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Phase I Final Report
Subcontract No. 2019702
"Energy Efficient Fluorescent Ballasts"

Stevens Luminoptics Corporation

June 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 I FINAL REPORT
SUBCONTRACT NO. 2019702
"ENERGY EFFICIENT FLUORESCENT BALLASTS"

SUBMITTED TO

Lawrence Berkeley Labratory
University of California
Berkeley, California

PREPARED BY

Stevens Luminoptics Corporation
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DATE SUBMITTED

June 21, 1978

This work was done with support from the U.S. Department of Energy

FORWARD

Stevens Luminoptics Corporation is pleased to submit the following report on their efforts to commercialize a fluorescent electronic ballast for widespread commercial application. The results are most promising and indicate that continued work in this area is justified.

Stevens can proudly point to a number of areas, of concern to all, where we believe we have been successful. The thrust and direction of the program is exciting in terms of it's benefit and potential as an energy conservation tool.

While Government funding has accounted for less than 8% of Stevens overall effort to date, it has been Government interest in the project which has allowed this accelerated commercial development work to progress. One measure of the program's effect to date has been the concentration of effort by the existing conventional ballast manufacturers to develop more energy efficient coil and core ballasts. From this standpoint alone the program has been worthwhile and the Government must be commended.

The Stevens ballast has been demonstrated to have the potential of conserving significantly more energy than the best conventional coil and core ballast while providing superior performance features not possible with conventional technology. Our projections indicate that at least 50% of the energy used for commercial and industrial lighting can be saved if the Stevens approach is implemented.

The larger question is implementation and remains unanswered. The Government could play a key role in this most worthwhile energy conservation program if it desires.

As reports of this nature tend to be quite technical, dull and boring, the following page is a reprint from the popular press which describes the program in more interesting non technical terms and is intended for those readers who may not wish to digest the whole report.
Permission was obtained from The Valley Pioneer to reproduce the article.

Second section

THE Valley Pioneer

★GENERAL NEWS
★FEATURES

Invention of Danville's Steve Stevens

Future looks bright for new light

by Kitty Chism

If Danville resident C.R. "Steve" Stevens has his way, every fluorescent light in America will one day be equipped with a device he has designed to make these lights run more efficiently.

If his dream becomes a reality, it could mean a 50 to 75 percent savings in this country's power bill for light.

The 46-year-old physicist and president of Stevens Luminoptics has come up with a new kind of "ballast" — that gadget inside every fluorescent light fixture that controls the current entering the bulbs.

But Stevens didn't stop there. He designed his ballast with a previously impossible feature for fluorescent lighting. He provided it with a full range dimming capability.

The dimming can be achieved manually or automatically in response to a light sensitive photo cell installed on the fixture. Used properly, this feature itself can mean a potential power savings of 25 percent.

The revolutionary new ballast is housed in a narrow eight-inch-long black metal box, exactly the same size as conventional ballasts. That makes the Stevens ballast easy to fit into any of the 600 million fluorescent lights in this country today.

It means the end to the annoying hum and flicker

Unlike the conventional copper wound "core" ballast, the Stevens ballast is "electronic." What his 170 solid state components can do is convert standard electrical power into a special high frequency current, 50,000 pulses per second as opposed to a conventional ballast's 120 current pulses per second.

High frequency current in this case means greater efficiency. As much as 35 percent more light is achieved from the same power. It also means the end to the annoying hum and flicker associated with fluorescent lighting, and it may even double the life of the fluorescent bulbs.

It is neither the largest nor the most complex of the many inventions Stevens has conceived over the years. But except for the first computerized traffic control system he developed in his garage a few years ago, the little lightweight ballast may well have the broadest ramifications on the world and market today.

Much will depend on a test soon to be conducted in San Francisco.

With $140,000 in matching funds from the U.S. Energy Research and Development Administration under the local management of the Lawrence Berkeley Laboratories, some 1000 prototypes of the Stevens ballast will be produced for installation on one floor of the Beale Street Pacific Gas and Electric building.

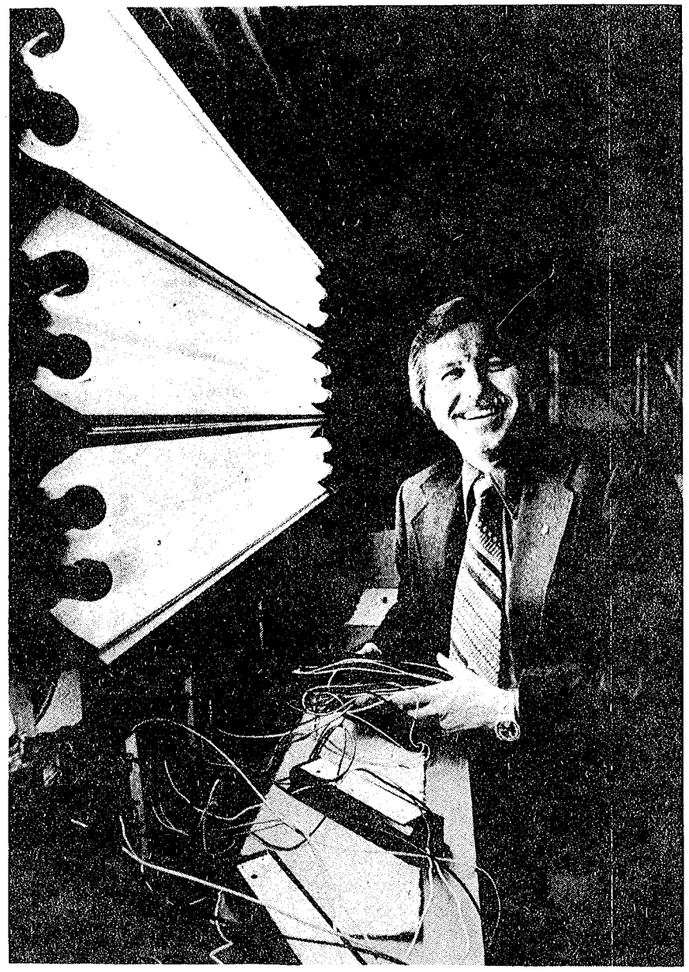

PHOTO BY R. SCOTT BOCKER

The company is already measuring the energy consumption of lights with the conventional ballast on a second floor.

Still another floor's lights will be equipped with a ballast made by Steven's only known competitor in the field, Iota Engineering of Tucson. In response to a request for proposals put out by ERDA, Iota came up with a more economical electronic ballast.

" could have a dramatic impact on waning energy sources"

But the Iota ballast doesn't have the dimming capability Stevens says can double the efficiency of his units. And, it doesn't have what Steven's executive vice president Bill Alling calls the "other break through" of the Stevens design that provides for trouble free connection with standard power lines.

The test is scheduled to begin April 1, and prototype production has already begun in the small Stevens Luminoptics location in Pleasanton.

The federal government, interested in making the technology available, has already invested in excess of $500,000 to pay for the demonstration and evaluation of the ballasts here. The appeal of the project to PG&E may lie in the stake that power companies everywhere may have in the outcome.

Since 40 percent of all the nation's lighting and almost all of the lighting used in business and industry today is fluorescent, a device that could provide a 50 percent savings in the daytime peak demand for light energy or a 15 percent savings in the country's total electrical energy demand each day could have a dramatic impact on waning energy resources.

The stumbling block may well be in convincing people to go to the trouble of making the switch. But Stevens is hopeful.

"The unit pays for itself in energy saved in from one to three years," he notes.

"The performance is such that there is a real need for it," Alling adds. "Unless it is kept off the market by existing suppliers or the government loses interest in the project, I am convinced that it will be the dominant ballast supplied in this country five years from now."

The obvious possibilities for the ballast's adaptation in other forms of lighting — particularly street lights and parking lot lighting — are equally exciting. Stevens had already developed prototypes for these as well.

His is ever a search for ways to do things better. With this invention behind him, the remarkable local scientist, who figured out how to put a telephone together at the age of six, is already busy thinking of new projects.

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I SUMMARY AND CONCLUSIONS

The high frequency electronic ballast is a viable product with large potential economic and other benefits, both for the end user and in terms of conserving precious energy sources. The electronic ballast reduces energy consumption for fluorescent and HID lighting without sacrifice, and has other superior performance features when compared to the conventional ballast. This program is one of the most cost effective programs in DOE in terms of energy payback and invested dollars. The ballast has the capability of reducing the base U.S. energy consumption between 1.2 and 2.5%.

Heretofore the combination of inexpensive electrical energy, high priced relatively unreliable electronic components, and the need for a technological breakthrough has discouraged the meaningful development of these energy efficient sources.

The efficiencies gained by driving fluorescent lamps with high frequency signals have been known since the end of War II. Significant work has been done by others to validate efficiency claims. The most notable effort has been undertaken by the General Electric Company (see seperate report by J. Campbell for LBL dated December 1977).

The existing "coil core" ballasts are manufactured by relatively few companies. According to U.S. Department of Commerce statistics, 58.2 million fluorescent ballasts of all types were shipped in 1972 with factory billings slightly under 400 million dollars. The fluorescent ballast market is growing at a compounded rate of 2.8%, a relatively mature market.

The most common type of fluorescent ballast, which is used in most commercial and industrial applications, is the two lamp forty watt ballast which consumes about 96 watts. The actual light or lumens produced is specified at 6,300 lumens by the lamp manufacturers with eighty watts being consumed by the lamps (two forty watt lamps equals 80 watts) and the remainder being ballast losses. The system efficiency or "efficacy", as it is called in the lighting industry, is generally stated at 60 lumens per watt (LPW) for the conventional ballast and lamps. Several conventional systems were tested by Stevens and it was learned that, in practice, wattage draw and efficacy varies significantly with line voltage, lamps, and temperature and that the published figures on the conventional system depicts the best possible set of operating conditions.

In contrast, the Stevens ballasts have displayed efficiencies in the order of 87-90 lumens per watt utilizing recently introduced, and mass marketed, high efficiency lamps. It is expected that with further engineering improvements, a fluorescent ballast can be built with efficiencies as high as 100 lumens per watt which would make fluorescent lighting as efficient as the most advance high pressure sodium systems.

Tests conducted with the conventional fluorescent ballast disclosed that as line voltage increases from rated values efficiency markedly decreases. At high line voltage and therefore high temperatures, the conventional ballast efficiency is only 50% versus almost 80% at rated voltage and temperature. The difference is in ballast losses which must be removed by air conditioning or other means which consumes additional energy. The Stevens ballast is totally regulated and draws a constant wattage over a very wide range of temperatures and voltages.

In fairness to the existing manufacturers it should be pointed out that most all of them have high efficiency ballasts on the market which consumes less power (88 watts) and run cooler. General Electric has recently introduced a very high efficiency ballast and special lamp combination which draws about 80 watts for full light output. These are impressive developments, brought about in part by this DOE program, however, the reader should be aware that with the Stevens ballast, and the new lamps, the Stevens ballast draws even less watts and the percentage efficiencies even increase somewhat. Eventually it is felt that a full light output electronic ballast, which utilize these new lamps, will be available that will draw 61-63 watts.

Of the estimated 58.2 million fluorescent ballasts shipped in 1972, approximately 42% or 24.4 million units were of the type sponsored by the DOE/LBL Phase II commercial demonstration. In addition, we estimate that there are in the neighborhood of 300 million fixtures installed which use the same type of ballast. This is a very large volume oriented marketplace.

The existing ballast business can be classified as a low technology mature industry. Current suppliers have relatively large investments in capital equipment and tooling, which most probably has been fully decreciated, and a firmly entrenched market/distribution system. There is little incentive to change especially when the change may require a radically different technology and distribution system.

The electronic ballast, by contrast, operates on an entirely different principle than the existing ballasts. While experts familiar with the electronic industry would not classify the electronic ballast as exotic or of employing "high technology", the reader should be aware that the existing ballast manufacturers are not necessarily comfortable with the technology.

A reasonable analogy, to the existing conventional ballast industry, is the watch and calculator industry. Both industries were revolutionalized by the advent of space age electronics applied to these everyday tasks. Most of the established suppliers virtually turned their backs on innovative circuits and technology until it was too late to catch up. It would appear that, based on discussions with the existing ballast manufacturers, that a similar pattern will be followed unles they are somehow motivated to take a position of leadership.

The electronic ballast has the capability to revolutionize the coil and coil ballast industry much in the same way that the watch and calculator business was changed. While the initial costs for the electronic units are, and likely will continue to be, higher, the electronic ballasts have superior performance features and will pay for themselves in reduced operating costs over a relatively short period. Like all similar changes in history, a period of transition must be planned for to educate and inform end users to this new way of doing business.

From a National needs point of view, it is thought that the electronic ballast is probably the key element in one of the most cost effective programs in DOE today. In house studies have indicated that between 1.2 and 2.8% of the Nations energy needs could be met with industrial and commercial conservation efforts utilizing these new ballasts at a cost far below other programs. Unfortunately, it appears that the combined Industry/Government investment to date and projected for the futue, will not be sufficient to exploit these possibilities to their fullest. Substantial funds will be required to finish commercialization of the ballast and to implement it's use.

The primary benefits of the Stevens Ballast are (1) it is a true retrofit device that is directly interchangeable with the conventional coil core ballast, and (2) it is dimmable over a wide and continuous range.

Of these two major benefits, the dimming feature is most significant in terms of reduced energy consumption. The dimming allows additional energy savings above the 29% obtained for full light output and makes possible overall system savings, including air conditioning, in the 60-70% range possible. Dimming provides the tool whereby the light output of a fixture, and therefore the power consumed, can be tailored to specific tasks. Each fixture becomes a "task lighting" fixture. This dimming or level of service concept can be implemented by both manual or automatic means.

From a user acceptance point of view, it is our opinion that any ballast system that produces less than a fifty percent overall savings will not find widespread acceptance and use.

There are, on the market, a number of more efficient conventional ballasts which save anywhere from 10 to 20% at approximately full light output. They are premium ballasts and require special more expensive lamps to obtain the higher savings. In addition, there are devices on the market which cut energy consumption by 33 to 50% while cutting light output at least as much. It should be noted that these savings figures published by the individual manufacturers of the devices are only vaild at one voltage input and one temperature, not a very realistic circumstance. Full evaluation should consider all reasonable ranges of operation.

The improvements to the existing technology are attempts to preserve the existing business environment and stave off the advance of the newer technology which offer some real improvements. The facts are that the electronic ballast will pay for itself much quicker than even the most ideal conventional ballasts and at the same time make a meaningful contribution to the National conservation goals.

For approximately two years prior to submitting a proposal to DOE, Stevens was in contact with every major ballast supplier with an offer to joint venture or license the electronic ballast. Our evaluation is that it is unlikely that any of the existing manufacturers are willing to make the investment to manufacturer and market the electronic ballast unless there are firm inducements to do so.

If the full potential of this program, and related lighting applications, are to be realized, the Government, as a leading purchaser of fluorescent ballasts should take the lead in procuring these vital devices for their own use thereby stimulating commercial acceptance. An alternative might be in the regulatory area by either tax incentives or penalties.

It is interesting to note that all existing ballasts could be replaced for 13.2 billion dollars plus approximately 1.3 billion annually for the new contruction and replacement market (1978 dollars). This would insure at least a 1.2% reduction in the Nation's energy requirements. In addition, there would be a decreased requirement (or a longer time frame) for added generating capacity and a decreased requirement on foreign oil sources. Approximately one half the cost and all the new or replacement costs would be saved in purchase reductions of foreign oil alone by 1985-1990.

II INTRODUCTION & BACKGROUND

In August 1976, Stevens Luminoptics Corporation submitted an unsolicited proposal to DOE/ERDA outlining a program to commercialize certain electronic products which have the potential of significantly reducing the amount of energy consumed for commercial, industrial, and residential lighting applications in the United States. The proposal was divided into three specific areas. They were: (1) Xenon technology applied to replace incandescent lighting, (2) a ballast for indoor and outdoor HID lighting, and (3) an energy efficient fluorescent lighting ballast. These three areas, each with their own distinctive applications, could be exploited to save between 2.8 to 4.5% of the projected 1995-2000 U.S. energy consumption if a comprehensive program were funded that included implementation plans.

