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ENERGY-EFFICIENT COMPACT SCREW-IN FLUORESCENT LAMP:

FINAL REPORT

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ABSTRACT

A compact fluorescent lamp has been designed and constructed which can replace an incandescent lamp. The lamp is slightly larger than a standard lamp (8 3/4" x 3 1/4"), but is designed to fit a majority of portable lamp applications. This version, with a core-coil ballast, results in a system efficacy of 54 lumens per watt, with a light output of more than 1800 lumens. This compares favorably with a 100-watt incandescent (17.5 lumens per watt and 1750 lumens light output). The color temperature of 3000 °K is compatible with an incandescent lamp (2800 °K). The color rendition index (CRI) is 84. With a solid-state ballast, the efficacy and light output could be increased by 20% (65 l/w, 2200 lumens) and could provide a direct replacement for a three-way, 150-watt incandescent lamp (15 l/w, 2200 lumens).

ACKNOWLEDGEMENT

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2.0 INTRODUCTION

In the United States, lighting consumes about 20 percent of all electricity generated, or five percent of the total energy consumed. With increased and proper usage of new, more efficient lamps, fixtures and ballasts, the nation's electricity requirement could be reduced 40 percent. The country would then save about 385 million kilowatt hours of electricity per day, or the equivalent of 700,000 barrels of oil per day.

A Westinghouse study indicates the potential savings for commercial facilities could be even greater than 385 million kilowatts/day. Department stores, offices, apartment complexes and other commercial buildings spend an average of 42 percent of their total electric budgets on lighting. Industry's lighting load is about 11 percent of total electricity costs. In the residential sector, lighting represents 16% of all electrical costs.

Government and industrial-commercial users are assumed to require a minimum of promotion and education regarding purchase and use of energy-efficient light bulbs. However, to promote the use of energy-efficient bulbs to residential users, we believe we have to confront not so much the conscious and rational, as the <u>unconscious</u> and <u>prejudicial</u>.

To do this, we shall have to rethink at least a few of the basics that may have been taken for granted. We must re-educate the consumer.

For instance, the consumer preceives fluorescent as a source for lighting <u>things</u>; incandescent is for lighting <u>people</u>. It is an uphill struggle to try to re-educate the consumer regarding this basic difference of perception between the two types of lighting. Moreover, we have observed that to say fluorescent is to say utilitarian, whereas when we say incandescent, we say environmental. Fluorescent is viewed as a utilitarian type of light for practical use where atmosphere is of no concern; incandescent is the preferred light source to comfortably illuminate our living environment.

The compact fluorescent is an alternative that can meld the appearance and convenience of incandescent with the efficiencies of fluorescent.

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4.0 TECHNICAL DISCUSSION

This report has its basis in the on-going program at the Westinghouse Lamp Business Unit to develop a compact energy-efficient lamp unit that is self-ballasted and fitted with a medium screw base for use in the industrial-commercial and residential domains. A primary goal of the Westinghouse Energy-Efficient Light Bulb (EELB) Program is the development of and production of a cost effective means for reducing energy consumption of present lighting systems, yet maintaining and improving visual clarity.

In this technical discussion, design parameters and performance specifications are detailed, as well as, from a technological aspect, the reasons why this particular approach was taken. The current status of work is also covered.

4.1 Compact Fluorescent Lamp Unit Design

Westinghouse developed a lamp unit in which the outer diameter is 3.25 inches and the height above the base is 8.75 inches as shown in Figure 1. The lamp unit is comprised of the Edison base, the ballasting section and the lamp section.

The lamp section is made up of an outer envelope and a compact fluorescent lamp. The outer envelope is a thin glass or plastic covering made optically diffuse with an opening at the top. The envelope serves three purposes.

The diffuse surface lowers the brightness of the unit and makes the appearance of the light more uniform. The envelope offers protection to the lamp from external impact. Lastly, the envelope together with openings in the ballast section promotes cooling of the lamp and ballast.

The fluorescent lamp is shown in Figure 2. It is made of long glass tubing that has been multi-folded to form a lamp that is only 6.5 inches long. The internal surface of the bulb is coated with a "warm" phosphor blend mixed in a water-soluble lacquer system. After the bulb is baked in air to remove the binder in the phosphor coating, a conventional glass stem is sealed to each end of the bulb. Each stem has two lead wires and a (BA SR CA) CO_3 - coated tungsten coil mounted thereon. At least one of the stems will have an exhaust tubulation.

