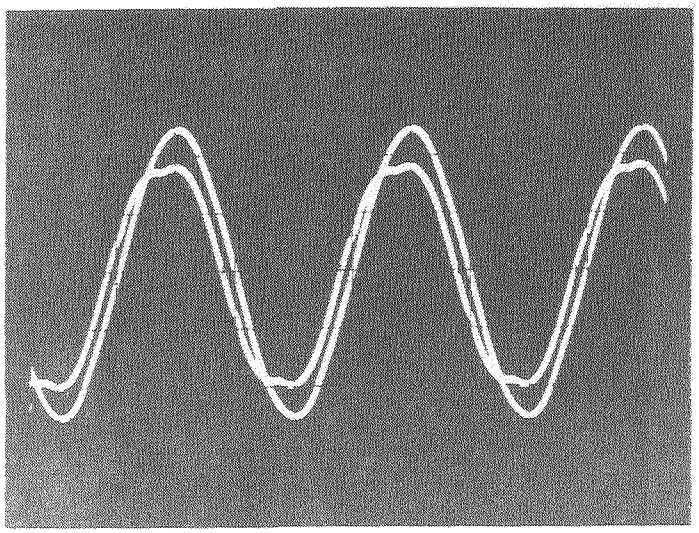


FIG. 3 XBB 8010-11584

Fig. 1. Primary Voltage, Standard Ballast

Fig. 2. Primary Current, Standard Ballast

Fig. 3. Primary Voltage and Current, showing phase angle

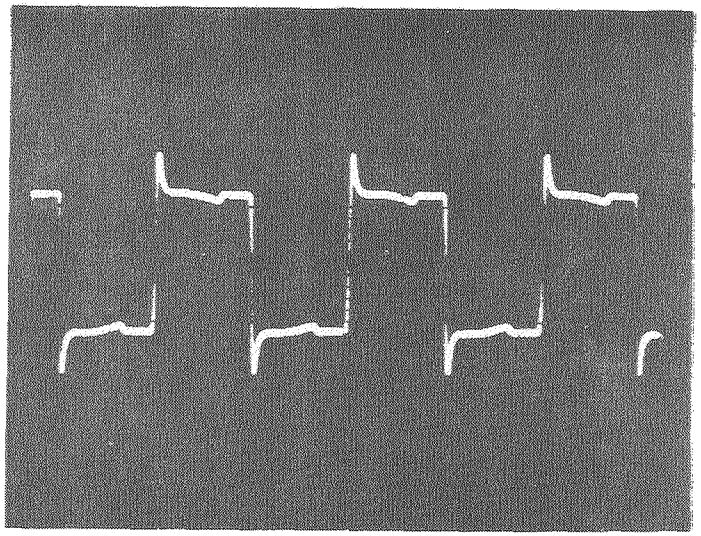


FIG. 4 XBB 8010-11585

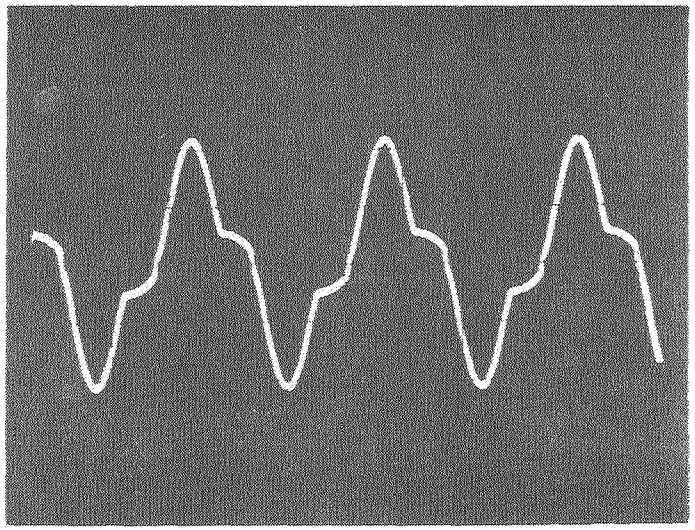