In November 1976, Stevens received an RFP from LBL for the fluorescent ballast portion of the unsolicited proposal. Along with many others, Stevens submitted their response to the RFP on December 20, 1976. After evaluation by LBL/DOE, Stevens was one of two contractors selected to participate in the first portion of the effort.

Under the terms of the proposal and contract, work was limited to production development of the concepts and hardware demonstrated to LBL as part of the evaluation process. The goal of the program was to manufacture a certain limited number of early production fluorescent ballasts for installation at the PG&E building in San Francisco. Stevens had a previous relationship with PG&E to use their facility for a commercial demonstration and test to validate, or disprove, the value of the electronic ballast as an energy saving device. With the Government now involved, it appeared appropriate to transfer the agreement with PG&E to LBL which was done.

The program experienced technical delays almost from the start. The two most significant problem areas were component selection and packaging. The present Stevens ballast employs over 160 discrete components (which will be reduced to under 20 with integration). Because of the sheer volume of parts, problems were encountered trying to package them into the can configuration needed. The component qualification task proved to be most difficult in that it was learned that published data for the individual components, in many instances, couldn't be relied upon. The prototype ballasts built prior to entering into the contract were built with a considerable number of factory samples which was learned were hand picked to meet the manufacturer's own specifications.

For instance, output transisters were found to have very wide tolerances in switching times and voltage characteristics when purchased in production quantities. In one case one lot of power transisters had less than a three percent yield when tested to the manufacturers own specification.

At least ten different manufacturers devices were tested and evaluated. It was common to find components and small sample lots that would meet the specification only to find when the first order came in, that there were wide, and unacceptable, tolerances. In every instance Stevens met with factory personnel and were assured that devices would be available but not within the time frame of this program. A slow time consuming process of weeding was necessary before devices could be qualified for the application which accounted for considerable delay.

Similar problems were encountered with IC's used in the Stevens design. Because Stevens is a small company without large financial resources, they were forced to deal through local distributors instead of directly with the factory. A problem developed with the IC which was almost impossible to test for outside the circuit. Upon contacting the factory Stevens was told that the ICs shipped from the distributor were indeed defective and that the manufacturer thought they had all been recalled from stock and replaced with redesigned units. Unfortunately recalls take time, and while the factory made good on the defective chips, the schedule was impacted.

Other problems encountered were in the area of magnetics manufacture. Because of the limited nature of the program it was not feasible to have magnetics manufactured by others and still attempt to keep to the schedule. A special Litz wire winding jig was constructed and coils manufactured in-house. Winding the magnetics with relatively little experience in this specialized field proved disappointing. The decision was finally made to purchase custom magnetics from a large international Corporation, however, the delivery times were quite long which also stretched the schedule.

These are representative samples of the types of problems encountered. A more definative essay is contained in Section IV.

The results of the Stevens efforts have been most worthwile and the Government must be commended for their efforts to study this most important conservation tool. Without their interest and effort it is doubtful that the electronic ballast would be in a position to contribute to the Nation's benefit for many additional years.

Stevens does not wish to understate the magnitude of the tasks remaining before the electronic ballast can find widespread acceptance and use. Considerable resources will have to be allocated to finish the product so that it will be cost effective when mass produced and meet all the required codes including ANSI and UL.

Assuming the Phase II tests go well and no unexpected problems crop up which would prevent the ballast from becomming commercially viable, the problem of gaining market acceptance must be addressed along with finding companies with sufficient resources to manufacture the device. The market is too vast and the financial requirements too high for Stevens Luminoptics Corporation to make a meaningful contribution in a reasonable time frame.

The Government can play a leading role in speeding up the commercialization process without interfering with normal market forces. By definition, the Government is a large user of fluorescent ballasts and could sponsor production in sufficient numbers to speed up commercial acceptance. Similar precedents have occurred with the development and purchase of the jet aircraft and the integrated circuit, whereby, early development and production was fostered by DOD and NASA to meet legitimate requirements. This allowed the product(s) to be manufactured in sufficient quantities to bring the unit costs down to the point where the products were commercially acceptable.

If the Government takes the lead and purchases large quantities of the Stevens fluorescent ballast, there are a number of large very stable companies that would be willing to manufacture the ballasts against the security of a Government order. In this regard Stevens assures the Government that they will license the technology to interested and qualified companies.

III CONTRACT WORK STATEMENT

The contract between Stevens Luminoptics and U.C. Lawrence Berkeley Labratory called for the accomplishment of certain tasks. The language of the contract work statement is reproduced here to give the reader a plane of reference when reviewing this report. The tasks are arranged in functional sequence.

TASK I

Proram Work Plan - Submit within ten days of execution of a contract a detailed program plan for review and approval which indicates for Tasks II through V, allocation of financial and personnel resources, timing of principle events, program management plan, technical approach, and other items of direct relevance to timely and successful accomplishment of the program objectives. The contractor shall not proceed with Task II or beyond until this plan is approved by the LBL program manager. Significant changes to the plan require the approval of the LBL program manager.

TASK IA

Submit work plan of events and milestones which must be completed to participate in the demonstration. Consider only the development of the 277 volt ballast.

TASK II

Performance Specifications - Define performance specifications for preproduction models of energy efficient ballasts/light sources which include, but are not limited to the following parameters: 1) light output; 2) spectral composition; 3) power input; 4) lifetime; 5) reliability; 6) interaction with building systems; 7) environmental factors; 8) health and safety; 9) emergency lighting capability; 10) provision for local and remote dimming. These specifications should be developed in consultation with various national product testing and certification organizations whose approval will be necessary if the product is to be successfully marketed.

TASK III

Demonstration Plan - Develop a detailed proposed approach for the demonstration phase of the program. The demonstration plan shall include, but is not limited to the following: 1) composition of demonstration team; 2) specific building choice and letter of agreement from building owner/operator; 3) type and number of installations (number of ballasts for retrofit and new applications); 4) contractor installation proceedures; 5) experimental plan and required instrumentation; 6) provision for removal of ballasts. It is essential that the installation design and associated experimental program demonstrates and records results from the full range of ballast capabilities.

TASK IV — Deliver Ballast Prototypes - Complete engineering, fabrication, and testing of pre-production units and submit them for evaluation to an independent testing organization to be chosen by LBL. These units will be tested against performance criteria developed by LBL based on the results of Task II. At least 12 such units are to be supplied.

TASK IIA — Product Development and procurement - Develop the present 277 volt system to prepare for the required LBL test prior to submission of the units to the independent lab. Ship 16 ballasts that have been tested at Stevens to LBL for reliability tests. The goal of the units is reliable performance and efficacy of 6,300 lumens/77 watts for the system.

TASK IIIA — Product Design Freeze - Based upon positive results in Task IIA freeze the design in preparation of production of the first short production run required to supply the ballasts for the demonstration. LBL will proceed with life tests of ballasts to determine the continuation of the contract.

TASK IVA — Documentation - Complete formal documentation of components and supplier qualification, circuitry design and packaging design.

TASK V — Manufacturing Plan - Design and optimize a manufacturing plan from which high volume, mass produced product costs can be estimated. Disaggregate production costs so the unit product costs can be derived over a range of likely production output levels.

TASK VA — Manufacturing Plan - Lay out a manufacturing plan and schedule to describe how 600-800 ballasts (277 volts) will be supplied for the ballast demonstration. The plan should focus on the manufacturing techniques and components needed to obtain good quality assurance; that is, how the more sensitive components will be manufactured and tested in-house prior to placing in the package.

TASK VIA — LBL Review and Report - The performance obtained in the above tasks and by the independent test labratory will be reviewed by LBL. A Final Phase I report will be submitted as a requirement to be considered for Phase II.

IV TASK I & IA REPORT - PROGRAM WORK PLANS

The TASK I final report was submitted to LBL in accordance with the terms of the contract. Because it is fairly extensive, detailed, contained sensitive information about the Company plans and financial capabilities, and was submitted separately, it is not reproduced here.

This task report covered the period March 21, 1977 to July 21, 1977 and consists of a personnel plan, timing of principle events, a management plan, and a financial plan. Because of delays experienced with the program a second plan was submitted for the period July 22, 1977 to March 31, 1978 and is labeled TASK IA WORKPLAN.

TASK V PERFORMANCE SPECIFICATIONS

This task included a somewhat expanded scope of work that contained, not only the device specifications, but, a detailed literature search to seek out works done by others. This expanded scope was included in the hopes learning what problems might be encountered in the ballast development.

A literature search was conducted using the computerized files of IEEE and NTIS as well as a Patent Library search at the West Coast library. In addition, a search of polular literature was conducted through the Library of Congress computerized records. The results of the four searches are quite extensive and are included as Appendix A to this report.

If the electronic ballast is to become a commercially acceptable product it must meet certain National codes and specifications. The most meaningful are Underwriters Labratory specification number 935 and ANSI C.82.1.

The primary specification is UL 935. Underwriters is concerned with the fire and safety potential of any new product. Acceptance by UL is the criteria most insurance companies use to determine the risks of insuring a product. Without UL approval, insurance premiums would be prohibitive. It is doubtful that the product will ever be viable if UL approval cannot be obtained. As the purpose of this program is to lay the groundwork for eventual commercial acceptance of the ballast, it is imperative that the device meet UL 935 or some derivative thereof.

Of second, but no less importance, is ANSI C82.1 and C.82.2, Specifications for fluorescent lamp ballasts and Methods of measurements of fluorescent lamp ballasts respectively. These specifications deal primarily with the industry and have economic impact. C82.1 is one of the specifications used by UL. It is also one of the determining criteria under which lamp warranties are determined. C.82.2 deals with the testing of lamps and ballasts and is therefore related to C.82.1.

A third specification of some importance is Publication No. 458 Transisterized Ballast For Fluorescent Lighting published by the International Electrotechnical Commission. This specification is important in that it is the only specification published by anyone which attempts to define what an electronic ballast should do.

It appears highly likely that a new specification covering the electronic ballast will be required by both UL and ANSI. This conclusion is drawn after spending considerable time researching the existing specifications. It also appears likely that it will take from three to five years to develop a new ANSI specification unless their normal process can be expedited.

Stevens estimates that it will take six to nine months to obtain UL approval and between five and ten thousand dollars. UL approval is not required for the limited commercial demonstration and test for the PG&E installation.

Stevens does not anticipate problems in obtaining UL approval nor complying with the functional intent of the ANSI specifications. In both cases a new specification will be written to weed out reference to dedicated 60 Hertz operation and those items or tests which are irrevelant to the electronic ballast.

Our intention is to work within the framework of the existing specifications as much as possible to broaden the specifications to allow the electronic ballast.

A specification for the Stevens Ballast follows along with a summary of key technical characteristics. A dedicated 277 volt device was selected as this is the unit that will be installed for the commercial test.

STEVENS SEMI-CONDUCTOR HIGH FREQUENCY FLUORESCENT BALLAST MODEL NUMBER 8441

SPECIFICATIONS

Light Output

The Stevens ballast shall operate with standard commercially available rapid start (RS) lamps, the combination of which must not exceed 80 watts to the lamps. Normally two F40T12 48" lamps shall be operated from the ballast. For the purpose of comparing lamp lumen output, the Stevens ballast shall cause the lamps to output as least as many lumens as compared with a conventional magnetic coil and core ballast with 77 watts or less (nominal) input to the ballast and lamps.

Power Input

The ballast shall operate from a standard line voltage of 277 Volts AC 60 HZ. The ballast shall be capable of maintaining rated lumen output over a 90-110% variation in the input main voltage within ± 1%. The ballast shall have a fused input.

Environment

The Stevens ballast shall operate at better than .9 power factor (leading) at full output. The ballast shall implant no appreciable third harmonic distortion on the input power lines (current cresting which is defined as a maximum of 1.2 times the normal input current when measured against a comparable incandescent load). The ballast shall operate over a temperature range of 0-60 degrees Celsius. The Stevens ballast shall be interchangeable with conventional coil core ballast and in no way shall adversely effect the building environment or power distribution systems.

Spectral Composition

At rated lumen output, the ballast shall not cause any appreciable change in the color or spectral composition of the light emitted from the lamps.

Reliability

The Stevens ballast shall have a minimum rated life of 30,000 hours or ten years when installed and operated in accordance with the manufacturers recommendations.

Lamp Life

Lamp life shall not be reduced by virtue of operation from the Stevens Ballast.

Health & Safety

The Stevens ballast shall meet the functional intent of all recognized National codes including UL and ANSI.

Emergency Lighting

The ballast shall be capable of operation from a standby battery source in the event of a failure in the main lines. Battery operation shall be a specified optional feature requiring a separate interface module when more than one ballast is to be operated from the same battery. The battery may be included within the lighting fixture itself and shall provide a minimum thirty minutes operation at low light levels.

Level of Service (DIMMING)

The ballast shall have the capability of being dimmed either manually or automatically through simple means. Local dimming is accomplished with a screwdriver adjustment on the ballast proper. Remote dimming shall be accomplished via a pair of low voltage wires connected to a simple potentiometer. Where more than one ballast is dimmed from the same control pot, a separate isolator module in the fixture is required. "Level of Service" dimming shall be accomplished with a proportional photocell module located either within the fixture or external therefrom.

Dimming shall be over a 40-100% range and shall be smooth in operation with no noticeable flicker or other objectional effects.

Size

The ballast shall be mounted in a standard fluorescent ballast metal case with mounting holes and wire color code identical to conventional ballasts. Where special wires are brought out (dimming, battery operation, etc.) they shall be color coded differently than other wires brought from the unit.

STEVENS LUMINOPTICS CORPORATION
MODEL 8441

SUMMARY OF KEY TECHNICAL CHARACTERISTICS

INPUT

AC Input Voltage	235 305 Volts AC, 60 Hz. (277 Volts Nominal)
Minimum Starting Voltage	235 Volts AC
RMS Operating Current @ 6,300 Lumens	.300 Amps
Maximum Starting Current	.350 Amps Maximum
Power Factor	.95 Leading (Typical) at full light output
Third Harmonic Distortion	Negligible

OUTPUT

Lamp Drive Frequency	21 KHZ ± 1 KHZ
Lamp Operating Current	300 Ma. Nominal
Lamp Operating Voltage	200 Volts Nominal (100 per lamp)
Open Circuit Voltage	*
Lamp Lumens	As Rated By Lamp Manufacturer
Heater Voltage	** .4 to 4 Volts
Lamp Crest Factor	1.48 ± 10%
Dimming Range	40-100%
Flicker Index	Zero
Percent Flicker	Zero
EMI	Projected to meets FCC Part 15

PHYSICAL

Ballast Weight	2 pounds
Ballast Size	1.5"H X 2.25"W X 9.5"L

* Open circuit voltage is 525 volts for 2-4 milleseconds each four seconds

** Heater voltage is proportional to inverter power

VI TASK III DEMONSTRATION PLAN

In the original Stevens proposal a joint venture between Stevens Luminoptics Corporation and Pacific Gas and Electric Company was proposed for a commercial test of the fluorescent ballasts. Pacific Gas and Electric Company has maintained a high level of interest in the program and has been most co-operative since the concept was first proposed to them in September of 1976.

A preliminary agreement with PG and E was entered into with the understanding that the purpose of the test was to prove or disprove the value of the electronic ballast in actual field trials. The testing was to be as rigorous as possible and the end result was to be a published paper in a journal such as the IES. PG and E was to have complete control of the testing. In this way it was felt that a totally unbiased report by a recognized major influence in the industry could be obtained.

As the Phase I program evolved, LBL decided to take a lead position in the selection and management of the Phase II test site and in monitoring the program. Accordingly Stevens agreements with PG and E were transferred to LBL and Stevens took a non-leading position in the planning portions of the program.

The objective of the test will be met as long as some definative data can be obtained either supporting the ballast or otherwise. If the tests show that that ballasts savings are insignificant (10% or less) or there are inherent problems with high frequency radiation, or some other unknown, the program will have been successful in that further work on the high frequency ballast can be terminated and the resources applied to some other worthwhile program. If however, as Stevens believes, the ballast shows significant improvements in power useage and there are no other unsolveable problems which would prevent commercial implementation, then we can proceed with tasks necessary for mass production development of the ballast.