After the lamp has been coated, air baked, sealed and bent, it is evacuated; vacuum baked; the coils treated; the lamp filled with about 2.5 Torr Argon; a drop of mercury; and then it is sealed off at the tubulation. The coils are heated to convert (BA SR CA) CO_3 to (BA SR CA) O and make the coating on the electrode a good election emitter.

The lamp, as presently constructed, will produce about 1,750 lumens (optimum mercury pressure, at a cool spot temperature of about 40°C) at a correlated color temperature of about 3,000°K when operating at 375 MA and 34 Watts(system).

The lamp-ballast arrangement we propose offers significant advantages in that various phosphors from the Westinghouse three-component blend (Ultralume) to Agro, Agrolite Bug Away and warm (2,500°K) as well as cool (5,000°K) color temperature versions may be used. Therefore, this extends the range of operation into "other" areas heretofore only available to unbent tubular heavily-ballasted fluorescent lamp systems. This compact fluorescent exhibits most of the advantages of unbent tubular fluorescent lamp system such as:

a. High Efficiency:

b. Sufficient Light Output;

c. Long Life.

4.2 Ballast Design

We have undertaken two approaches in this area:

a. Inductor - Capacitor (L-C) Ballast - Through the use of a lightweight, elongated inductor in series with a low dissipation factor capacitor, we are able to provide a low-cost, physically attainable system that exhibits long life, high power factor and good efficiency. (See Figure 3.) In addition, a preheat starter (Hybrid-Solid State and Conventional Glow Switch) is used to start the lamp. The advantage of using the preheat start approach whem compared to the rapid start mode is the attendant savings in the energy when cathodes are not heated continuously (e.g., at 3.6 V and 360 MA, this amounts to approximately 1 Watt per cathode or 2

Watts per system of lost energy). The voltage doubler circuit, C1, C2, D1, D2 and R2 provides the initial voltage to break down the glow starter and initiate the heat rise necessary for closure of the glow bulb bimetalic electrodes. This causes preheat current to flow through the lamp coils. When the starter electrodes open, an over voltage pulse of approximately 500V. starts the lamp and the waveforms shown in Figures 4 and 5 result. Moreover, Figure 6 shows the spectral power distribution and Table 2 details <u>typical</u> operating <u>parameters</u>.

b. <u>Solid State High Frequency Ballast</u> - This approach is currently being developed to operate the multi-folded lamp. This approach will further reduce the system weight. However, areas that require investigation associated with this approach are RFI and EMI, as well as component reliability versus overall ballast cost.

5.0 ENERGY EFFICIENT LIGHT BULB SPECIFICATIONS

a. Input Voltage - Our units have been designed to operate reliably throughout the 120 + 5%, -10% voltage range.

b. Frequency - The lamp ballast system is designed for operation on 60 HZ; but the system can be readily adapted for operation at 50 HZ, if desired, by appropriate changes in capacitor design and inductor windings.

c. Power Factor - We have obtained readings in excess of 75% capacitive using the L-C Approach. Since this is capacitive and "most" loads are reactive, a "built-in" plant/building power factor corrector can be obtained by using this unit.

d. Initial Light Output - Our unit has delivered 1,750 Lumens at 120 V input after 100 hours burn in for the initial samples.

e. Lumen Maintenance - Our initial results indicate that maintenance should be approximately 75% at rated life of 10,000 hours.

f. Lamp Life - We are predicting lamp life of 10,000 plus hours based on our experience with long narrow fluorescent lamps under various loading conditions and cathode designs.

g. Ballast Life - The L-C Ballast should bave a life in excess of 20,000 hours based on our testing to date. We have tested a few of the lightweight low dissipation factor capacitors for approximately two years on a three-hour on, 20-minute off cycle test with no capacitor failures. The Hybrid starter will last more than 20,000 hours at a rate of 7 starts/day.

A solid state high frequency ballast should last approximately 25,000 hours based on the life of the capacitive components in the circuit and will also be a function of transistor-heatsink thermal characteristics.

h. Color Temperature - We have the ability to produce a variety of color temperatures and phosphor blends. However, as a replacement for the incandescent lamp, it is felt that 3,000°K ±200 is the ideal color temperature and to that end we have developed a phosphor blend that we feel not only delivers this color temperature, but does so with a reasonable color-rendering characteristic.

i. CRI - With our new phosphor blend we are at present measuring 84 CRI and 99 CPI.

j. System Efficacy - We are presently accomplishing 53 LPW at 120V input. However, through improvements in ballast efficiency (e.g., high frequency solid state), we feel that a 60+ efficacy system is attainable.

k. Regulation - The L-C circuit has demonstrated superior regulation ±15%.