FIG. 5 XBB 8010-11586

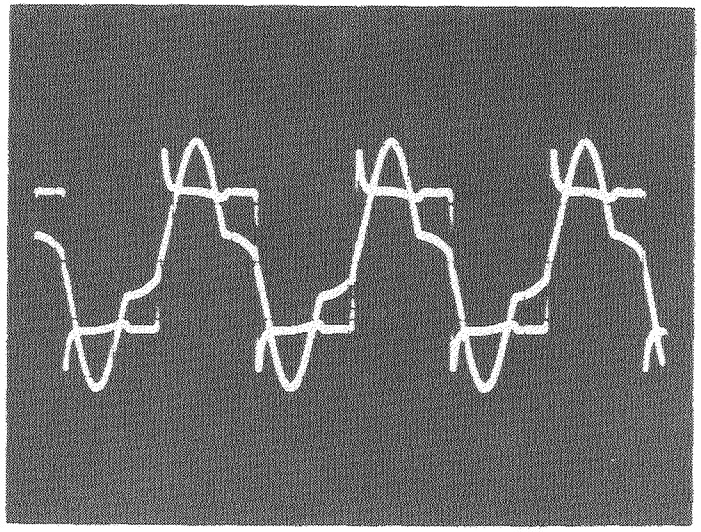


Fig. 6 XBB 8010-11587

Fig. 4. Secondary Voltage, Std. Ballast

Fig. 5. Secondary Current, Std. Ballast

Fig. 6. Secondary voltage & current, showing phase angle

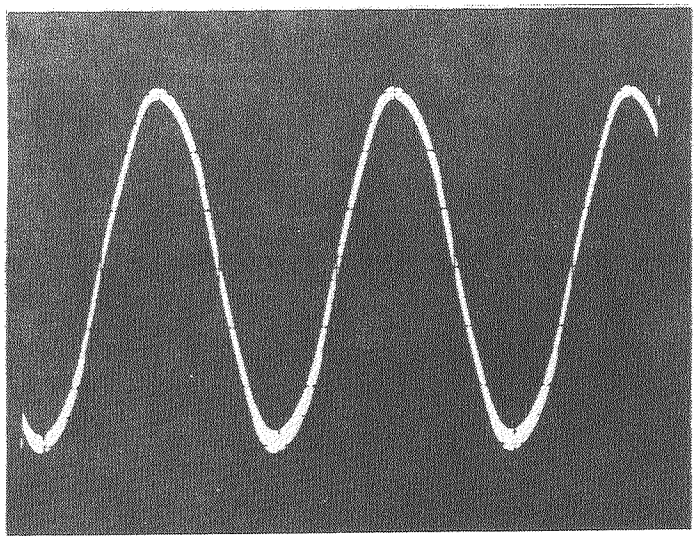


FIG. 7 XBB 8010-11588