Proof can be categorized as performance from both a technical and economic standpoint. The first hurdle is technical proof. Is there anything about the electronic ballast which would prevent it's eventual implementation? Examples of this might be the effects of sonic radiation on employees, coherent effects (both sonic and RF) of many ballasts operating in close proximity, power factor and third harmonic distortion effects on the service distribution system, power consumption, physiological effects of flicker free lighting, and the ability to fully exploit the ballasts capability with remote dimming system, computer control, photocell dimming, and other ancillary systems and concepts.

The economic hurdle is second, and, no less important. Once the technical performance is proven, can we afford it? This is a very complex problem although some answers can be generated. The units installed for the tests will be early production units which will not resembly the eventual mass produced units although, electrically they will be similar. An economic evaluation can be made from the base data and the expected evolution of the ballast design to prove the ballast's worth.

The following memorandum to LBL dated June 27, 1977 sums up the type of testing we feel is necessary for Phase II. LBL's plans have been reviewed and Stevens concurrs with them.

MEMORANDUM

TO: Rudy Verderber, LBL

FROM: W.R. Alling, Stevens

DATE: June 27, 1977

SUBJECT: Summary of proposed test criteria for PG and E.

Our understanding of the proposed revised Phase II demonstration is that LBL is desireous of running tests of four different types of ballasts as follows:

1. Stevens
2. IOTA
3. Conventional HPF Ballast
4. Conventional High Efficiency Ballast

We concur that one entire floor with seperate metering, should be done for each ballast type.

The following minimum tests and/or recording should be accomplished:

PHYSICAL INVENTORY

1. Identify each fixture and ballast by type and part number.
2. Assign a test serial number to each ballast, fixture, and lamp.
3. Identify work stations by fixture and ballast serial numbers.
4. Identify age of each ballast and lamp
5. Identify lamps by manufacturer and type.
6. Identify air handling fixtures by test serial number.

METERING (INSTRUMENTATION)

7. Determine KWH recording meter type (24 hour)
8. Line transient recording device.
9. Line voltage recording device (24 hour)
10. Line current recording device (24 hour)
11. Identify test equipment to determine:
    a. Current cresting (third harmonic distortion)
    b. Line transients
    c. Temperature
12. Photometric requirements
    a. Continuous recording of non-dimming ballasts
    b. Continuous recording of Stevens ballasts

ELECTRICAL

13. Baseline power input tests

    a. System
    b. Selected fixtures (6) vrs light output/line voltage/temperature
    c. Voltage
    d. Current
    e. Power factor
    f. Current cresting

14. Stevens Power Input tests

    a. System
    b. Selected fixtures (6) vrs light output/line voltage/temperature
    c. Voltage
    d. Current
    e. Power factor
    f. Current cresting

15. Photometric

    a. System lighting levels
    b. Window light levels
    c. Selected light station lighting levels

16. Stevens VRS ?

    a. System power comparison, Standard
    b. Task lighting power input comparison vrs lighting levels on selected six fixtures
    c. System power comparison with Stevens set a minimum lighting levels (James Jewell to determine).

ENVIRONMENTAL

17. Temperature, Stevens VRS?

    a. Ambient
    b. Ballast Case
    c. Forced air (air handling fixtures only) input vrs exhaust

18. Neutral currents, Stevens VRS ?

VII TASK IV & IIA PROTOTYPE BALLASTS AND PRODUCTION AND PROCUREMENT DEVELOPMENT

TECHNICAL CHRONOLOGY OF THE COMMERCIALIZATION OF THE STEVENS LUMINOPTICS 2-40 FLUORESCENT BALLAST

The Stevens Ballast is composed of four major sections, as follows:

1. A power conditioning and conversion section
2. A switching inverter section
3. A lamp interface section
4. A heater control section

Conceptually, the entire ballast had been proven and demonstrated prior to the commercialization contract.

The two major areas to be addressed during commercialization were:

A.. Device selection for reliability and cost.

B.. Packaging with special attention directed to fitting the entire ballast electronic hardware within the space confines already dictated by the size and shape of the conventional ballast.

1. POWER CONDITIONING AND CONVERSION SECTION

The power conditioning and conversion section is composed of:

A. An input filter stage designed to hold line transients and surges at a level that will not damage the semi-conductors within the ballast.

B. A bridge rectification stage and high frequency filter to supply unregulated DC to the next stage.

C. The power conditioning section for DC regulation and power factor correction.

The high frequency filter refered to in the rectification stage is necessary to prevent the ultra sonic frequency of the power conditioning section from being presented to the power line. The input filter also serves to attenuate transmitted EMI. Since the high frequency filter does not filter the 120 Hertz ripple, current flows in the bridge rectifiers for all of the significant portion of the sine wave, thus, producing the desired near unity power factor. A proprietary power conditioning circuit with special drive and feedback circuitry accepts the unfiltered, unregulated 120 Hertz pulsating DC current from the bridge rectifier and converts it to a smooth, ripple free DC output to the switching inverter without causing input line cresting and at high power factor.

Since almost all new fluorescent ballast installations are now using 277 volts, Stevens Luminoptics elected to commercialize a 277 volt ballast as it's first entry into the marketplace. This necessitated the selection of transister devices that could switch the peak line voltage while remaining in it's reverse and forward biased safe operating areas. To this peak voltage must be added a margin to allow for line transients and surges as attenuated by the input filter network.

It is obvious that line transients and surges can be attenuated to the point of being insignificant. The cost of doing this and the size of the components are naturally a trade off with the cost and availability of a high voltage transistor. It is also possible to operate many transistors in this application by holding them within the safe operating areas with the use of a snubber circuit. Here the switching speed of the transistor is extremely important.

The slower the speed of the device, the larger the snubber capacitor must be. A resistor must also be incorporated within the snubber network to absorb the energy stored in the snubbing capacitor while it is protecting the transistor. If the snubbing capacitor is too large, the power lost in the resistor becomes excessive. Since the total thrust of the the development of the solid state ballast is to produce an energy effective device, a transistor had to be located that would require the smallest snubber possible.

A great number of input filter, transient protection devices, transistors, and snubber combinations were tried during Phase I. It is significant to note that few of the transistors actually met their published specifications, or that the particular areas of greatest concern were simply not specified. During this stage of testing and qualification the alternative of placing a small autotransformer within the ballast to step down the line voltage was considered. This would have allowed the use of more commercially available devices. Since this autotransformer had to operate from 60 Hertz it had to be large, and therefore, it's mere presence placed severe packaging limitations on the space available for the electronic components. While it was not absolutely necessary at this phase of the demonstration to produce a package that the market would eventually require, it was felt that it would be to the advantage of all concerned with the program to produce an electronic ballast that would fit within specified packaging constraints. The autotransformer approach was therefore rejected.

The first transistors that Stevens was able to locate, test, and qualify for the application were in a TO-3 package. This proved to be a large, clumbsy package configuration since not only was it large and difficult to connect to, but it had to be connected in some manner to a heat sink that would conduct heat while maintaining voltage isolation to the case of the ballast. It was desireable to use a small plastic package if one could be found with the proper work function.

Extensive investigation in conference with many manufacturers satisfied Stevens that an acceptable plastic package could be found. This was based on the fact that, although not all manufacturers had brought the reliability of this type of device up to what we considered acceptable, some had done so, and the techniques of manufacture were being rapidly improved thereby increasing reliability and reducing costs, whereas the manufacturing know-how as it effects cost reduction on the TO-3 package had peaked out.

Another consideration that had to be investigated was whether to use a Darlington transistor combination or a single transistor switch. The Darlington offered the advantage of reduced base drive requirements, and, in the initial configuration, this presented an interesting challange. As indicated before, the ballast had to be energy effective. The engineers were working on a very tight budget relative to the amount of power that could be lost for any reason within the ballast. As it turned out, Darlingtons' are available that will perform in this particular application. They are, however, slightly slower than the single switch and offer the added advantage of a higher forward drop during full saturated on condition as the final transistor of the Darlington pair can never reach saturation.

The problem was somewhat further compounded by the selection of a free-wheeling diode that is used in conjunction with the input power conversion section. In most applications, currect flows continuously in the input inductor, either through the switch connected to the power line or through the free-wheeling diode during the time the switch is off. This presents a problem to the transistor in the forward biased safe operating area since it must turn on looking backwards into a forward biased conducting diode. The diode, of course, turns off but does not do so immediately; thus, high currect spikes are generated at the initial turn on time through the transistor. This is a common problem with this type of technology, and is normally solved first, by selecting a very high speed diode, and secondly, if required, by pacing a small limiting inductor in series with the diode which saturates itself out of the circuit during the time the diode is normally conducting. Unfortunately, for this application, there are not available very high speed diodes in the voltage and current ranges required for the ballast. The addition of the protective reactor, not only complicated the circuit, but consumed precious package space. Stevens therefor chose to calculate the value of the inductor to allow it to unload completely between each on-switching condition of the transistor switch. Once the inductor unloads, the free-wheeling diode is biased to the off condition by the voltage which is fed back through the inductor from the output filter capacitor; thus, when the transistor switch turns on, it looks only into an unloaded inductor. This is the best possible condition for the transistor to see regarding it's forward biased safe operating area.

The disadvantage of this approach lies in the fact that the transistor current is a saw tooth starting from zero each cycle and reaching a point equal to twice the average load current. This additional current carrying capacity in the transistor switch, of course, had to be figured in it's selection and its turn off safe operating characteristics. Testing of many devices disclosed that Stevens was ahead with this configuration.

After extensive testing, Stevens became convinced that the present state of the art in switching transistors required transformer drive. The decision to use transformer drive was further validated by the cost reduction afforded by our ability now to use transistors rather than Darlingtons as switches. Energy was also conserved by the elimination of the Darlington forward drop, and through the impedance matching available with the transformer, a reduction in overall drive power even after employing a single transistor as a switch.

Once the criteria was established that would meet all of the required conditions, i.e., fast switching---- allowing for minimum snubber loss, plastic package, and a specified reverse bias safe operating area covering the voltage ranges where the ballast was operating, Stevens was ready to proceed to design the input filter for its transient noise suppression characteristics. The transistor selected at this point had the following characteristics:

Collector-Emitter Voltage		
Base Open	400	Volts
Base Reversed Bias	700	Volts
Collector Current		
Continuous	8	Amps
Peak	16	Amps
Thermal Resistance		
Junction to Case	1.5^{o}	C/W
DC Current Gain		
@ 1c = 5A VCE = 5 VDC		
Minimum	6	
Maximum	30	
Switching Times		
Storage	3	usec
Full Time	.5	usec

Plus other acceptance and test criteria

With the specifications now pinned down, Stevens determined that an input pi network was necessary to supress line transients within the acceptable ratings of the transistor. These ratings also, of course, had to apply to the diodes used in the bridge and the high frequency filter capacitor following the bridge. Extensive calculations and testing indicated that the input inductor element of the filter had to be too large to be practical unless at least one transient suppressor was used in place of, or in parallel with the pi network capacitor. This device was to be placed preferably on the bridge side of the inductor.. Some difficulty was encountered in that no devices were available which were designed for 277 volt operation, although assurances were received that units would be available. By carefully selecting lower voltage devices Stevens was able to get units that would function as intended.

During testing of the balance of the circuitry in the ballast, it became apparent that if we were to proceed rapidly on a commercialization proceedure, we would need to have devices whose output could be short circuited without damaging components. Conventional current protection circuitry was added, but its response time was found not to be fast enough to protect the transistor because of the circuitry included to maintain unity power factor. A small sacrifice in the power factor maintenance was taken to acheive this protection. This deviation shows up most readily when the ballasts are dimmed. It is a leading power factor, however, and in most installations should be beneficial. With later stage engineering development it is expected that the ballasts will be short circuit protected while still maintaining unity power factor over the entire range of operation.

Because of the proprietary nature of the power factor conversion circuitry, the output filter capacitor (as contrasted with an input filter capacitor) must be considerably larger than in a conventional supply. Considerable time was expended learning the methods of capacitor construction and fabrication in order to obtain a large capacitor that would have the desired temperature range and life yet still be small enought to fit within the projected package size. Shape was also an essential consideration because of the possible interference with other components. It was soon learned that no capacitor manufacturer ever expects that their capacitor will be operated at their rated voltages and ripple currents with any reasonable life expectancy. There is a wide variation in the amount of derating that must be applied. The mode of failure must be considered, and the amount of change in ESR and capacity that could be tolerated over the lifetime of the device. A series of capacitors was finally identified that were available and had the desired technical properties, operating life, and physical size.

The power conversion section also has to supply logic power for the entire ballast. Initially, when the step down autotransformer was considered, a secondary on the autotransformer was utilized to supply low level logic power. However, because of space limitation previously outlined, the transformer was eliminated. Because the low level logic power requirements are modest, a small series pass regulator was tried to drop the DC voltage out of the power conversion section to the required level. Two basic considerations eventually forced Stevens away from this approach and back to the use of a more conventional, small power transformer and rectifier followed by an IC chipped series pass regulator to provide the required +24 logic power.

With this approach it was necessary to provide for the fact that initially there is no output voltage from the power conversion section; therefore, no logic power could be prodided. This meant that a startup circuit had to be included in the ballast to start and run the power conversion momentarily until it could boot-strap itself into operation. This is not an unknown proceedure in the industry but added unwanted complexity to the overall ballast. The second consideration was the power lost in the series pass element at high output conditions. Stevens was programmed to accept a few watts loss here since any other form of generation would probably consume a similar amount of power. However, this loss had to be dissipated in a semi-conductor element and added to the heatsinking of the other main switching semi-conductors. This produced heat in the ballast where it was not advantageous to have heat. Therefore the conventional transformer supply was adopted.

In the original Stevens design, prior to this contract, a small special proprietary circuit was utilized to generate the low level logic directly off the main input lines with very little loss. At present, this does not appear to be a practical cost effective method, however, once the semi-conductor industry develops reliable high voltage semi-conductors (within three years) we would anticipate going back to this approach.

Another requirement of the ballast is that it operate from a standby battery installed within or near the fixture. Under standby battery operation, the battery effectively replaces the power conversion section and supplies DC power directly to the switching inverter section. However, it is necessary that the low level logic also be supplied with power. Initially we allowed for the interconnection of diodes in such a manner that the external battery supply would feed both the switching inverter section and the low level logic supply through a single wire leading from the ballast. However, it became apparent during the first stage assembly and troubleshooting that it would be far easier to test the ballast if the input to the switching inverter section and the low level logic were brought out on two separate wires and accomplished the diode isolation externally in the battery interface module. This had the additional benefit of eliminating the cost of the diodes on all ballasts that were not to be operated on a standby battery and also greatly facilitated testing and troubleshooting. The 24 volt logic power is now also able to operate external logic such a photocell modules and multiplex transceivers.

II SWITCHING INVERTER SECTION

One of the primary advantages of utilizing the special proprietary circuitry in the power conversion section is that the output voltage and current to the inverter section is regulated, and there is control as to the maximum amount of voltage applied to this section. This means that we were able to select transistors which are normally commercially available. There are three types of standard switching inverters that can be used in this application:

1. The push pull
2. The bridge
3. The half bridge implementation

The main advantage of the push pull mode is that the emitters of both the switching transistors are tied to a circuit common. This simplifies some of the drive considerations. The disadvantage of the push pull type is that the transistor must hold off at least twice the applied DC voltage plus a margin for spikes. The bridge and the half bridge types of inverter have the advantage of eliminating the inverter transformer, thus, removing a large magnetic element in the circuit; however, one of the transistors in the half bridge and two of the transistors in the full bridge must have an isolated drive. Since Stevens had earlier opted for transformer drive in the power conversion section, this did not present a problem. It was therefore decided to use a half wave bridge as this involved the fewest number of components.

Because of the characteristics of the lamp interface circuitry, as will be discussed, very little current is drawn through the switching transistors during the time they are actually transferring from the on to off condition. Here again, initial investigations indicated that the TO-3 type package would be the most available for this application, but again, the awkwardness of such a device necessitated us pursuing the use of a plastic transistor. After extensive testing and several baskets of discarded components, a number of conclusions were drawn:

A. A transistor was more practical than a Darlington.

B. There were plastic transistors available that would do the job.

C. The method by which turn-off and storage times had been measured and specified on the available transistors in the marketplace were not appropriate to the Stevens application.

D. Considerably more current drive in the reverse direction was necessary to shut off the transistors than the specifications would indicate.