5.1 Physical Size

a. Base - Medium Screw

b. Size Diameter - Maximum diameter is 3.25 inches.

c. <u>Length</u> - 8.75 inches. The advantages resulting from the use of this system are the increase in lamp life, as well as a cool (to touch) unit that does not cause injury to skin because of lamp ballast heat.

d. <u>Weight</u> - The unit weighs 22 ounces.

e. <u>Base Temperature</u> - The base temperature of our device is less than 55°C for the L-C circuit.

f. <u>Operating Position-Any</u> - We are stating any operating position. Limited testing indicates starting and operation appears to be good at 90° and 270° burning positions, however we recommend, in these positions, that outer envelope be removed.

g. <u>Audible Noise</u> - Class A.

h. <u>Radio Frequency Interference</u> - The L-C circuit does not display any RFI. However, the high frequency solid state does. Our tests to date, though, indicate that at 10 feet away, only the most sensitive receiver can pick up and detect signals from our light source when it is high frequency ballasted.

6.0 FUTURE DEVELOPMENT WORK

In order to complete the development of the compact lamp system to the LBL Lamp Performance Specification Targets, and to the point of commercialization, an additional 10 to 12-month Phase II Program will be required. The primary objectives of this program would be to resolve the remaining technical problems in compact fluorescent lamp and ballast development, to fabricate and deliver to LBL a number of engineering prototype Energy Efficient Light Bulbs for testing, evaluation and demonstration by LBL, and to submit to LBL a manufacturing plan for large-volume production of the Energy Efficient Light Bulb and one or more demonstration plans for a large-scale installation of Energy Efficient Light Bulb.

In order to complete the development program the following Tasks have been identified:

a. Complete the development of a compact fluorescent (low pressure) discharge lamp that will deliver at least 2,200 lumens light output with an overall efficacy $\geq$ 50 lumens/Watt.

(1) Optimize lamp design parameters for maximum light output, luminous efficacy, and reduced size.

(2) Optimize the mode of lamp operation for maximum light output and luminous efficacy of the compact fluorescent lamp system (including ballast).

(3) Determine lifetime of compact fluorescent lamps in relation to 10,000-hour specification target.

(4) Determine lamp lumen maintenance at rated life in relation to specification target of $\geq$ 80%.

(5) Evaluate the effect of burning position on heat management requirements and on lamp system operation, and develop a compact fluorescent lamp system that will burn in any position.

(6) Determine compact lamp system RFI compliance with FCC Specifications and compatability with radio and TV reception when operating on a solid state high-frequency ballast.

(7) Establish trade-offs available between color and color rendition and other lamp characteristics such as efficacy, light output, lumen maintenance and lamp cost.

b. Complete the development of a high efficiency, miniaturized, reliable, solid state ballast (or drive circuit) for compact fluorescent lamps.

(1) Obtain or develop power transistors for a high-efficiency ballast-transistors with a high breakdown voltage rating, fast switching times, and low saturation losses (the latter two items to minimize power losses), that is also cost effective.

(2) Investigate the possibility of reducing the size or eliminating entirely the electrolytic-smoothing

capacitor from the ballast circuit. If the capacitor cannot be eliminated, select a low cost capacitor which can be rated at 15,000-hour lifetime.

(3) Obtain or develop an integrated circuit containing as much of the ballast circuitry as is feasible.

(4) Conduct a study of heat management versus heatsink and package size in the solid state ballast, and determine the minimum ballast size.

Westinghouse will provide the necessary engineering assessment of materials, material costs, testing of materials, testing of components and systems, and the quality assurance of components, materials and system to assure that the units delivered would be safe to handle, be uniform in performance and physical appearance, and will operate with a low probability of failure during testing and small scale demonstration.

All ballast components and materials will be tested by Westinghouse for compliance to the purchase specifications, to the extent necessary to assure high quality in the assembled ballast units.

All ballast units will be tested by Westinghouse for the following requirements:

(1) All units will be electrically safe to handle while operating.

(2) All units will have approximately the same performance.

7.0 SUMMARY

A compact fluorescent double-fold lamp has been described in terms of concept, construction and operation. The lamp unit has been operated at an overall circuit efficacy of 53 LPW, more than 3.1 times the efficacy of the 100W incandescent lamp. This Energy Efficient Light Bulb is designed for application primarily in industrial, commercial and government installations. Its high efficacy and compact size allows it to be used in stairwells, ceiling fixtures, globular fixtures, table lamps with harps 12" or greater, wall sconces and other incandescent sockets.

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4. W. J. Roche, "Theory, Design and Application of Single-Socket Single-Electrode Fluorescent Lamps," Journal of the IES, Vol. 3, No. 1, October 1973, p. 65.