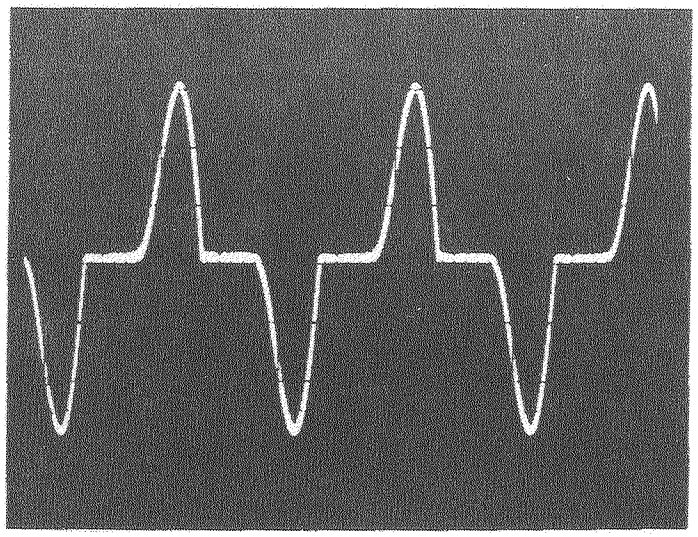


FIG. 8 XBB 8010-11589

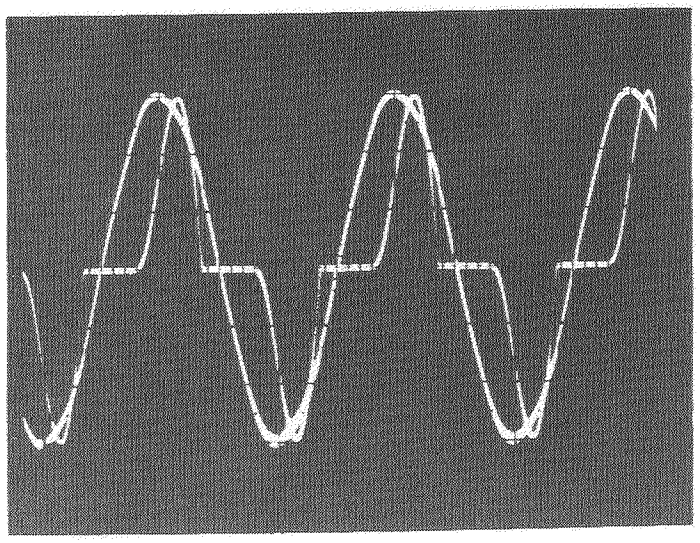


FIG. 9 XBB 8010-11590

Fig. 7. Primary Voltage, HF Ballast

Fig. 8. Primary Current, HF Ballast

Fig. 9. Primary Voltage & Current, showing phase angle

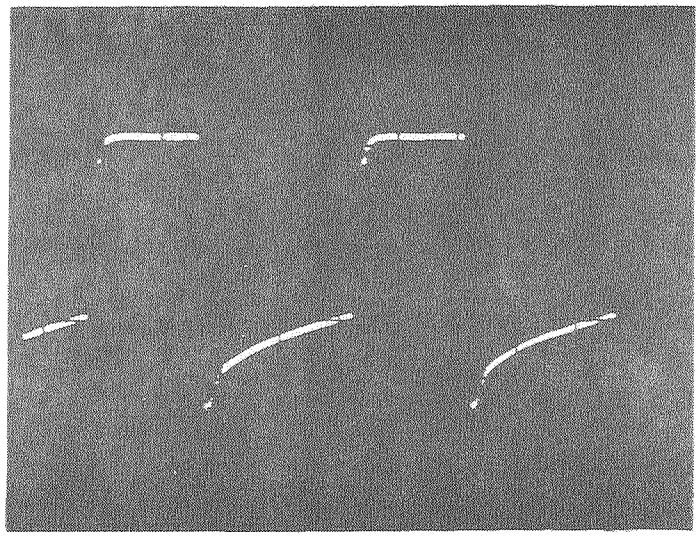