Relative to these last two items, as previously stated, Stevens proprietary concepts allow the transistors to be switched at near zero current. We found, however, that some transistors would not turn off unless there was substantial collector current flowing regardless of the amount of negative bias applied to the base junction. Stevens circuitry allows for the turn off time of each transistor by shutting one off before before applying turn on power to the second, and under most operating conditions, the time allocated is more than adaquate; however, no matter how much time is alloted with some transistors, they will not turn off until the next transistor turns on causing short circuit current to flow in the first transistor. This leads to high current spiking and quite often operation of the transistor beyond the forward biased safe operating range for the turn on device and the reverse bias safe operating range for the device turning off. Stevens was forced to alter the circuit slightly at a penalty in efficiency in order to allow the transistor to have collector current flowing when it is scheduled to turn off. Improved devices are coming onto the marketplace now where such limitations will not be a problem and the efficiency of the ballast will improve somewhat because of these improved devices. This will also be an area where some ballast heat will be removed.

III LAMP INTERFACE SECTION

The lamp interface section was designed specifically to match the output of the inverter to the lamp regardless of the lamps characteristics. Any form of gas discharge lamp has a wide variety of impedances where it might be operational based on the amount of current passing through it, the temperature, and the conditions of the electrodes. A great deal of literature is available on the subject of improved efficiency of fluorescent lamps as a result of high frequency. In the days when these tests were first run, higher frequency was considered to be in the hundreds of cycles or a few thousand cycles (hertz). Until the advent of solid state electronics, the generation of such high frequencies had not been an energy efficient thing to do. Even with the first solid state ballasts the costs were prohibitive.

Investigations of the lamp efficiency versus frequency showed some interesting new developments not previously discussed in the literature. It has long been accepted and understood that a gas discharge was, in a sense, a constant voltage type of phenomenon.

In other words, regardless of the amount of current flowing through the gas, the voltage across the discharge was relatively constant, or it changed at a much smaller rate than the current but in a negative direction. As the current increased up to a point, the voltage decreased. In low frequency applications, this has the effect of clipping off the top of the voltage waveform producing a trapazoidal like wave across the lamp.

The gasses in the tube have a finate ionization and deionization time, a time considerably shorter than the normal 60 HZ operating frequency; thus, this trapazoidal wave form is observed. As the frequency is raised, there is a point where the ionization and deionization time very nearly track the wave form of the applied voltage. At this point, the tube appears very nearly resistive. It is Stevens intention to investigate this phenomenon more in the future.

At first glance, it would appear that this is the optimum efficiency point frequency-wise of the tube. Unfortunately, this frequency occurs within the audible range (i.e. somewhere around 10 KHZ) at a very annoying and perceptive tonal point. As the frequency is increased, the voltage changes faster than ion creation and recombination can occur within the gas plasma. Thus, the lamp takes on a positive impedance characteristic with voltage such that there is a limit as to how much current can flow each cycle regardless of the voltage applied. An increase in the average voltage will increase the average current over several cycles, but on a cycle by cycle basis this effect is observed.

From the above, it can be seen that to get the most efficiency from the lamp, we must have a lamp interface circuit that takes into account all of these characteristics. It is also apparant that we wish to operate just above the audible bank and no higher.

The Stevens ballast incorporates a proprietary lamp interface section which is coupled from the inverter drive to produce at all times a resistive load on the output of the inverter while optimizing the lamp characteristics. The wave form of the lamp voltage and current is very nearly sinusoidal. This is highly desireable in reducing radiated EMI.

The lamp interface circuitry is designed to eliminate the odd harmonics created by the square wave output of the inverter. A conventional square wave has almost 48% harmonic content as compared to the fundemental. These harmonics contribute far more to the radiated EMI than does the fundemental and far less to the production of light whithin the lamp; therefore, the elimination of these harmonics is one of the reasons for improved efficiency. Such circuitry as described incorporates magnetic elements.

To keep the magnetic element small while still allowing for adaquate storage of energy, it was necessary to use a gap configuration. Presently, today, the most economical form of core would be the EI or EE configuration. Naturally at these frequencies we had to utilize ferrite material. Almost immediately we learned the the use of a gapped EE or EI core within the high density packaging of the ballast presented some very undesirable side effects. Considerable fringing existed around the gap, and if the gap was in proximity of any metal parts, a great deal of heat ensued as well as a loss in efficiency. It became apparent, therefore, that a pot core had to be used in this application with the gap on the center post only. This has the effect of not only shielding the gap with the coil but with the magnetic material of the core. A highly efficient design, while minimizing core size for packaging purposes and still keeping the power sources very low, necessitates unusually large gaps. Such gapped cores are not obtainable off the shelf and must be ordered special from the factory with considerable lead time. Accordingly Stevens developed a specialized gap grinding technique to facilitate early production. Also, because of the large gap size and the amount of fringing involved, we found it necessary to utilize special litz wire in the inductive devices including the inductor used in the power conversion section decribed previously.

A great deal of time and effort went into selecting the right ferrite material to minimize losses. Most manufacturers rate their inductors on the basis of the amount of heat rise allowable and calculate their copper to core losses appropriately. This, of course, is totally unsatisfactory in the Stevens application since we are concerned with the actual amount of energy lost. The upshot of all our efforts resulted in magnetic assemblies far more efficient than would be normally expected for this particular type of application.

The proprietary lamp interface circuitry section also incorporates capacitive elements that have to handle substantial current at the 20 KHZ + frequency. Testing showed that the conventional mylar capacitors would tend to overheat in this application. and it was necessary to locate a source of reliable polypropylene dialectric devices that have a dissipation factor an order of magnitude less than that of mylar. Two re-configurations of the ballast packaging concept had to be undergone to accomodate available devices of this type with a high enough AC voltage rating

IV HEATER CONTROL SECTION

The primary mode of failure of the fluorescent lamp centers around the condition of the electrodes, or heater cathodes, at the end of each lamp.

In the conventional circuit, inadequate voltage is presented across the lamp to strike the tube when the cathodes are cold. Once the heaters have obtained a temperature that will allow the lamps to strike, they light. This is an inefficient method of controlling the point at which the tube will fire because it is also a function of the applied line voltage. In the high line consideration, the tube may actually be struck well before the lamp cathodes have reached the temperature specified for striking the lamps for maximum lamp life. In the Stevens ballast, the voltage is held off the tube until enough time has elapsed to assure that the heaters are up to temperature.

Once the tube is fired at full intensity, there is normally enough heat generated by the natural bombardment of the electrodes to maintain the cathodes at the proper temperature which assures long lamp life. If the fluorescent lamp is to be dimmed, however, as the current through the lamp diminishes, the heat on the cathodes must be maintained by driving them from the ballast. In past applications where dimming is considered, the heaters were normally driven at full power all the time. Under this condition they will always be adequately hot. However, during maximum light output condition, the heaters or cathodes run hotter than they need to and a shorter lamp life probably results. With the Stevens system, heater power is carefully controlled in accordance with a preconceived control scheme to assure very long lamp life.

Because of the various potentials of each of the heaters, it is necessary to have a heater transformer with isolated secondary windings. This transformer is driven in a simple push pull configuration by two heater drive transistors, and a duty cycle control system is incorporated to control the actual amount of power flowing to the heaters. It was necessary to incorporate a number of safeguards in this circuitry so that the ballast would not be damaged if any of the heater windings were inadvertantly shorted. High frequency was used to drive the heaters so that the output transformer and associated components would be small in size. Some time was expended locating a bobbin-core combination to formulate the output transformers small enough to fit within the ballast and still allow for reliable connections to the PCB for the three isolated secondaries and the center tapped primary. In the Stevens ballast, the heater power is, therefore, responsive to the current flowing within the lamp.

V MISCELLANEOUS DESIGN CONSIDERATIONS

In addition to having an ideally operational ballast, as described above, several other potential operating conditions had to be investigated.

1. Start Up Sequence - Because of the nature of the switching devices, both in the input circuitry and the switching inverter, it is absolutely necessary that they be switched with proper drive and reverse bias voltage and current so that they will always operate within their safe operating areas and reliability will be assured. Stevens found it necessary to monitor the +24 VDC logic supply to assure that this voltage was always high enough to guarantee safe operation of the components; and, should this voltage ever drop below a predetermined level, automatically shut the ballast down. Some overlap had to be incorporated in this level sensing circuitry to prevent the unit from oscillating near the cut out region.

2. As previously discussed, the heaters must warm up before the lamp is struck. Once the level sensing circuitry has determined that adequate voltages are available for safe operation, a start up sequence is initiated. This sequence allows the heaters to warm up within the tube before high voltage is applied to the lamp to light it. A timing circuit was instituted for this purpose and it is thought that long lamp life will be the result as the heaters are always allowed to come up to full temperature. The characteristic of the lamp interface section is such that it will supply a voltage adequate to strike the lamp regardless of the condition of the heaters. This is another reason for the delay in turning on the inverter following the warm up proceedure of the heaters. To further improve lamp life, the start up sequence automatically allows the tube to start at a lower than normal brightness.

3. Open Load Condition - (tube out of socket) One of the characteristics of the lamp interface section is that it will try to interface with whatever impedance is present including no lamps at all. In other words the voltage will rise attempting to fire a non existent tube. Limiting circuitry had to be installed to prevent this voltage from rising to the point where it might damage components. Even then, it did not seem appropriate to leave that voltage there on a constant basis; thus, the final circuitry was included that detected the attempt to light a non existent lamp and automatically shut the ballast down causing it to go back into it's start up sequence. Thus, if a lamp is left out of the socket, the ballast will come on for a period long enough to allow the heaters to warm up, attempt

to strike the lamp, and shut down; and a few seconds later, start this process over again. Thus, high voltage is present for only milliseconds when the lamp is out of the socket.

The selection of the integrated circuit chips for driving the ballast proved to be an interesting development in incoming inspection equipment. The use of off-the-shelf integrated circuit components did require some specilized engineering in this particular application to design around certain chip defects that were not evident from the specifications. These problems will not exist in the future units as Stevens contemplates having a chip designed to specifically eliminate the large amount of discrete solid state components in the ballast.

VIII TASK V & VA MANUFACTURING PLAN

General

It is the responsibility of the manufacturing organization not only to assemble the product properly but also to perform the necessary in-line inspections and tests to verify conformance with all applicable design drawings, specifications, and standards, and with workmanship and other quality assurance standards. It is also their responsibility to perform rework and repair as necessary.

It is the function of the Quality Assurance section to monitor and report on conformance in all aspects throughout the manufacturing sequence, and to judge whether non-conforming material at any stage of completion is fit for use or must be rejected. It is also their responsibility to determine the cause of non-conformance and to initiate corrective action.

Assembly Drawings and Materials Lists

Only the latest issues of drawings and materials lists will be used for production purposes. Quality Assurance personnel will monitor the production areas to ensure that out of date documentation is not being used.

Mechanical Inspections

All equipment manufactured in the assembly areas will be subjected to a 100% mechanical inspection.

The mechanical inspection is a visual inspection of an assembly to detect possible quality defects prior to electrical inspection and test. The inspector will look for wrong or defective components, correct polarity of components, potential shorts, broken leads, soldering defects, stamping, corect hardware, etc. as instructed by the assembly or test supervisor and in accordance with published test proceedures and criteria. Quality Assurance will assist the supervisors by providing them with information on quality defects detected at a later stage of inspection.

Equipment which has passed the mechanical inspection will be identified by an MI (mechanical inspection) stamp.

Rejected equipment will be identified by attaching a Fault Report Tag, stating in a much detail as possible, the reason for rejection. The tag will be removed after the fault is corrected and filed with the accepting inspector.

Should an assembly be rejected by QA, a Quality Assurance Report Tag shall be attached, stating the reason for rejection. This tag will remain attached to the assembly until after final inspection and filed appropriately. This tag may only be removed by a QA inspector.

Electrical Tests

All operational tests called out for an assembly on the QA Test Proceedures and time cards, i.e. temperature cycling, burn in, electrical test, etc., will be performed on a 100% basis and in the sequence listed. The successful completion of the various tests will be individually evidenced by applying the appropriate test stamp to the assembly/ documentation (travel card).

Faults detected during any of the tests will be corrected and the test repeated. Should it not be possible to immediately repair a rejected assembly, a Defect Tag will be attached to it. The reason for rejection will be listed on the tag in as much detail as possible.

Acceptance of Non-Conforming Material

Electronic assemblies, manufactured parts, mechanical and/or other assemblies, which in appearance, assembly or performance, deviate from the appropriate standards, drawings or specifications, but are acceptable on a non-conformance basis, may be submitted for non-conformance acceptance.

When a release of non-conforming material is requested by manufacturing personnel, a "Request for Release of Non-Conforming Material" will be filled out and submitted to Quality Assurance. Q.A. will evaluate the request and in co-operation with Engineering will decide if the material can be used on a non-conforming basis.

NOTE: The material non-conformance release is an in process inspection device and will only be used to accept deficiencies encountered during or prior to the manufacture of an assembly. It is not to be used to accept deficiencies detected during final test, system test, or final inspection.

Inspection Stamp Control

All manufacturing stamps will be controlled by the Test Supervisors. All Quality Assurance (QA) stamps will be controlled by the Quality Assurance Supervisor.

Measuring Tool and Test Equipment Control

To preclude the use of worn, defective or inaccurate measuring devices, including voltmeters, ampmeters, oscilloscopes, light meters, etc., all measuring tools and test equipment will be check and/or calibrated annually against defined standards. The QA department will have responsibility for this task.

It is the responsibility of the manufacturing department to assure that all measuring devices are forwarded to the Quality Assurance department once per year, or more often if needed, to have them serviced or calibrated. Records of these inspections shall be retained by the QA department.

The QA department shall have responsibility to spot check each measuring device to insure conformance with the above.

Fluorescent Ballast Test and Final Inspection

All ballasts and other assemblies manufactured by Stevens and/or other manufacturers will be thoroughly tested to ensure that the ballast is in conformance with all specifications, drawings, test criteria and other appropriate documentation. Prior to shipment to a customer, all orders will be inspected for completeness, workmanship, appearance, and proper documentation.

Fluorescent Ballast Test

After assembly of the ballast is completed, interunit wiring will be thoroughly checked to insure conformity will the applicable drawing. Before power is applied to a ballast, the assembly will be inspected to verify:

- That all assemblies are manufactured to the latest issue of the appropriate drawings
- That all assemblies and sub-assemblies passed their applicable continuity and functional tests as indicated by the related inspection stamps.

Ballasts and other assemblies will be tested per the appropriate System Test Proceedure and any other documentation specified for a particular system on the Top Assembly Drawing.

System performance characteristics will be recorded on the appropriate pre-shipment test record or in-house traveler as appropriate. If a fault detected in system test is corrected by replacing a component, a Defect Tag will be attached to the defective unit. The reason for the defect will be listed on the tag. After all tests are completed, the pre-shipment test record will be submitted to QA for acceptance. QA will verify the test results and may audit some of the test parameters. QA acceptance will be indicated on the pre-shipment record by a "FINAL INSP" Stamp.

Instrument Calibration Control

All test instruments and test fixtures used for acceptance and test of saleable products will be periodically calibrated. The frequency of calibration will be as recommended by the manufacturer as approved by the engineering department. Each test instrument or fixture will bear a calibration sticker, stating information on the date calibrated, the next calibration date, and the serial number. It is the responsibility of Manufacturing to assure that instruments are serviced and calibrated before their calibration interval expires. Overdue instruments will not be used for production and final tests.

Quality Assurance will perform periodic instrument calibration audits to assure that the specified calibration intervals are maintained.

Final Inspection

After clean up, all shipments, i.e. complete assemblies, will be 100% inspected. Each shipment will be inspected for the following:

- General Appearance
- Completeness of shipment per sales order

- Adherence to Stevens Quality Assurance Standards and manufacturing practices.
- Test documentation in order
- Potting
- Serial numbers

After the factory inspection, QA will audit each shipment on a sample basis. A final inspection report will be completed for each sales order, the sample size, the assessed quality level, the faults found, and the disposition will be recorded. If the equipment meets all quality and other requirements, including those listed above, the QA inspector will release the shipment by placing a "FI" stamp on the factory sales order. No equipment will ship without such a release by QA. The final inspection report will be retained by QA, together with the pre-shipment records.