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TABLE I

LIGHTING AS PERCENTAGE OF ELECTRICAL CONSUMPTION BY SECTOR

		Oil (Bbls./Day)
Residential	16%	433,000
Commercial	42%	805,000
Industrial	11.5%	446,000
Street/Highway	100%	65,000
		1,759,000

TABLE 2

COMPACT FLUORESCENT LAMP DATA

LAMP #	V (VOLTS)	I (MA)	W WATTS	L (ZERO HOUR) LUMENS	LPW
#2	120	378	34.4	1840	53.5
#1	"	376	34.8	1813	52.1
#7a	"	370	33.5	1812	54.1

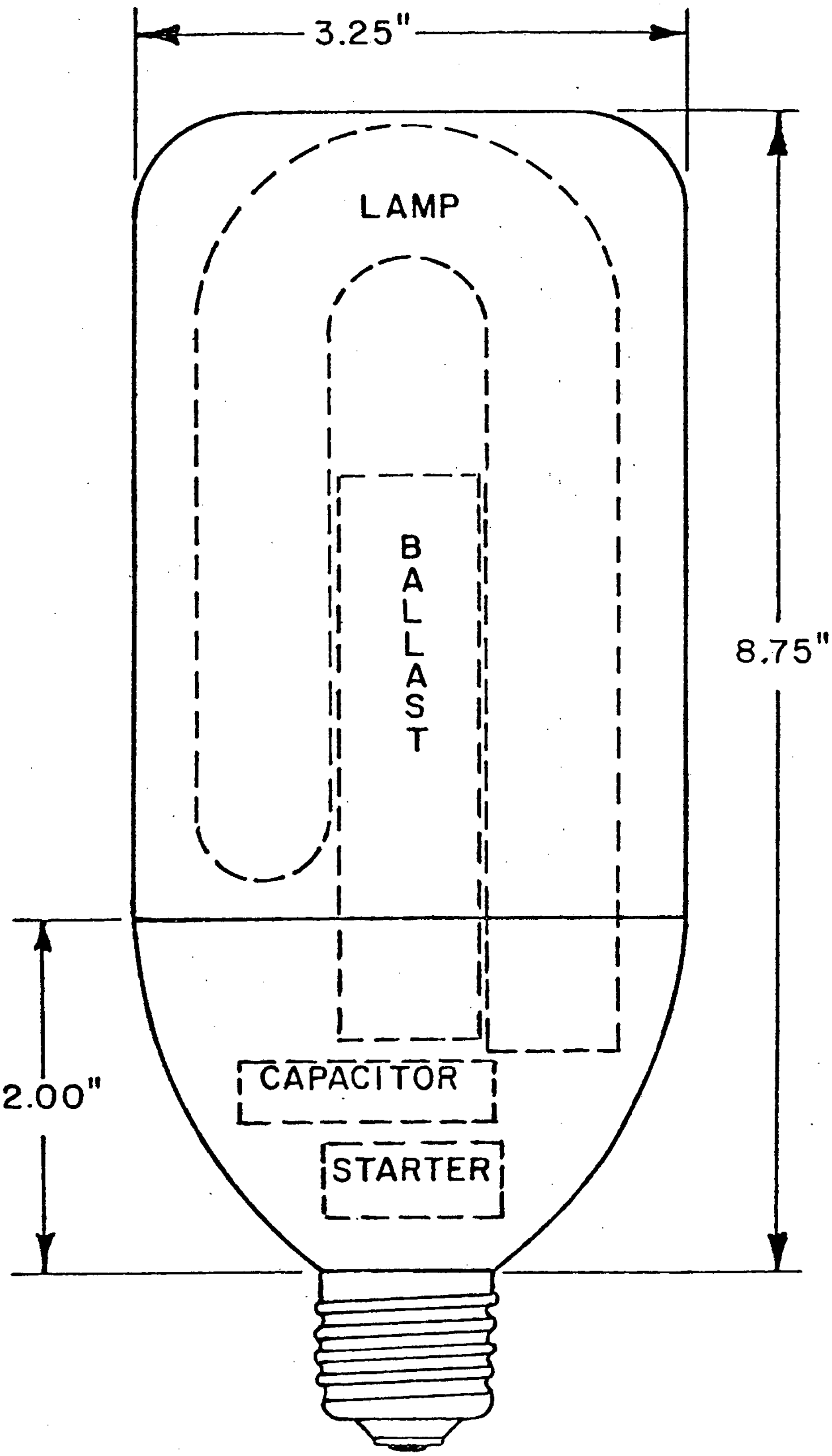


Figure 1 LAMP-BALLAST WITH L-C BALLAST

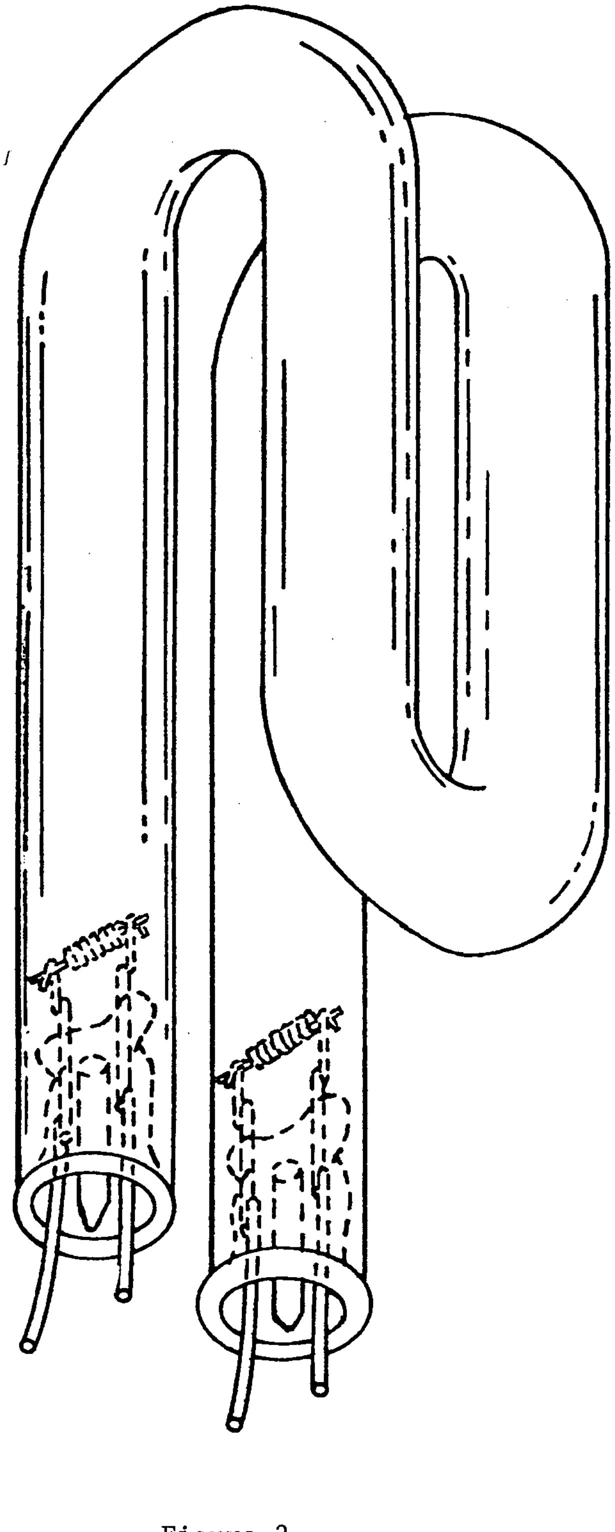


Figure 2

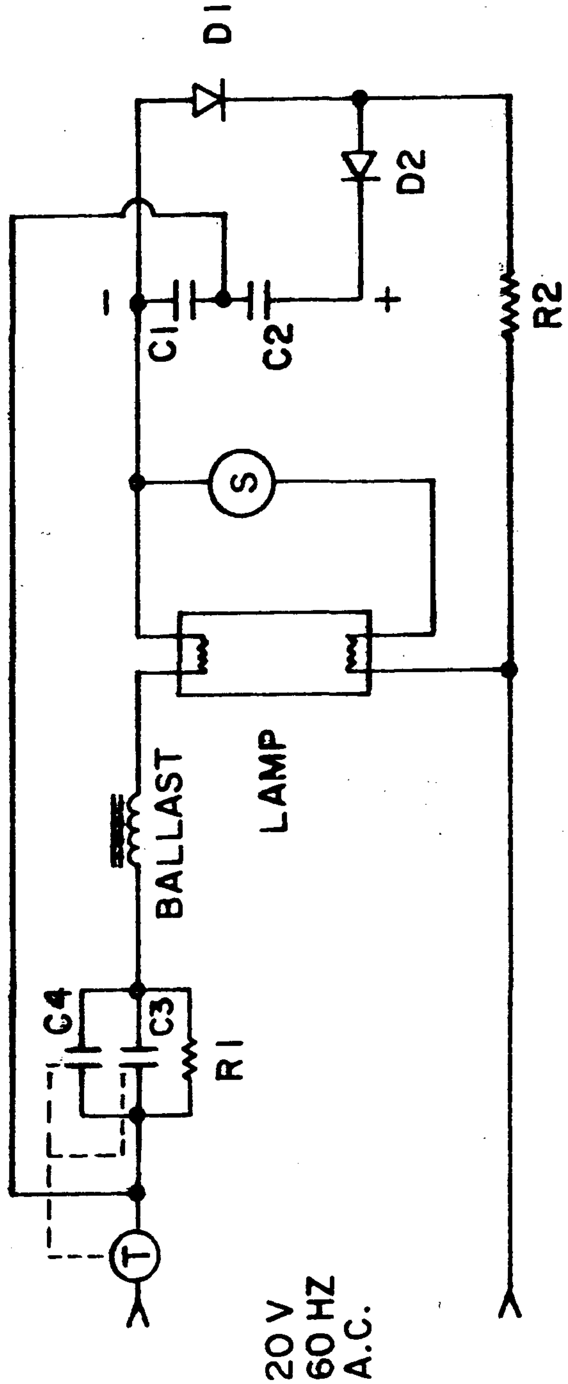
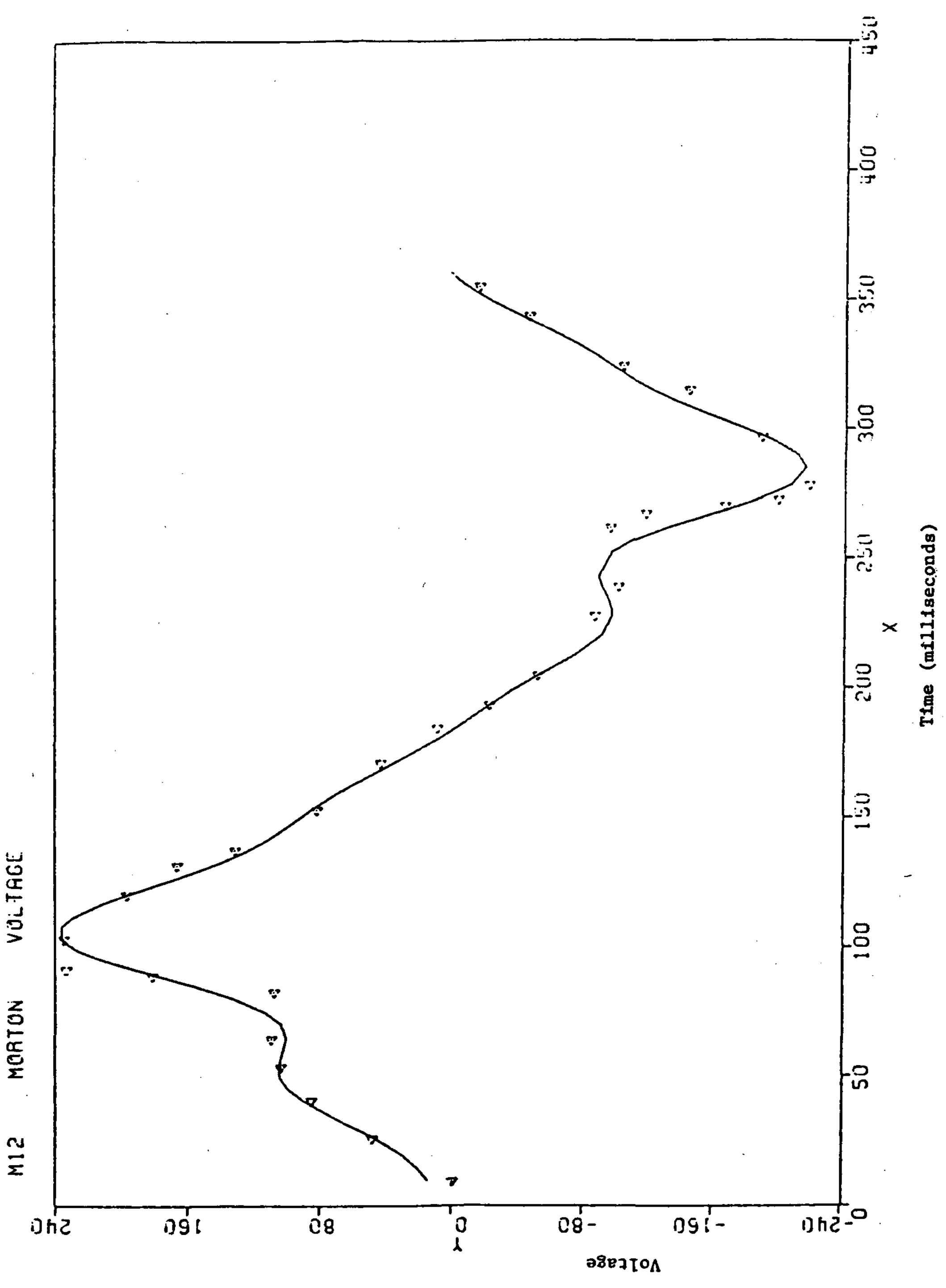