FIG. 10 XBB 8010-11591

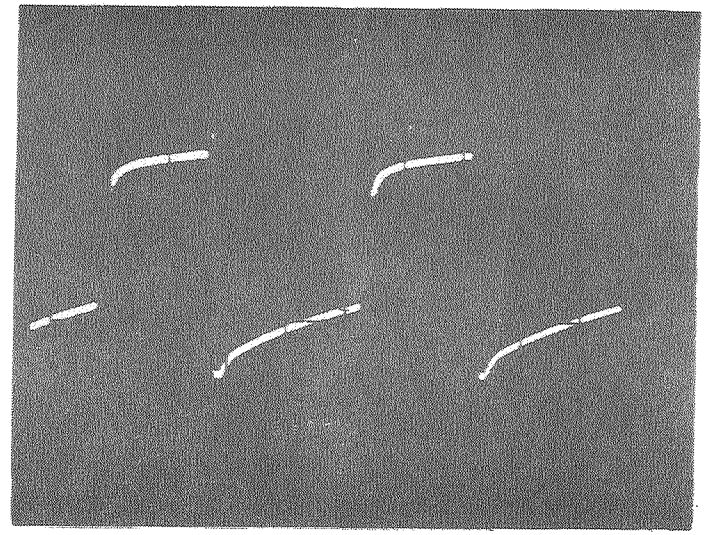


FIG. 11 XBB 8010-11592

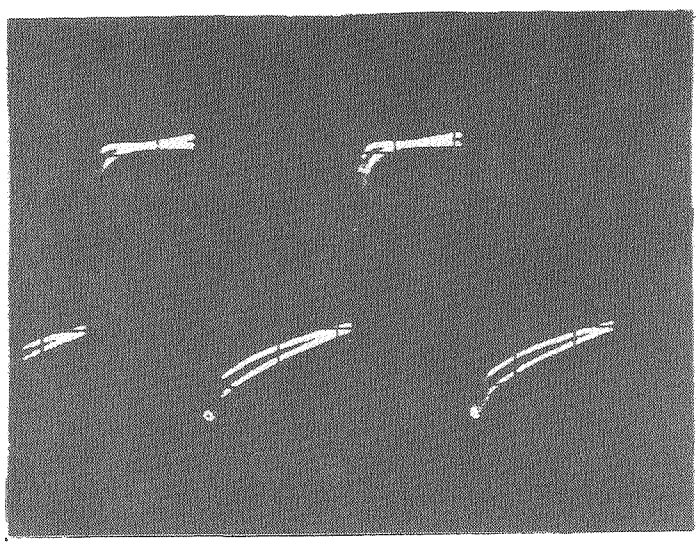
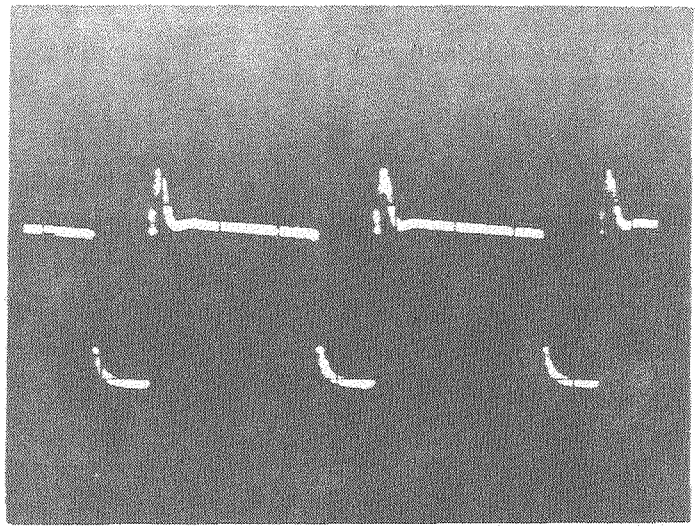


FIG. 12 XBB 8010-11593

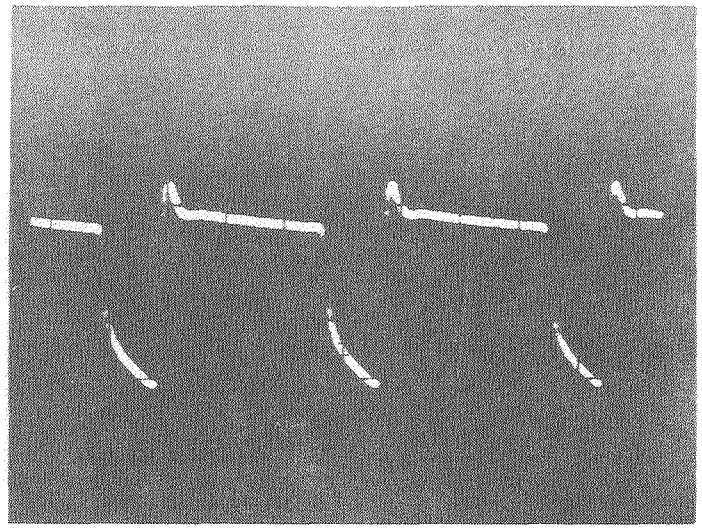
Fig. 10. Secondary Voltage, HF Ballast (22 Khz)