If a shipment is not accepted, QA will advise the factory of the reason for rejection and stipulate the corrective action required. Should the factory not be able to correct the deficiency, QA will initiate a Stopped Shipment Notice. A Stopped Shipment will be released only by correction of the deficiency or by Special Shipment Release prepared by QA and authorized by both Engineering and Marketing. Masters of both Stopped Shipment Notices and Special Shipment Releases will be retained by QA and copies will be distributed to concerned parties.

Shipping

The packaging of shipments will be periodically audited by QA to assure that the equipment is properly handled, adequately packaged for shipment, and in conformance with the applicable standards.

PROJECT MANAGEMENT

Introduction

In order to provide for an orderly flow of information, and keep the cost of supervisory personnel to a minimum, Stevens has devised a management structure, coupled with a documentation proceedure, which will reduce the time and interaction effects that a change in project scope can impart to a project.

Project Managers Responsibility

The Stevens Luminoptics Project Manager is responsible for coordinating all out of house activities with the supervisory development group. Items such as establishing technical liasion channels, approval of reports, and the handling of customer requirements, fall under his jurisdiction. His major in house activities are:

- The preparation and updating of management charts to assure the orderly application of manpower and material to the project.
- The preparation, updating, and analysis of production flow and critical path charts to ensure a timely completion of the ballasts being produced.
- The welfare of project personnel.
- Preparation of progress reports.
- System definitions
- Financial

Quality Assurance Responsibility

Quality Assurance (QA) is responsible for two areas. First, he carries out and directs all testing of out-of-house purchased equipment and material, ensuring that all equipment and materials received meet with the purchase specifications. Second, he maintains and approves all test records of in house produced equipment assuring that all such manuafctured item meet the required specifications and goals.

Engineer, R&D, Parts Design and Fabrication

This engineering supervisor normally works in the Research & Development section and is responsible for the technical definition and design of the Company products.

In addition to his normal duties, he oversees the fabricating and testing of Company produced equipment. His group designs and fabricates any special test equipment required by the supervisory system.

Engineer - Hardware Organization

The engineer and his sub-group are responsible for production engineering support working within the framework of the manufacturing organization. His duties consist of:

- Mechanical configuration and control
- Writing source control specifications
- Purchase evaluations
- Technical information flow between sub groups
- Supervision of technicians, assemblers, testing, and draftsmen within his sub group
- Field Support
- QA Support

All project material and equipment purchases are handled by the purchasing department. This department solicits tenders on all equipment and materials and works closely with the hardware engineering group to select the most appropriate materials and vendors. Once the selection has been made, the purchasing department provides vendor liasion and assures that the order is properly expedited and delivered to the shipping and receiving department. The receiving clerk receives the material purchased and performs incoming inspspection in accordance with appropriate QA proceedures, and then delivers the material for in-house use.

Accounting

One of the major functions of the project management is cost control. This function is normally handled by the accounting department. Accurate cost records are kept on all project activities and monthly progress and status reports are prepared. The accounting department also processes and validates all project invoices. Project cost control is compatable with the Company's chart of accounts, thus providing a formal audit trail.

The foregoing manufacturing plan, is of necessity, broad in nature. The following describes Stevens Luminoptics plans for the manufacture of up to 1,000 units which are to be used for the Phase II demonstration tests. Accordingly, this section is split into six sections as follows:

- Facilities
- Personnel
- Organization
- Material Procurement
- Quality Assurance and Testing
- Phase II Manufacturing Schedule

Facilities - Stevens Luminoptics Corporation is presently located in two separate facilities. A comprehensive Research & Development labratory is located at Danville, California which provides production engineering support to the group. The production facilities are located at Pleasanton, California. Because ballast manufacture will be accomplished at Pleasanton, the remainder of this report will deal with that facility.

The production group is centered at 7063A Commerce Circle near the intersection of interstate highways 680 and 580, approximately 15 air miles from the San Francisco International Airport. Approximately 1,600 square feet of combination manufacturing and administration is devoted solely to manufacturing ballasts for the Phase II demonstration and test. The building is a modern single story tilt up concrete building typical of the area. Approximately 1,000 square feet is devoted to manufacturing. Substantial capital improvements were made to the building to accomodate the type of manufacturing required.

Improvements consisted of adding approximately twenty two work stations including; dip solder and clean up, incoming inspection and test, assembly, PCB clean up, magnetics manufacture, production test, production rework, burn in and final test, potting, and various Quality Assurance stations. Because of limitations in parking spaces, rest room facilities, and cafeteria requirements it is not possible to work more than ten direct production employees at one time. While this is more than adequate for building the Phase II units, present plans call for moving to larger quarters in late summer 1978.

The work stations are fully equipped with the required tools and test equipment to perform each task assigned. The equipment list includes:

- 1,600 watt semi-automated soldering fixture
- Eight double size work benches including electrical power
- Two potting and curing fixtures with temperature sensors
- Two complete electronic final test and rework stations equipped with required precision ampmeters, voltmeters, oscilloscopes, power supplies, light meters and other special constructed jigs and fixtures.
- Eight complete sets of production assembly tools including soldering irons, PCB holders, stuffing jigs, etc.
- Shelving and storage bins for production parts and equipment.
- Twenty Five 2-40 fluorescent fixtures for production burn in.
- One each J-16 calibrated photometer.
- Various component and lead forming equipment.
- Special electrical service and distribution equipment for 277 Volt operation including an automated fire sensing system.
- A vapor degreaser cleaning system
- Miscellaneous equipment including work stools, heaters, air conditioners, PCB washers, general purpose tools, etc.
- Special fixtures and jigs, including transistor testors, diode testers, Hi-Pot (high voltage) test equipment, IC testers, etc.

Personnel - Production personnel assigned to manufacture the Phase II ballasts number three full time employees and four part time employees. Other personnel include a production supervisor, two production test technicians and a shipping and receiving clerk. In addition the manufacturing group can call on the engineering department to assist should problems develop with the manufacture of ballasts.

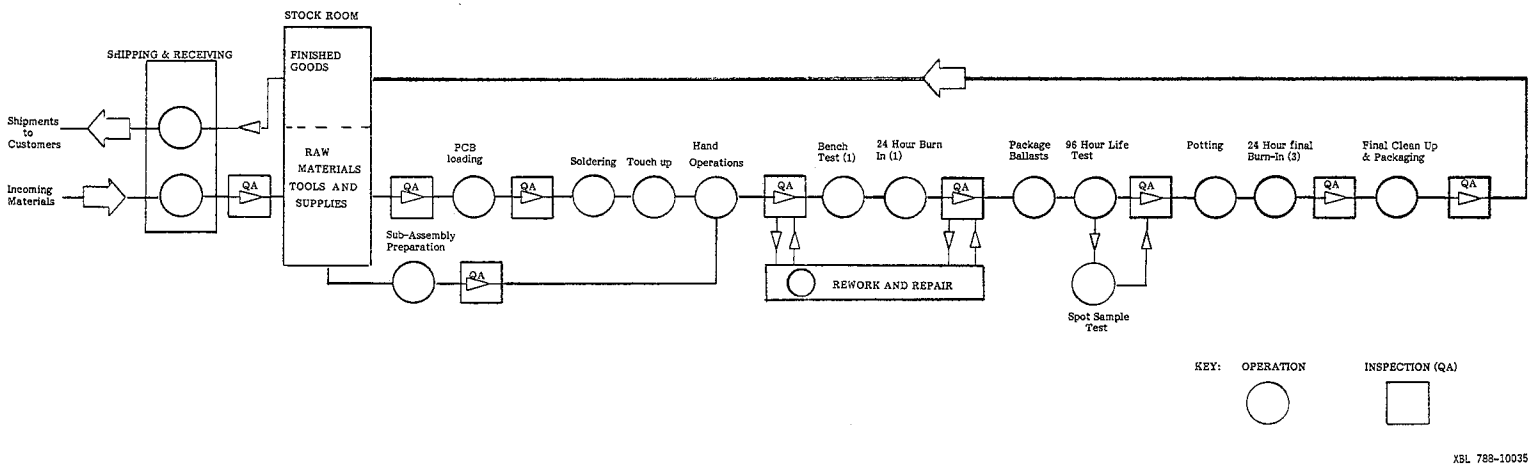
Organization - A current organization chart of Stevens Luminoptics is included along with a current production schedule, and a work flow diagram.

Quality Assurance & Testing - A copy of the final test proceedures and quality assurance specification for the Phase II ballasts is enclosed. This plan was generated with LBL.

Material Procurement - As of June 1, 1978 all material required to manufacture the Phase II demonstration units are on hand.

46./

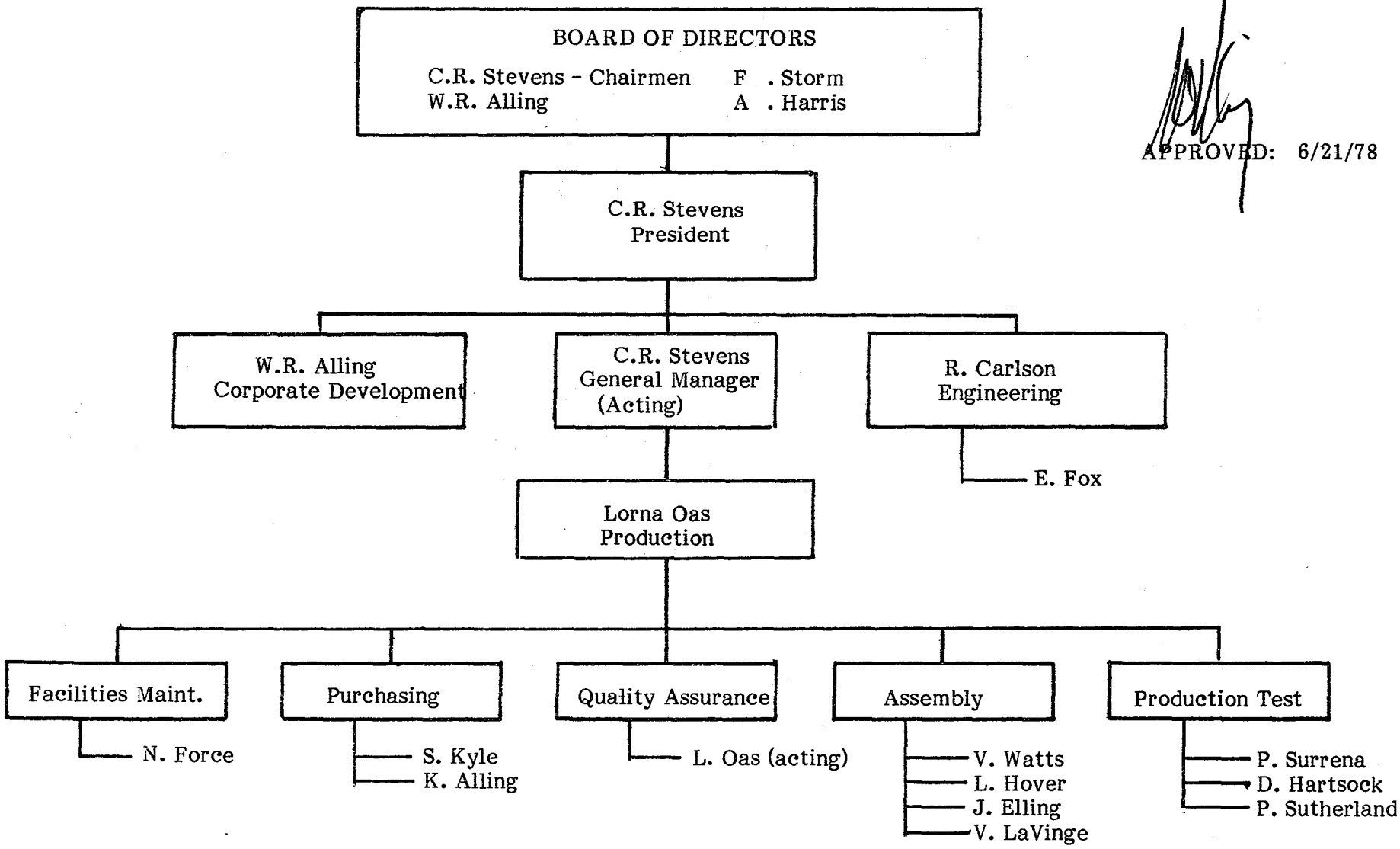
DOE PHASE II MANUFACTURING FLOW DIAGRAM & QA POINTS



XBL 788-10035

STEVENS LUMINOPTICS CORPORATION

ORGANIZATIONAL CHART



APPROVED: 6/21/78

TEST PROCEEDURE

PURPOSE OF THIS PROCEEDURE: To perform such static and functional tests as may be necessary to qualify the performance and reliability of the Stevens model 8441 fluorescent electronic ballast.

OBJECTIVE OF THIS TEST: The objective of testing shall be to reasonably assure Stevens and LBL/DOE personnel that the test ballasts completing the series will have a high probability of operating a minimum of 3,500 hours in the intended application without failure.

GENERAL: A first series of 100 model 8441 ballasts will be submitted to LBL/DOE for qualification testing in accordance with these proceedures. Prior to delivery of these ballasts to LBL/DOE, Stevens shall have completed those tests labeled STEVENS QUALITY ASSURANCE PROCEEDURES and a copy of the appropriate documentation on each ballast shall be transmitted to LBL/DOE accordingly. Upon receipt of the 8441 ballasts from Stevens along with the appropriate documention, LBL/DOE shall immediately commence testing the transmitted ballasts in accordance with the test proceedure labeled LBL/DOE QUALITY ASSURANCE PROCEEDURES.

STEVENS QUALITY ASSURANCE PROCEDURES

Stevens will perform certain tests on the 8441 ballast prior to their submission to LBL/DOE. In general, they are:

1. T&A (Test and Adjust) criteria--this is the final test record and measures the performance of each ballast as it is completed but prior to burn in. These tests consist of power measurement, light output, dimming tests, power factor measurement, and the like. A copy of the T&A final report is attached as exhibit A.

2. After final test, the ballasts will be placed on a burn in fixture where they will be run a minimum of 96 hours to ferret out any early failures. They will be run the first 24 hours at normal 277 volt line, then run 24 hours at high line (305), 24 hours at low line (235), and the remaining 24 hours back at normal line voltage (277). During the high line tests a ballast case temperature measurement will be made and compared to the norm.

3. After completion of the burn in test, every 10th ballast will be subjected to certain additional tests consisting of (1) cycling the ballast for one hour while removing a lamp from the ballast under full load each 15 seconds, (2) a high line/low line transisent test, and (3) cycling the ballast input power every thirty seconds while under full load for two hours.

SCHEDULE A

TEST & ADJUST FINAL REPORT
(T&A REPORT)

1. Serial No. _____ Date _____ By _____

2. Minimum starting voltage and start time. At 235V (-15%) how long does the ballast take to start the lamps? _____seconds.

3. The standard ballast is (_____ f/c).

4. Stabilize ballast at 235 volts input AC for 60 seconds with warm lamps and full ballast output. Record each of the parameters listed below (*RMS).

line voltage*	amps*	watts	P.F.	max light output (FC)	min light output (FC)
235					
*255					
277					
*295					
305					

* First 10 units only.

5. Check operation of ballast with ancillary equipment.

   A. +24V battery operation _____.

   B. External dimming _____.

   C. Leakage green wire to ground _____.

SCHEDULE A

SUPPLEMENT 1

Additional data is required for marketing and engineering reference. These data will be taken on ten (10) units of each production run or at each engineering change phase which might affect those parameters.

1. Measure harmonic distortion of the input line current, versus line voltage and load.

2. Measure harmonic distortion of load current (approximately 20 KC), versus light output.

3. Measure light output linearity versus control pot rotation and/or control voltage.

% Rotation	Light Output FC	Control Voltage	PF	Amps	Watts
100					
90					
80					
70					
60					
50					
40					

SCHEDULE C

SPOT SAMPLE PROCEDURE

This procedure is to be accomplished on every fifth ballast after 96 hours burn-in, but before potting, and consists of three parts:

Part I - lamp removal test while ballast is operating under various light output levels.

Part II - a line cycle test.

Part III - a line transient suppression test.