Figure 3


M12 MORTON VOLTAGE
Voltage
Y
240
160
80
0
-80
-160
-240
X
Time (milliseconds)
0
50
100
150
200
250
300
350
400
450

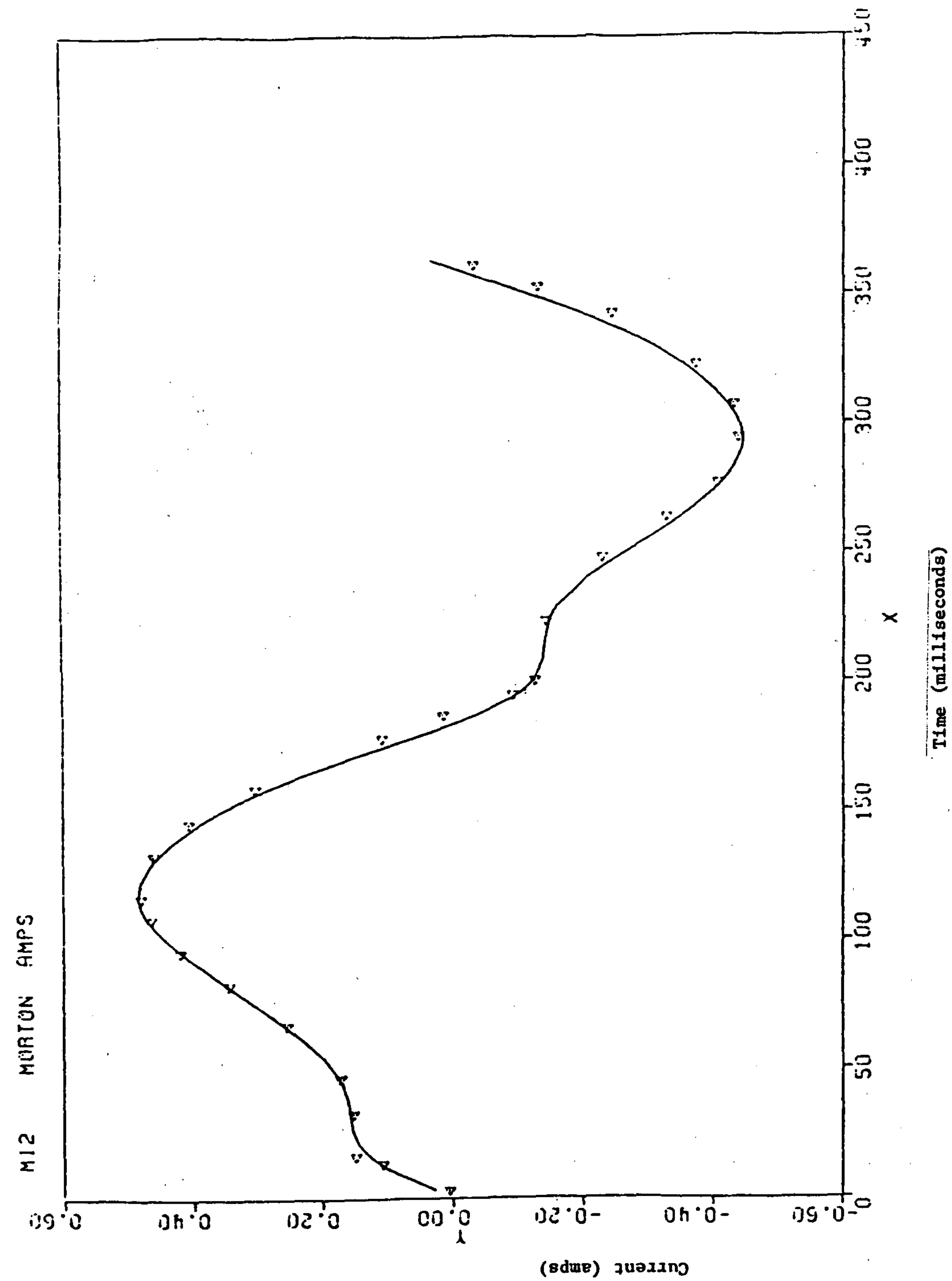

M12 MORTON AMPS
Current (amps)
Y
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
X
Time (milliseconds)
0
50
100
150
200
250
300
350
400
450