Fig. 11. Secondary Current, HF Ballast (22 Khz)

Fig. 12. Secondary Voltage & Current, showing phase angle

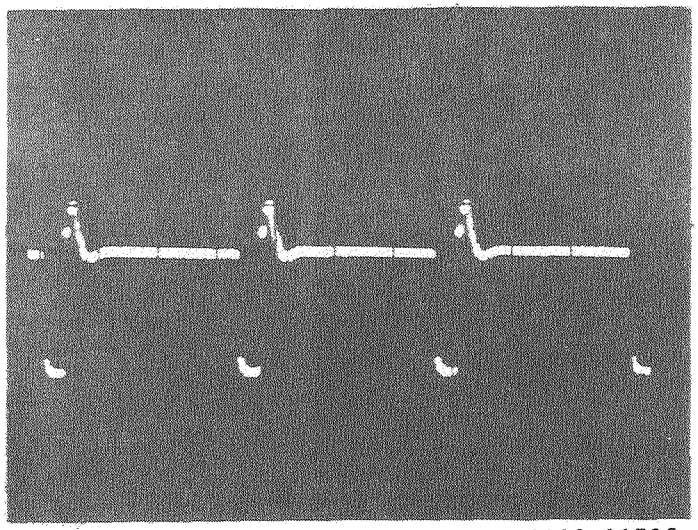


XBB 8010-11594

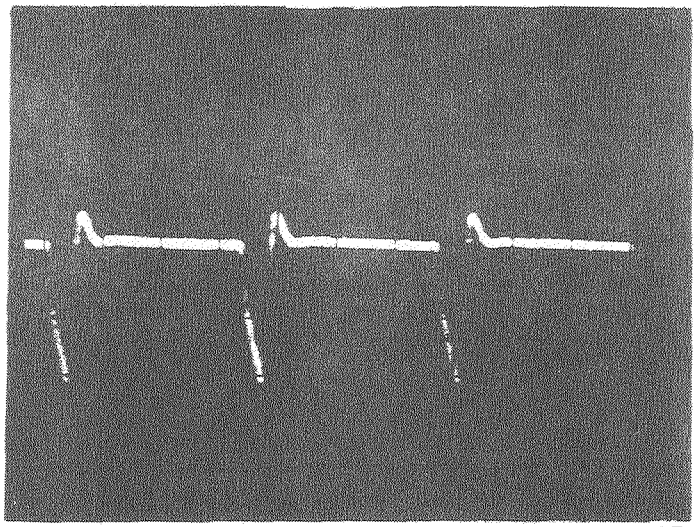


XBB 8010-11595

Fig. 13. Voltage (left) and current (right) waveforms at half dim



XBB 8010-11596



XBB 8010-11597

Fig. 14. Voltage (left) & current (right) waveforms at full dim

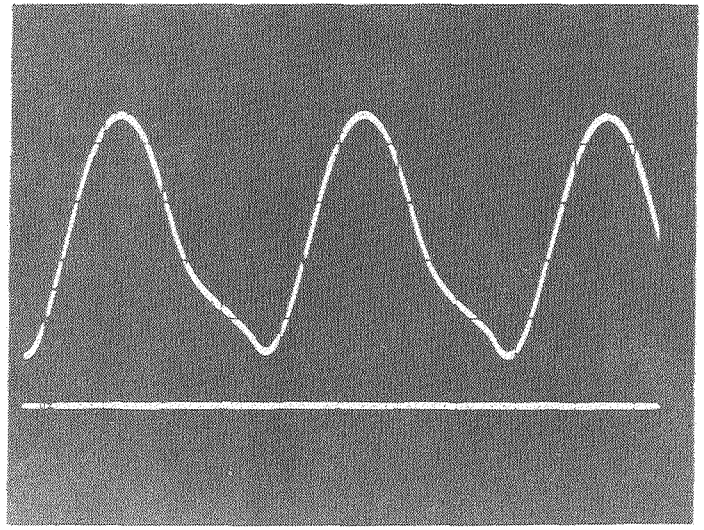