Part I: The ballast(s) to be tested shall be placed on a special test fixture for two hours which shall remove and replace (open up) both red output leads once every 15 seconds for a period of 2 seconds while the ballast is operating at normal line input and light output.

Part II: The ballast(s) to be tested (1 hr.) shall be placed on a special test fixture which shall apply 277 volt line power to the ballast input every *3, 6, 9, and 15 seconds, in sequences, and disconnect line power for an equal amount of time before proceeding to the output during these tests. (test period 1 hr.)

Part III: The ballast(s) to be tested shall be subjected to a line transient test defined elsewhere.

* The lamp will never light on the 3 second test.

PROJECTED COST SCHEDULE

277 Volt Fluorescent ballast for 2-40 Rapid Start Lamps
Based On an Annual Build of the Following Quantities

Annual Production	12,000	50,000	1,000,000
Materials	$ 66.00	$ 42.00	$ 12.00
Assembly Labor @ $3.00/hr			
@ 4 hours each	12.00		
@ 30 minutes each		1.50	
@ 12 minutes each			.60
Test Labor @ $5/hour	5.00	1.50	.50
Overhead			
@ 125%	21.25		
@ 75%		2.25	.83
Subtotal (factory cost)	$104.25	$ 47.25	$ 13.93
G&A and Selling Expense			
@ 12.5%	13.03		
@ 18.0%		8.51	2.51
Subtotal	$117.28	$ 55.76	$ 16.44
Profit @ 15%	17.59	8.36	2.47
Reserve For Warranty @ 2%	2.08	.95	.28
OEMPrice	$136.95	$ 65.07	$ 19.19
Retail Price	$273.90	$130.14	$ 38.38

The following is a summary of the key material elements of the Stevens fluorescent ballast and the expected areas for cost reduction. The future quantity cost is based on an annual production rate of one million ballasts or more.

MATERIAL COST ELEMENT	NOW	FUTURE
Low power control devices and logic, including transistors, diodes, resistors, etc.	$ 34.50	$ 1.50*
Coils and other magnetics	18.00	4.00*
Power transistors and diodes	6.00	2.00
Miscellaneous components including diodes, capacitors, wire, PCB, case, etc.	7.50	4.50
	$ 66.00	$ 12.00

* Based on quotations from major international suppliers, minimum order one million pieces, includes tooling costs.

PROJECTED COST REDUCTION EFFORTS

Present Status of Development - The Stevens fluorescent ballast is presently designed to the level of "proof of concept" in that the units are produceable in quantity but are not yet designed to be cost effective in the intended application. There are four goals to be met in particular sequence:

1. Prove the energy efficiency of the concept in a practical environment.
2. Prove the repeatability of the design.
3. Prove the reliability of the design.
4. Design for cost effective operation.

The efficiency of the Stevens design has been proven in the labratory and will be verified during PG and E field trials expected to begin sometime during the summer of 1978. The repeatability of ballast performance will also be proven to a certain extent during these field trials in that between 300 and 600 ballasts will be installed and their combined performance measured.

The next step in the program is to redesign the ballast for reliability and cost reduction. In practice the two go almost hand in hand in that once custom ICs' and magnetics have been designed the reliability will increase dramatically and the cost will drop significantly.

The reliability of the present design has been estimated at between 30,000 and 70,000 hours MTBF in accordance with MIL STD 217, as modified. The major improvements in reliability will come about through the use of custom integrated circuits and improved magnetic elements. The ballast component count, a key factor in MTBF calculations, will be reduced from 160+ components to under 20. The most significant improvement gained from the use of integrated circuits lies in the fact that literally all of the components can be manufactured and tested under ideal manufacturing conditions and the package hermetically sealed to eleminate environmental changes from effecting circuit operation.

Cost effectiveness will be greatly enhanced at the same time because of drastically reduced manufacturing cost both in the materials and the labor area. One integrated circuit, which can replace several thousand components, can be produced for less than 50¢ in million quantity including test labor which is highly automated. Custom magnetic elements which now cost between thirty and forty dollars to produce can be manufactured for between four and six dollars in million set quantity.

Cost reduction to the levels projected will require further engineering effort. In addition, custom integrated circuit and magnetics fabrication will require a substantial investment in tooling costs to produce inexpensive devices. It is the purpose of producing these relatively expensive first ballasts to prove the way from a technical and performance standpoint so that the required investment can be made with relative assurances of success.

IX TEST RESULTS

Page 58 contains a summary of test data on the first nineteen 8441A fluorescent ballasts. Average efficiency improvement is approximately 30% in free air at full light output (6,300 lumens, nominal). These tests were conducted at Stevens Pleasanton facility using a Weston electrodynometer type wattmeter, a Clark-Hess model 235 electronic wattmeter, a Data Precision multimeter, and a Tecktronic J-16 photometer.

Line voltage and amperage was read directly from the Clark-Hess meter and checked against the Data Precision unit. The V.A. product was calculated (Volts times Amps), and the power factor was measured in two ways. The first column lists the calculated power factor (Watts divided by V.A.) and the second power factor reading was taken directly from the Clark-Hess instrument. Light output was taken using the J-16 photometer with two F40T12 standard 40 watt rapid start lamps which had been aged approximately 100 hours. Frequency was determined using a Tecktronic oscilloscope.

It should be noted that there is a difference between the wattmeters ranging up to four watts. Both instruments were calibrated using standard methods. It is thought that the difference in readings is do to high frequency components being implanted on the input power line. To double check the wattmeters a series of watthour tests were run utilizing a 277 volt kilo watt hour meter supplied and calibrated by Pacific Gas and Electric Company's, San Ramon Research Center. The PG and E KWH meter indicated power was being drawn at a rate about halfway between the Weston and Clark-Hess wattmeters further complicating the problem. The problem of accurately measuring watt input power is a complex one and Stevens engineering staff is looking into the matter further.

Stevens is designing an electronic wattmeter using a special semi-conductor chip developed by National Semi-Conductor Company which measures true power under a broad range of input voltages and currects and at higher frequencies than commercially available testing equipment. As the goal of the Phase I program was to supply fluorescent ballasts which would provide full light output with less than 77 watts input at better than .90 power factor, and this goal was met, further work in this area was deferred into Phase II.

One can see from the test results that the Stevens Ballasts generate full light output at .935 power factor at less than 77 watts input and thereby meets the program goals. It should be noted that these tests were run on A model ballasts. Since those tests were conducted several improvements were made which should improve base ballast efficiency further. Also, the tests were conducted at 277 volts input voltage. A further series of tests conducted at high line (305 volts) and low line (235 volts) indicates improvements as much as 44% over the conventional ballast. These tests are not included with the report as the series is not yet finished and will be published as an addendum at the appropriate time.

Page 59 displays a series of tests conducted using the Stevens ballast with the newer G.E. Wattmiser II high efficiency lamps and the Sylvania Supersaver I lamps. For equivalent light output the Stevens ballast draws approximately 63 and 65 watts. Please note that on these tests no attempt was made to reduce light output of the stevens ballast to that of the conventional ballast (this is done by making a simple adjustment on the ballast itself). A later series of tests will be conducted which will closely match light outputs. This data will be published as soon as it is available.

In summary the Stevens ballast has a basic efficiency of 29% when used with conventional lamps. With the more efficient lamps, the efficiency increases drastically. Another way of looking at this is to use a common method of comparison called Lumens Per Watt. This is the amount of light output divided by the power it takes to achieve that light output. The conventional ballast and lamp has an efficiacy of approximately 60-63 lumens per watt (LPW). With the Stevens ballast the efficiacy raises to between 75 and 80 lumens per watt. When the Stevens Ballast is utilized with the newer high efficiency lamps the efficiacy increases to 90-95 lumens per watt or a full 51% improvement over conventional coil and core ballasts and 25% over the best high efficiency premium coil and core ballasts.

STEVENS LUMINOPTICS CORPORATION
8441 277Volt AC FLUORESCENT BALLAST
TEST RESULT SUMMARY

	LINE VOLTS	LINE AMPS	V.A	WESTON POWER	CLARK HESS POWER*	pf	pf *	LIGHT	FREQ	% EFFICIENCY IMPROVEMENT
Conventional Ballast	277	.361	100	96.1	98.2	.94	.97			
Stevens Serial Number										
001	277	.297	82.27		75.8	.92	.98	100%	20	27
002	277	.286	79.22		73.0	.92	.954	100%	20	32.0
009	277	.3146	87.14	74.0	80.0	.92	.961	100%	20	30.0
010	277	.3007	83.29	74.0	79.1	.95	.961	100%	20	30.0
011	277	.3125	86.56	74.5	80.0	.92	.92	99%	20	28.7
012	277			73.0				99%	20	31.7
013	278	.3062	85.12	75.0	80.7	.95	1.0	100%	20	28.0
014	277			76.0				104%	20	27.0
015	277			75.0				102%	20	28.5
016	277	.320	88.64	76.0	81.23	.92	.90	101%	20	26.3
017	277	.315	87.26	75.0	80.3	.92	.88	102%	20	28.7
018	277	.299	82.82	72.5	78.1	.95	.966	99%	20	32.7
019	277			72.0				100%	20	33.0
020	278	.3006	83.57	74.0	79.3	.95	.96	100%	20	30.0
021	277	.304	84.21	73.5	79.1	.94	.91	100%	20	31.0
023	277			75.0				100%	20	28.0
024	277	.306	84.74	75.0	80.8	.95	.956	101%	20	28.3
025	277			74.0				100%	20	30.0
026	277			72.0				101%	20	33.4
AVERAGE	277	.301	84.67	74.1	78.93	.933	.9435			29.82%

* Clark-Hess Model 235 electronic wattmeter

STEVENS LUMINOPTICS CORPORATION
TEST SUMMARY
WATTMISER II AND SYLVANIA SUPERSAVER I LAMPS

WATTMISER II LAMPS

	G .E.* CORE	G .E.** MAX	UNIV*** CORE	ADV MK 3	STEV-ENS	STEV-ENS
INPUT VOLTAGE	120.0	120.0	277.0	277.0	277.0	277.0
INPUT CURRENT	.730	.660	.315	.265	.360	.305
POWER INPUT	81.0	77.0	82.0	71.0	93.0	76.0
POWER FACTOR	.92	.97	.94	.97	.93	.90
LIGHT IN FOOT CANDLES	44.1	46.1	43.6	42.8	63.2	53.0
RELATIVE EFFICIENCY (FOOT CANDLES/POWER IN)	.55	.60	.53	.60	.68	.70
LAMP TEMPERATURE	40.2	40.9	40.8	39.6	39.3	39.9

SYLVANIA SUPERSAVER I LAMPS

INPUT VOLTAGE	120.0	120.0	277.0	277.0	277.0	277.0
INPUT CURRENT	.740	.675	.320	.260	.325	.360
POWER INPUT	82.5	79.0	83.0	72.0	82.0	94.0
POWER FACTOR	.93	.97	.94	.98	.92	.94
LIGHT IN FOOT CANDLES	42.4	45.0	42.3	41.3	53.7	62.6
RELATIVE EFFICIENCY (FOOT CANDLES/POWER IN)	.51	.57	.51	.57	.65	.67
LAMP TEMPERATURE	28.5	29.4	29.0	28.3	29.6	41.0

* Standard GE core ballast

** High efficiency Wattmiser ballast

*** High efficiency core ballast

April 25, 1978

Rudy Verderber
Technical Representative
U.C. Lawrence Berkeley Labratory
Berkeley, California 94720

Dear Mr. Verderber:

We are in receipt of LRL report number 378-8 dated March 24, 1978 describing tests performed on our 8441 Fluorescent electronic ballast. We are quite pleased with the test results, however, we do wish to comment on the test notes given in the report and desire that a copy of this letter be included with the report when distributed outside LBL.

Our comments will follow the format of the report.

Page 1- Comment - LRL indicated that ballasts serial numbers 007, 009, 016, 020 and 021 failed during testing.

The units were returned to us and we have completed a failure analysis for the units. Serial number 007 had a blown input line fuse and a shorted transister in the input line conditioning circuit. This was most likely due to a large transient. Serial numbers 009, 016, and 021 had blown input fuses. When the fuses were replaced, the units operated satisfactorily. Serial number 020 had a blown fuse which was caused by a short to ground in the +24 volt logic power supply. The problem was traced to a manufacturing defect.

As you are aware, the first sixteen units submitted to LBL did not have transient protection circuitry included nor were they open circuit protected. These modifications are planned for the Phase II build and were not included in the initial batch because of internal scheduling problems. It appears likely that 007's failure was due to a line transient which won't happen on later updated units. With regard to the failures of 009, 016, and 021, we can only speculate on the possible reasons for failure. It appears that the failures were caused by either a short duration line transient or a defect in the testing proceedure in that if the tests were performed with grounded test equipment it might be possible to get an unexpected "sneak" path to ground which would cause the fuses to blow. During our initial testing we had some similar in-house problems. In as much as we were not present during the testing it is difficult to state conclusively what caused the ballasts to fail. We do know that once the units were returned to operation they performed as specified and have operated some 216+ hours to date without failure.

As a matter of interest, if the gray, blue, red, violet, or brown leads from the ballast are accidentially shorted to ground the fuse will blow without damaging the unit. If the yellow wire is grounded nothing will happen and if the organge wire is grounded the ballast may be damaged (along with blowing the fuse). Needless to mention that under normal operating conditions these wires are attached to specific places and would not be grounded or inadvertantly misplaced.

We wish to take issue with the reports conclusion that the units "are too sensitive to abnormalities in operating conditions, and would not be adaptable to field conditions". The reader should be aware that these are pre-production units and that we have not yet built a sufficient quantity of units to draw any sweeping conclusions that would be statistically significant. It is highly unlikely that any potential end user would perform tests similar to the ones done in the report. We have had at least four units, on an in-house testing fixture, that have accumulated in excess of 2,500 hours under strenuous conditions and feel that with modification to update the ballasts to latest configuration the units will operate satisfactorily in the manner intended.

Page 2

With regards to the efficacy tests in both free air and in the calorimeter, it should be pointed out that while the Stevens ballast is twenty nine (29%) more efficient than the standard 2-40 coil and core ballast, and 11% more efficient than the best "high efficiency" premium core and coil ballast, we anticipate considerably more improvement in the design as we approach the production engineering phase of the program. As correctly pointed out on page 4 of the report, the Stevens ballast is running a little hotter than is necessary and this is an area for improvement. The reader should also be aware that our approach was to first optimize the ballast lamp interface and second to optimize the ballast as a power source. We can forsee a production ballast with system efficiencys in the order of 90-100 LPW using new high efficiency lamps coupled with the Stevens ballast. The reader should also be aware that considerable additional engineering resources will have to be applied before the 90-100 LPW efficiency can be obtained and that the maximum presently obtainable with the existing designs' is probably 80 LPW, which is significant.

The starting times for the Stevens ballast may seem a little excessive when first evaluated. The reader should be aware that there are two independant power supplies contained within the ballast. The first controls the heater power and the second controls the main lamp drive. In the Stevens design, the heaters are sequenced and allowed to come up to full power before the main inverter supply is turned on. It is thought that by allowing the heaters to warm up thouroughly before lamp drive is applied that the life of the lamp will be extended, or at very least, not reduced. Four seconds was the minimum time selected for heater warm up as this appeared to be the point where the lamps would never "instant start", a highly undesireable condition which adversely effects lamp life. The timing is performed by analog circuits with admitted large variances in sequence times (4-7 seconds). The next generation of ballasts will have a digital sequencer with much closer control of timing. The reader should know that with the present design the heater power is a function of inverter power and it is therefore possible to control the heater power in accordance with a number of different control schemes. We purposely designed this option into the ballast so that we can keep up with the collective wisdom of the industry without having to redesign the ballast should it decide that one control sequence or schedule is better than another.

Page 2

III C - It is unfortunate that LRL was not able to test the ballasts at low temperatures because of inoperative units. The Stevens ballast displays excellant regulation (both input and output) and should start reliably even under extreme variations in temperature.

IV Using a normal voltmeter, the open circuit voltage would probably read zero or close to zero. The reason for this lies with the unique control characteristics possible with an electronic ballast. Essentially, the ballast applies starting voltage accross the lamp for very short periods of time. If a lamp is present, the lamp fires and the voltage applied adjusts to the characteristics of the lamp. In the event a lamp is not present the ballast automatically senses that the load is missing and shuts itself down for a short period of time and then repeats the sequence. An oscilloscope must be used to measure open circuit voltage with the Stevens design and the resultant will be the maximum voltage present, the amount of time it is present, and the sequence interval.