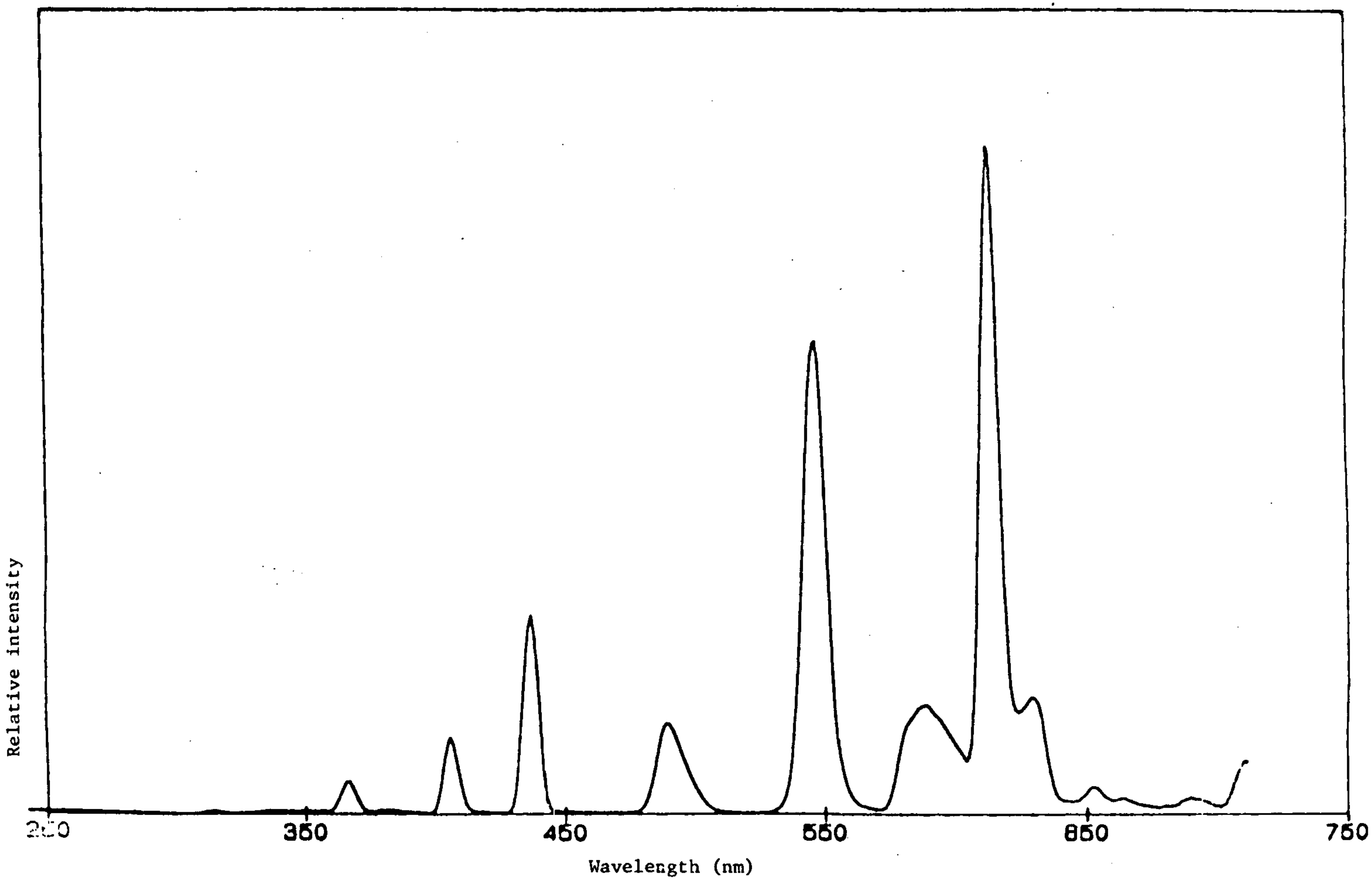
Figure 5

FOLDED LP #1 120.0V 34.85W .384A 820PMV S031002 1882

X= .4585 Y= .415 LBAR= 572.7 ETA= .502 LUMENS=

U= .2803 V= .3527 CCT= 2738 K BETA= WATTS OUT=

CRI= 84.41 G= 52.1 CPI= 98.85 LPW=



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