FIG. 15 XBB 8010-11598

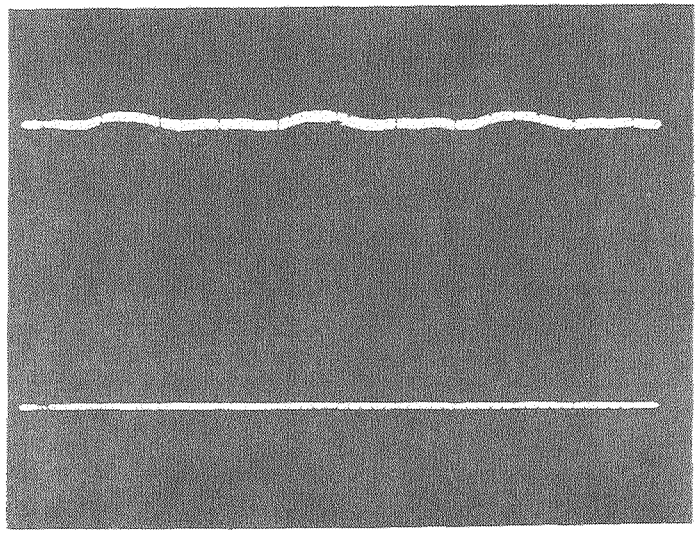


FIG. 16 XBB 8010-11599

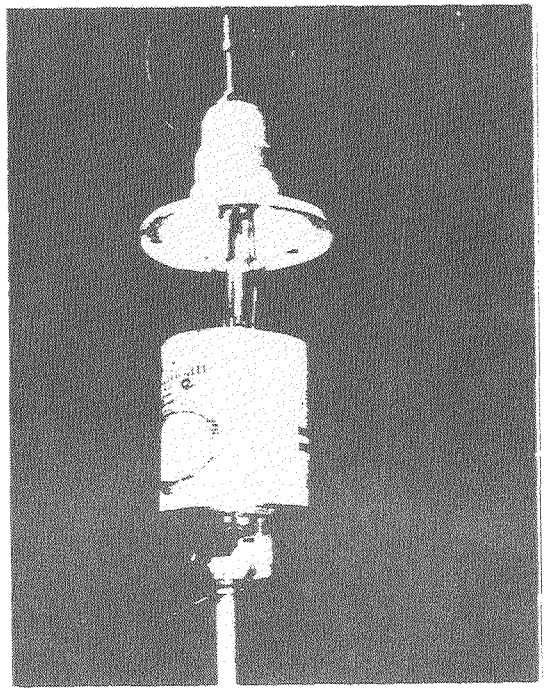


FIG. 17 XBB 8010-11600

Fig. 15. Light output waveform @ 120Hz for standard ballast

Fig. 16. Light output waveform @ 120Hz for HF ballast

Fig. 17. Method of enclosing lamp for voltage vs. wattage traverse. Can is raised and lowered to change heating conditions