Page 3 VII The ballasts submitted for testing by LRL were pre-production units and were much noisier than those expected to be produced for Phase II. The reason for this is twofold. One, because of the limited number of ballasts produced, it was not possible to purchase magnetics manufactured under stringent conditions and we therefore were forced to manuafcture the units in-house under something less than ideal conditions. The noise emanates from three magnetic elements (pot cores) and is magna-strictive in nature both in the 120 HZ and 20KHZ range. We have since received samples of cores manufactured by a division of TRW which are very quiet. Secondly, the sample ballasts submitted to LRL were not potted as noted in the report. Potting appears to eliminate the noise problem completely and it is anticipated that the ballasts submitted under Phase II will be potted. A sound rating of A is achieveable with the present design.

Page 3 X - With regard to decreased power factor with dimming, it should first be noted that the Stevens ballast exhibits a leading power factor under all conditions. For the units submitted to LRL, the input conditioning circuitry (which corrects for power factor) was optimized for good power factor at high output levels. An engineering evaluation was performed in-house to determine what work was necessary to be done to correct the power factor for all output levels. Our conclusion was that the power factor would be corrected during the production engineering phase of the program due to a limitation on the resources available to us at this time to accomplish the necessary work. We have demonstrated very high power factors (.95 or better) under all conditions in the labratory and do not feel that very much would be gained by optimizing the input conditioning circuitry at this time.

All things considered, we commend LRL for their report and wish to add the above comments in order balance out the report. The reader should also be aware that the Stevens ballast is not yet ready for commercial mass production and that additional engineering is necessary before large runs can commence and that the solutions to the mentioned problems have been worked out and will be implemented at the appropriate time.

Sincerely,

W.R. Alling
Executive Vice President

WRA/kma

LIGHTING RESEARCH LABORATORY

Design • Testing • Consulting

3-24-78 REPORT 378-8

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

Attn: Mr. R. R. Verderber

Subj: Test of light output and electrical characteristics of six samples of commercial 2/40W High Frequency ballasts as mfd. by Stevens Lumenoptics; reference Uc Purchase Order 2889502 Section E, and Change Orders #1 and 2. 8441-803 Series Units.

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. Relative accuracies and instrumentation are as described in LRL 677-5, which see.

Results: Test elements and results are tabulated in Tables I and II.

Comment: Comment is keyed to classifications under "Scope" in subject Purchase Order and C. O. #1 and 2. Not all tests were possible on all units, because as test sequence progressed, samples of unit failed. Although great care was taken to avoid conditions which might lead to failure, five of six samples failed during test program. Failures occurred as follows:

007 - Never lighted lamps
016 - Failed after dummy load tests
021 - Failed during measurement of line current waveform
009 - Failed during noise level test
020 - Failed during noise level test

While reason for failures is not known, it is felt that the samples as submitted are too sensitive to abnormalities in operating conditions, and would not be adaptable to field conditions.

I. Efficacy

A. Free air tests. Average free-air efficacy for the "high-efficiency" 60-cycle ballast reported in LRL 677-5, and representing the current state of the art, is 67.4 LPW. The five samples of Stevens tested averaged 74.9%, an increase of 11% over the HE 60Hz unit. This is indicative of the performance to be expected in industrial, suspended commercial, and bare-lamp units.

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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.

B. Calorimeter tests.

1. Four lamp unit tests. As reported in 677-5, the HE 60Hz ballast produced 9773 lumens at 62.5 LPW. The Stevens produced 12036 at 75.4 LPW, an improvement of 21% over the HE 60Hz. These are the best figures so far encountered, and are an improvement of 29% over a standard model 60-Hz ballast.

2. Two lamp unit tests. Evidently two lamps in a recessed 2 X 4 troffer are operated at a near-optimum temperature, as evidenced by an efficacy of 78.4 lumens per watt. Compared with the HE 60Hz unit value of 66.4, this is an increase of 18%.

II. Regulation. All of the Stevens units showed excellent regulation, the average being 0.85% and the maximum 1.7%. This is far better than standard 60 Hz units.

III. Starting Characteristics.

A. Starting Time. These units have an exceptionally long starting time, ranging from four to seven seconds. I have been informed that this is due to a delay mechanism in the ballast which delays the application of high voltage until the cathodes are properly heated. The cathode voltage available for heating (see dummy load figures in line 13, Table I) should produce sufficient preheat in one to two seconds, and the delay should be shortened to these values.

B. Peak Starting Current. A value of 0.67 ampere was obtained in the one test conducted (See Fig. 5). This is 1.6 times normal operating current, and should not cause any problems.

C. Low-temperature starting. Since only one sample was still in operating condition at the time of this test, it was decided to determine if the unit would start reliably at 80% of rated voltage and 50°F, rather than chance failure based on an abnormally low input voltage. The unit started reliably at 80%.

D. Cathode circuit voltage. Voltage measured across a dummy load was used as an indication of starting voltage. During this period the waveshape is nearly a square wave (See Fig. 6). This is probably due to the clipping action of the protective circuit within the ballast. After the unit starts, the cathode voltages drop to a much lower value, which is advantageous from an energy conservation standpoint. If the dimming control is operated, the cathode voltages rise again, reaching maxima as shown in Table I at an intermediate setting of the dimmer control.

IV. Open circuit voltage was not measured.

V. Crest Factor and Waveshapes.

A. Primary current. Substantial harmonic content is present, mostly at high frequency. The amount is not excessive, as seen by the high power factors obtained. See Fig. 2. Crest factor is 1.48, not much above that for a sine wave.

B. Secondary (lamp) current. The waveshape of the secondary current is essentially a sine wave, and its crest factor therefore 1.41. See Fig. 3.

C. Secondary (lamp) voltage. Somewhat surprisingly, the secondary voltage exhibits a peaked waveform, which contains a fair amount of third harmonic distortion and has a crest factor of 1.64. While this is not excessive, it does preclude the lamp from reflecting a power factor of unity. It should be noted that the smooth waveforms exhibited should result in less EMI than usual.

VI. Power Factor. All of the comments in Section VI of 677-5 apply to evaluation of the absolute magnitudes of power factor obtained. Reference to Fig. 1 will show that the voltage and current are essentially in phase, which means that the reduction in power factor is completely due to the harmonic content of the current waveform. In the secondary, voltage and current are again in phase, as is seen in Fig. 3. Less than unity power factor in this circuit, therefore, is also due to harmonic content. A harmonic analysis of this set of waveforms will probably show a power factor in excess of 98%. Refer to Sect. X for effect of dimming on power factor.

VII. Noise. Noise level tests were successful on only one sample. This showed a high noise level, equivalent to a Sound Rating of C or D, with strong components at 120 cycles (modulation) and at the secondary frequency of about 20 KHz (carrier wave). See Fig. 8. Since the units were not production samples and were not potted, this is only indicative. Also, when dimmed close to the lowest level, noise levels increased.

VIII, IX. Flicker and stroboscopic effect. The units showed no perceptible variation in light output over a cycle of line frequency (60 Hz). Reference to Fig. 7 will show a very fine serration showing a small variation at the secondary frequency (about 20 KHz). This small magnitude of variation at this high frequency results in flicker index and percent flicker that are both essentially zero.

X. Dimming. Performance of the units under dimming conditions are shown in Figs. 9 and 10. The units dim smoothly down to approximately 30% of their maximum output. No attempt was made to start the units at the low end of their dimming range. Efficacy drops to about 50 LPW at the end of the range, and the power factor to about 76%. The units operate at less than 90% power factor when dimmed to less than 35% of their maximum power level. Note that two dimming curves are shown relating light output to power level. The solid line is the best curve that can be drawn through the combined data points for the five units. However, the statistical significance of the data variations is such that a linear function such as that shown is probably just as valid, and perhaps more applicable to a large sampling of units of this type.

XI. Spectral Energy Distribution curves were not run for this unit.

66./

TABLE I - FREE AIR CHARACTERISTICS

LINE	ITEM						
1	Ballast	009	016	017	020	020	021
2	Lamps	9,10	9,10	9,10	9,10	4,5	4,5
3	Volts	277	277	277	277	277	277
4	Amps	.303	.310	.308	.301	.298	.303
5	Watts	79.0	82.0	81.4	78.8	78.7	78.5
6	Power Factor	.941	.955	.954	.945	.953	.935
7	Lumens	5880	6160	6140	5880	5880	5880
8	Efficacy, LPW	74.4	75.1	75.4	74.6	74.7	74.9
9	Regulation, 90%	-1.7%	-1.1%	-1.1%	-0.7%	-0.5%	-1.0%
	110%	+1.2%	+0.5%	+0.5%	+0.7%	+0.7%	+0.5%
10	Starting Time, 90%	7	5	6	4	5	6
	100%	7	5	6	4	4	6
	110%	7	5	6	4	5	6
11	Peak Start I, 100%						0.67
12	Crest Factor:						
	Primary Current	1.48		1.48			
	Sec. (Lamp) I	1.41		1.41			
	Sec. (Lamp) E	1.64		1.64			
13	Cathode Ckt Volt:						
	Yel Dum. Load		4.09	4.07			
	Full. L.O.		0.67*	0.40			
	Max***			4.16			
	Red Dum. Load		4.15	4.16			
	Full L.O.		1.30*	1.09			
	Max***			4.24			
	Blu Dum. Load		4.15	4.15			
	Full L.O.		0.17*	0.15			
	Max***			4.23			
14	Flicker Index	0.0					
	Percent Flicker	0					
15	Secondary Freq.,Khz		20.5	20.8			
16	Lamp Temp.	34	34	35	34	35	34
17	Rel. Noise Level**			49db			

* Varied considerably. Unit failed shortly thereafter
** V2S40-1#6 measured 36 db
*** Obtained by setting dimmer control for maximum cathode voltage

XII. Temperatures. It will be noted that temperatures obtained during calorimeter operation are quite similar to those obtained for standard, HE 60Hz ballasts as reported in Table II, page 12 of 677-5; and are quite dissimilar to those for the high-frequency ballasts reported in the same table. While no measurements were made of ballast temperatures, due to the pre-production nature of the samples, it was observed that the ballasts did attain temperatures comparable to those of 60 Hz ballasts. In other words, they got quite hot. Since this indicates that losses within the ballast were similar in magnitude to those for a 60 Hz ballast, the high efficacy of these units must be due to improvements in the lamp operation itself. Part of this may be due to the constancy of light output over a cycle; part may be due to the low harmonic content and consequent high power factor of the secondary circuit. In any event, it is apparent that several watts could be saved by reducing losses in the ballast itself, and that the mode of operation is a very efficient one.

CERTIFIED FOR LRL:

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

Notes to Table I:

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

Line	Note
1	Ballasts furnished by client, Stevens 8441-803 Series, serial numbers as shown. Comparisons are made with Advance V2S40-1, #6 as tested in 677-5, calibration checked by reference to this ballast.
2	Lamps selected for equal light output ± 1%. Same lamps used as in 677-5.
3	Voltage accuracy ± 0.5%
4	Current accuracy ± 0.5% @ 60Hz, compensated to 800 Hz.*
5	Wattage accuracy ± 0.75%
6	Power Factor = Watts/Volt-Amps, Approx. accuracy ± 1%.
7	Measured by monitoring 90°CP of lamps @ 20 ft. Calibrated by complete photometry of lamps on both 60 Hz and 30 KHz. Calibration transferred to this series by reference to standard lamp traceable to NBS.
8	Lumens per Watt
9	Steady-state regulation, % change in light output at 90% and 110% rated voltage compared to that at 100% rated voltage.
10	Approximate time required to start lamps at 90%, 100% and 110% of rated voltage, lamps warm but deionized.
11	Peak current occurring during start cycle. See Comment IIIB.
12	Crest factor = peak current/rms current. Peak measured on calibrated oscilloscope, calibrated on sine wave. Crest factor for secondary voltage determined from waveform.
13	Measured on Fluke 8000, calibrated at 20 KHz
14	Determined by inspection of waveform
15	Measured by calibrated oscilloscope sweep. Accuracy ± 5%.
16	°C, measured by thermocouple affixed to bulb wall at point representative of lamp temperature. Figures are relative.
17	dbA reading for ballast installed on mounting plate in sound-isolating box. See Comment Part VII, and Fig. 8.

* No direct current component was found in the primary current.

TABLE II - CALORIMETER OPERATION

LINE	ITEM		
1	Ballast & Lamp	009-9,10	020-4,5
2	Combination	020-4,5	
3	Volts	277	277
4	Amps	.600	.297
5	Watts	159.6	78.7
6	Power Factor	.960	.957
7	Lumens	12036	6174
8	Efficacy, LPW	75.4	78.4
9	Regulation, 90%	-1.7%	-0.7%
	110%	+1.1%	+0.7%
10	Starting Time, 90%	7	5
	100%	8	5
	110%	7	5
11	Temperatures, °C		
	A. Ambient	25	25
	B. Plenum	36	30
	C. Lamp Compartment	53	42
	D. Ballast Compartment	47	37
	E. Lamp	60	48

Notes to Table II:

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

Line	Note
1	Both two and four lamp combinations were tested, to determine the effect of the two most common luminaire loadings, since they may be expected to differ from those with 60-Hz ballasting. See LRL 677-5.
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%.
8-10	See Notes to Table I
11	Temperatures measured by thermocouples and temperature bridge, accuracy ± 0.5°C. Thermocouple locations 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 inner and outer lamps D. Thermocouple suspended in center of ballast compartment E. Thermocouple fastened to lamp at same point as in free-air tests.

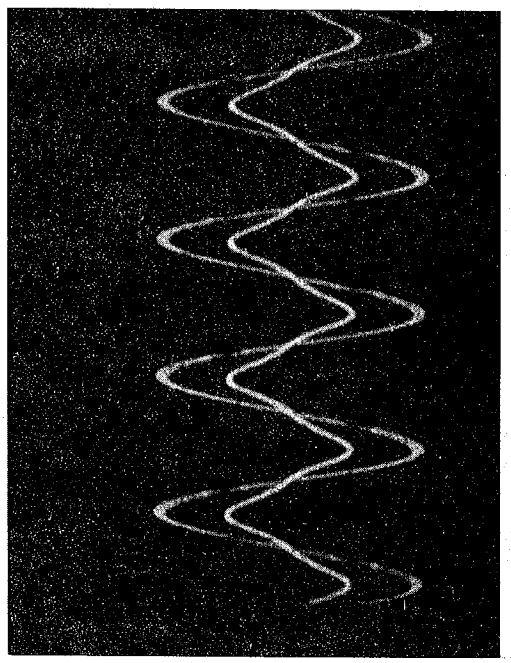

Fig. 3

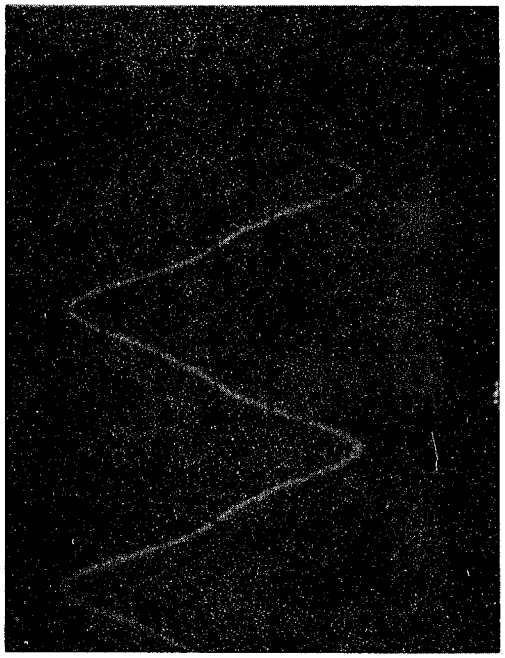

Fig. 4

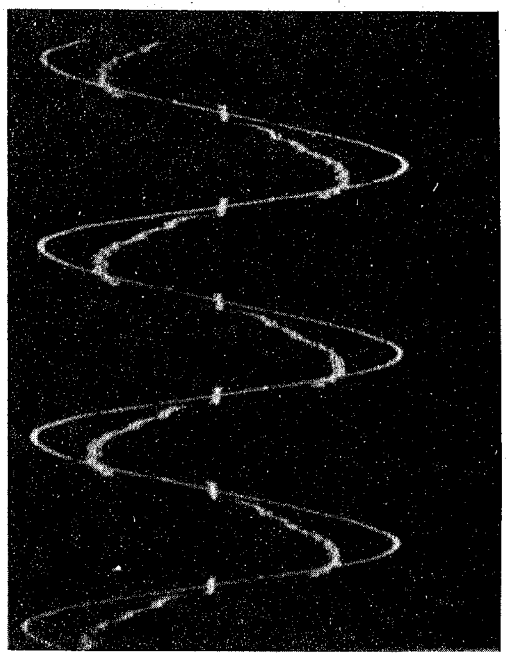

Fig. 1

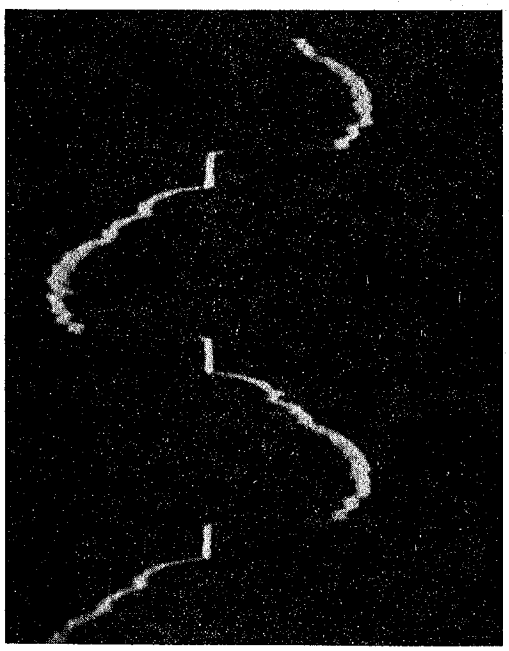

Fig. 2

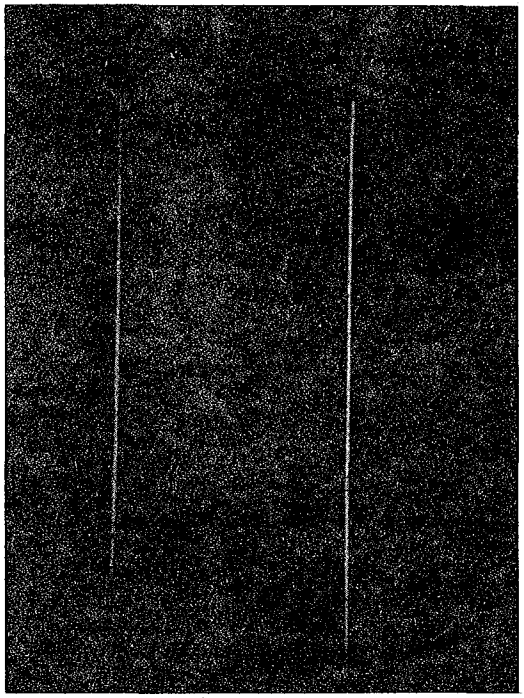

Fig. 7

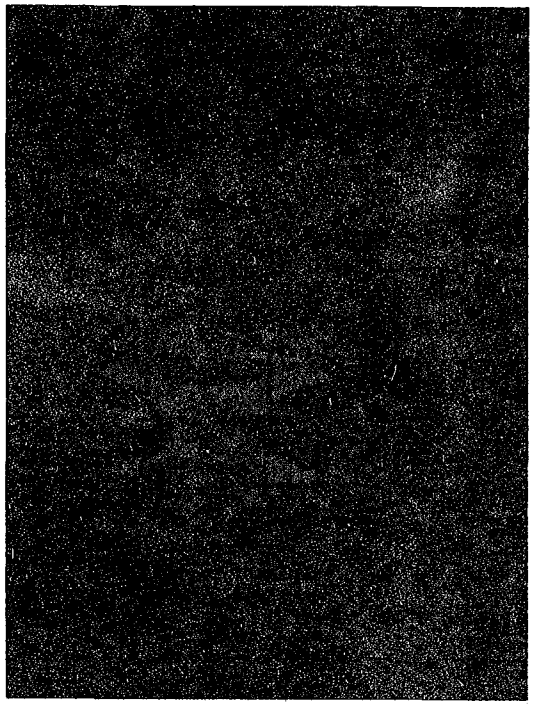

Fig. 8

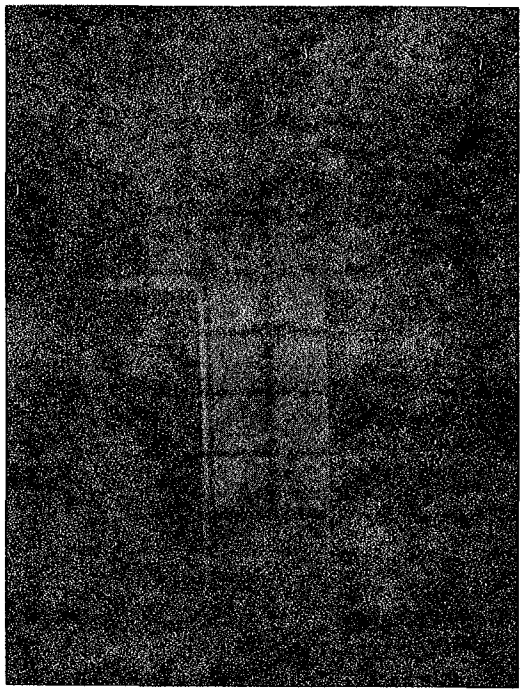

Fig. 5

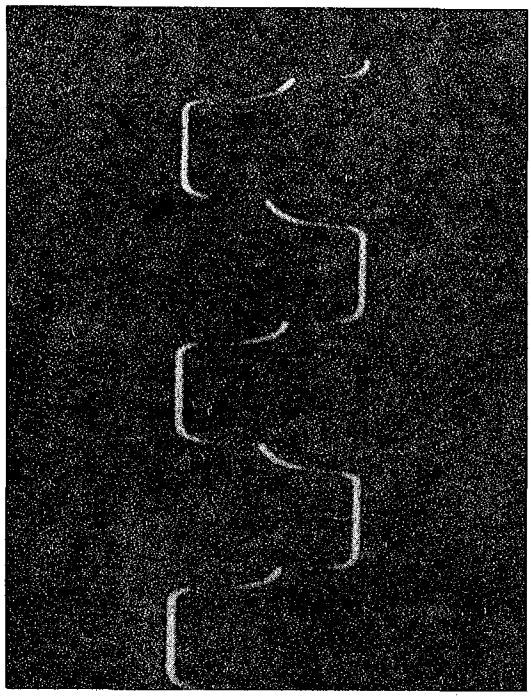

Fig. 6

CAPTIONS FOR FIGURES

1. Input voltage and current waveforms, typical of all samples, showing phase relationship. Frequency = 60 Hz

2. Input current waveform, frequency = 60 Hz.

3. Secondary (lamp) voltage and current waveforms, showing phase relationship. Frequency = 20KHz.

4. Secondary (lamp) voltage waveform. Frequency = 20KHz.

5. Typical start cycle, primary current. Horiz: 1 Scale Div = 0.5 Sec. Vert: 1 scale div. = 0.15 amp. RMS.

6. Cathode voltage across dummy load. Frequency = 20KHz

7. Light output variation. Frequency of fine serration on top line = 20KHz.

8. Noise waveform. Modulation frequency = 120 Hz. Base (carrier-wave) frequency = 20KHz.

LIGHTING RESEARCH LABORATORY

Design — Testing — Consulting

DIMMING CHARACTERISTIC STEVENS 8441-803 SERIES
AVERAGE RANGE: 30% to 100%

P.O. BOX 6193
ORANGE, CALIF. 92667

BILL F. JONES, P.E.
(714) 771-1312

● DATA POINTS
BEST AVERAGE CURVE
BEST LINEAR FUNCTION
%L.O. = 1.32(%PWR) - 32

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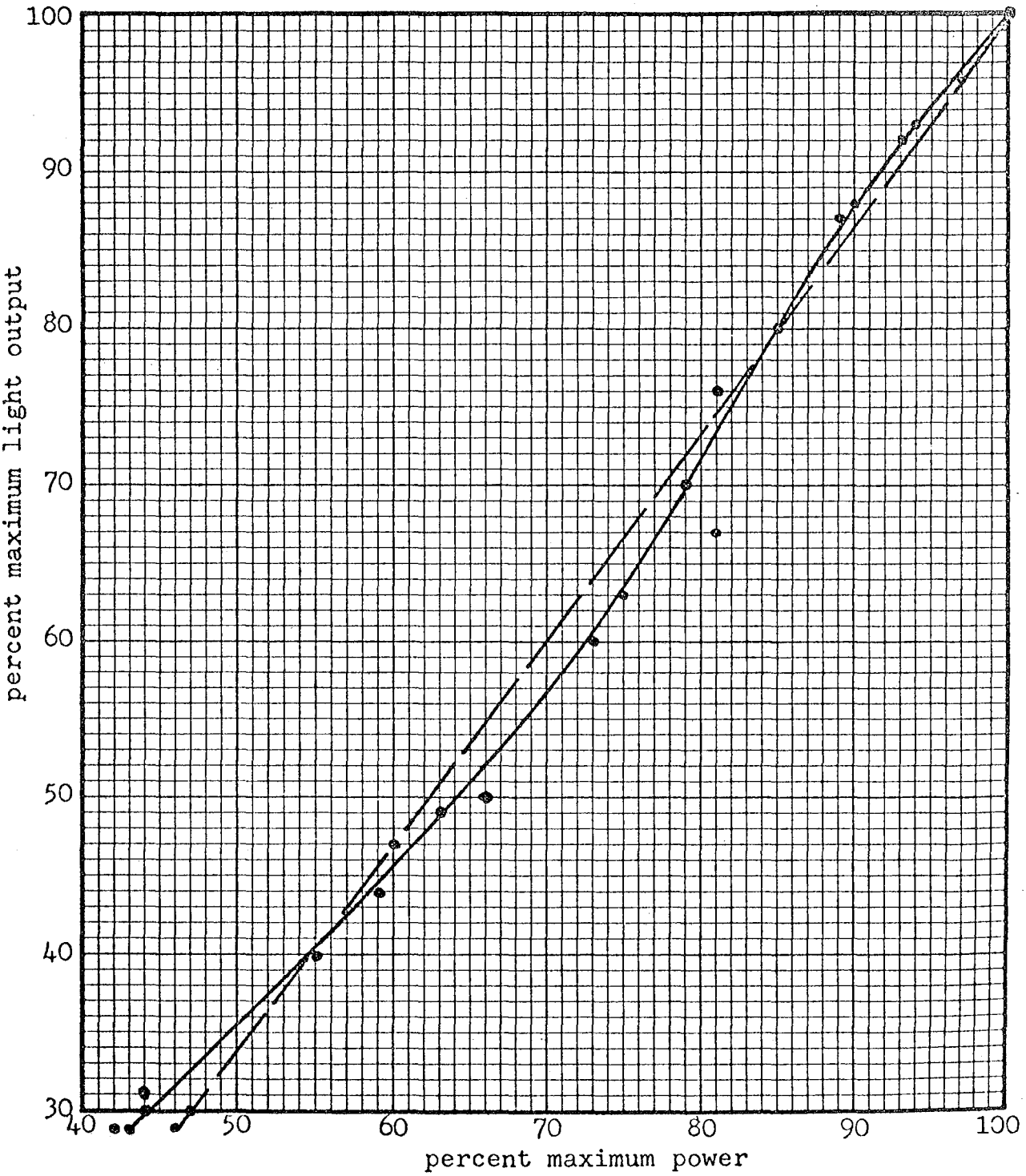

Unless otherwise stated, all tests are performed in accordance with IES or other applicable standard procedures; are accurate within standard photometric tolerances; and are based on rated performance conditions. LRL assumes no responsibility for applicability of this data to field conditions or to any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

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DIMMING CHARACTERISTICS STEVENS 8441-803 SERIES
POWER FACTOR VS. PERCENT MAXIMUM POWER

● DATA POINTS

——— BEST LINEAR FUNCTION
%P.F. = .306(%PWR) + 63.9

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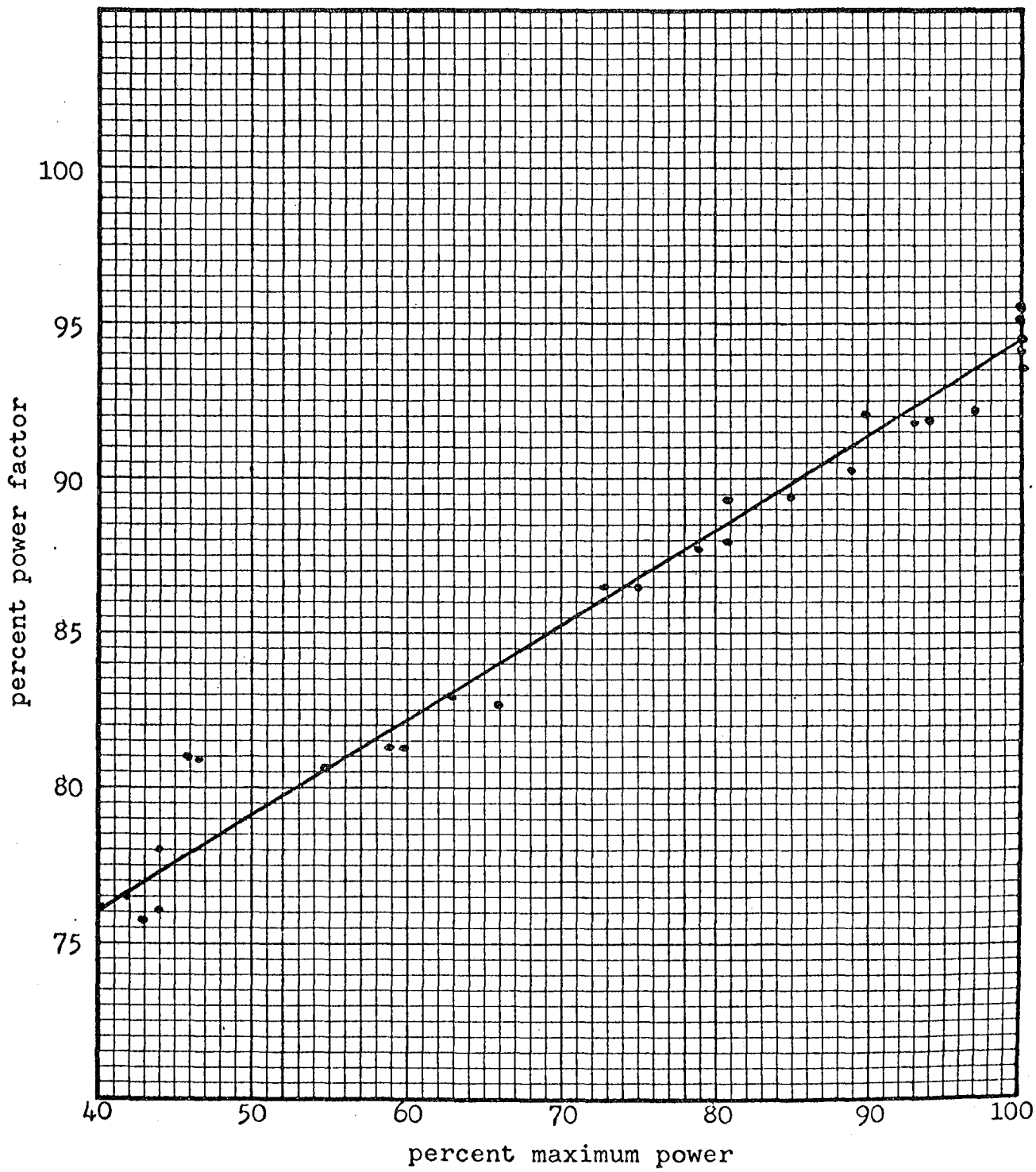

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This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley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