LIGHTING RESEARCH LABORATORY

Design — Testing — Consulting

LAMP VOLTAGE VS. WATTAGE, OPERATION ON HF BALLAST

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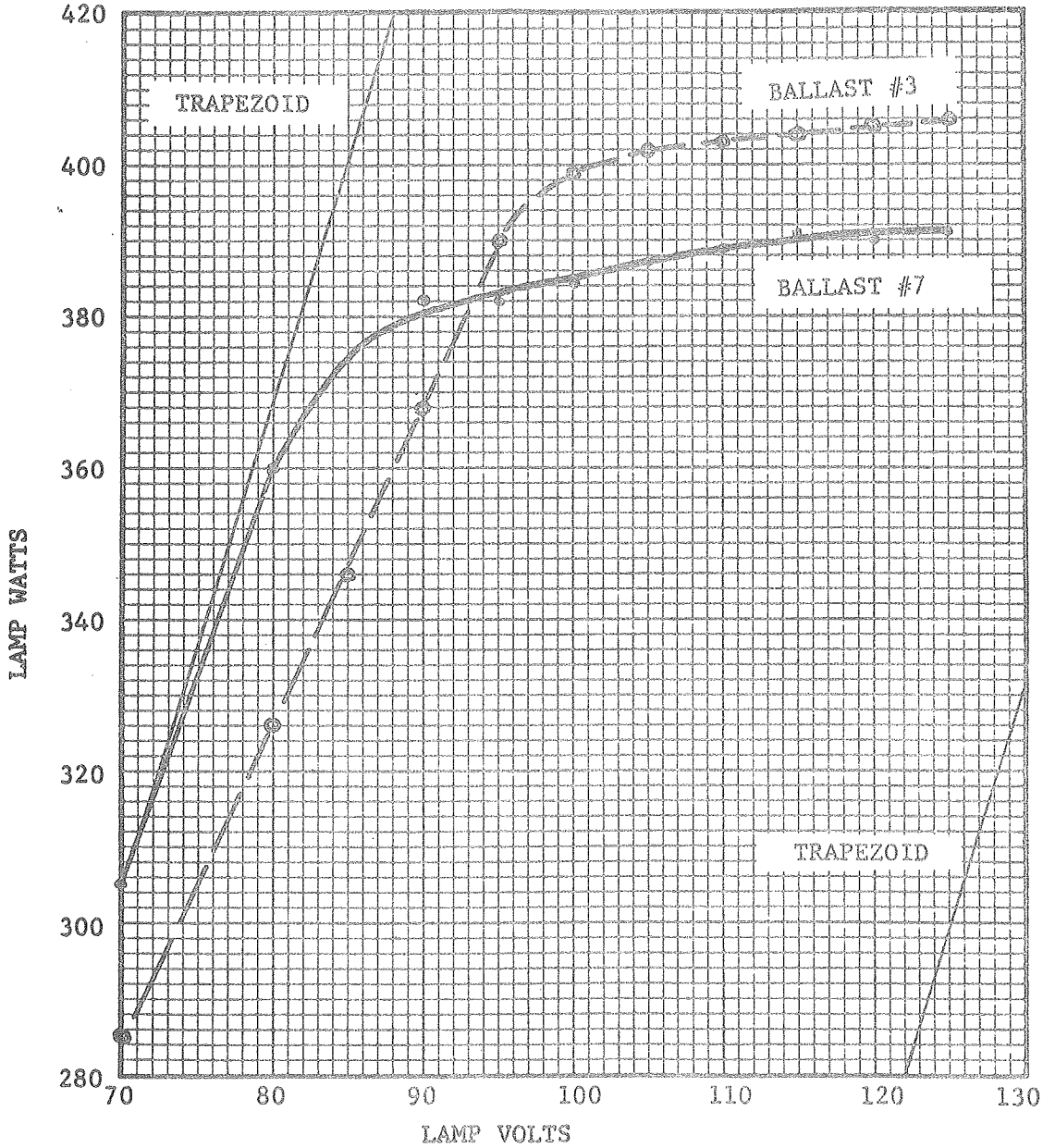
4-10-80

FIG. 18



Unless otherwise stated, all tests are performed in accordance with IES or other applicable standard procedures; are accurate within standard photometric tolerances; and are based on rated performance conditions. L.R.L. assumes no responsibility for applicability of this data to field conditions or to any sample of the luminaire other than the specific unit tested.

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