Title
QUALITY ASSURANCE ASSESSMENT OF NEW EFFICIENT LIGHTING SYSTEMS FOR NAVAL SHIPS: FINAL REPORT

Authors
Verderber, R.R.
Morse, O.
Dumm, C.

Publication Date
1984-12-01

LBL-18425 Rev.
UC-95c

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

APPLIED SCIENCE DIVISION

QUALITY ASSURANCE ASSESSMENT OF NEW EFFICIENT LIGHTING SYSTEMS FOR NAVAL SHIPS: Final Report

R.R. Verderber, O. Morse, and C. Dumm

December 1984

APPLIED SCIENCE DIVISION

Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

LBL-18425 Rev.
EEB-L 84-13
L-95

QUALITY ASSURANCE ASSESSMENT OF NEW EFFICIENT LIGHTING SYSTEMS FOR NAVAL SHIPS: FINAL REPORT

R. R. Verderber, O. Morse, and C. Dumm

Lighting Systems Research Group
Applied Science Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

December 1984

This work was supported by the U.S. Naval Research and Development Center under Contract No. 0167784RC00009 and partially by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Energy Research and Development, Buildings Equipment Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

ABSTRACT

Ballasts and lamps, which have been selected to replace existing lamp/ballast systems based on improved performance, were tested to determine if they meet standard Naval MIL specifications. Fifty ballasts manufactured by Advance Transformer Corporation and Universal Manufacturing Corp. and 100 lamps manufactured by GTE were tested to determine their quality assurance and durability. These components met all of the MIL specifications that lamp/ballast systems in use must meet. In addition, these new systems have an improved system efficacy, 62 lumens per watt, and lower third harmonics, which will reduce the need for generating capacity for lighting on ships.

Based on the results of this study, we recommend that these systems be used on ships to replace existing lamp/ballast systems.

An addendum to the original study describes the assessment of the performance of the advanced ballast system with a new F-17 fluorescent lamp. The results indicate the system performs reliably and shows increased efficacy. This new lamp/ballast system reduces the harmonic content to within Navy limits, and improves the power factor, resulting in a 50% reduction in line current. We have recommended its use on ships.

1.0 INTRODUCTION

This report evaluates the performance of 50 efficient, core-coil ballasts and 100 F-17, cool-white (CW), T-12, fluorescent lamps to determine whether they meet Navy requirements for use on ships. The ballasts were manufactured by Advance Transformer and Universal Manufacturing Corp. The EXP, F-17, CW, T-12 lamps were supplied by the GTE Lighting Division. These particular components were selected based on ballasts and lamps submitted by four lamp companies and four ballast manufacturers in a preliminary competition.

The assessment involves measurements of the quality assurance of the products, lumen depreciation of the lamps, life of the lamps and ballasts, harmonic content, conducted and radiated electromagnetic interference (EMI), and the thermal performance of the lamp/ballast systems.

2.0 REFERENCE DOCUMENTS

<u>Specifications</u>

MIL-F-16377F General Specification for Shipboard Use, Lighting, Fixtures and Associated Parts.

MIL-F-16377F Amendment - 1, 31 August 1971.

<u>Standards</u>

MIL-STD-461A Electromagnetic Interference Characteristics

Requirements for Equipment

MIL-STD-462 Electromagnetic Interference Characteristics

Measurement of

DOD-STD-1399 Section 100 and Section 300 - Interface Standard for Shipboard Systems, Electric Power, Alternating Current

MIL-STD-756A Reliability Prediction

<u>Other Publications</u>

The following documents form a part of this specification to the extent noted herein:

ANSI C82.1 - 1977 - Specifications for Fluorescent Lamp Ballasts

ANSI C82.2 - 1972 - Methods of Measurement of Fluorescent Lamp Ballasts

3.0 TASKS

3.1 Assess the performance of each lamp and ballast system submitted by

DTNSRDC in accordance with para. 3.1.6. This is a test for quality assurance.

3.1.1 Determine whether ballasts can be installed and easily replaced in Navy lighting fixtures described in Military Specifications Sheets MIL-F-16377/8,/11,/12, and /57.

3.1.2 Determine that ballasts conform to marking requirements and that color coding of leads is as specified in Section 4 of ANSI C82.1 - 1977.

3.1.3 The furnished fluorescent lamp will be 17-watt, pre-heat, cool-white lamp, Sylvania Part No. EXP, F-17, T-12, CW.

3.1.4 The government shall furnish ballasts from not more than two (2) different suppliers and lamps from one (1) supplier.

3.1.5 The government shall furnish twenty-five (25) ballasts from each supplier and fifty lamps (50) not later than 10 days after award date of contract.

3.1.6 The ballast/lamp system shall be measured for the following parameters:

(a) Input power, current, voltage

(b) Output power, current, voltage

(c) Flicker

(d) Harmonic content (1st to 32nd harmonic) per DOD-STD-1399 Section 300 6.2.7

(e) Voltage regulation $\pm 10\%$ of design voltage

(f) Light regulation, lumen output

3.1.7 The contractor shall provide a written report in accordance with DI-T-5247, which shall include all pertinent test data including, but not limited to, test procedures followed and test equipment used.

3.2 Determine performance of Government-furnished lamps over a lamp wall temperature range of $0^{o}C$ to $70^{o}C$.

3.2.1 The government shall furnish fifty (50) lamps not later than 10 days after award date of contract.

3.2.2 Report - Same as 3.1.7.

3.3 Assess the performance of ballast/lamp systems in Navy lighting fixture described in MIL-F-16377/8 in accordance with para. 3.3.2.

3.3.1 The contractor shall perform tests on not less than three (3) nor more than five (5) ballast/lamp systems.

3.3.2 The ballast/lamp systems shall be measured for following parameters:

(a) Radiated EMI per MIL-STD-462 Test Method RE02.

(b) Conducted EMI per MIL-STD-462 Test Method CE02.

3.3.3 Report - Same as 3.1.7.

3.4 Complete life test of fifty (50) lamps and fifty (50) ballasts supplied by the government under Request for Contractual Procurement (RCP) N0016782RC00237, Lawrence Berkeley Laboratory, DE-AC03-76SF00098. Measure performance at one thousand (1000) and three thousand (3000) hours.

3.4.1 Report - Same as 3.1.7.

3.5 Survey the United States lamp manufacturers for capability of furnishing off-the-shelf F-20, T-8, CW lamps in terms of efficiency.

3.5.1 Procure not less than five (5) nor more than ten (10) lamps for evaluation in accordance with the ballast/lamp systems found to be acceptable by the Government in accordance with para. 3.1.6.

3.5.2 Report - Same as 3.1.7.

3.5.3 Unless otherwise stated in this specification, all methods of performing the tests shall agree with those in ANSI C82.2 - 1972.

3.6 Final Report. Same as 3.1.7.

4.0 INITIAL CHARACTERISTICS

Twenty-five new efficient core-coil ballasts were received from two manufacturers (Advance and Universal), and 100 EXP, F-17, CW, T-12 fluorescent lamps were received from GTE. The ballasts conformed to the size requirements and all leads were properly color-coded. The ballast designs were based on the information supplied by Lawrence Berkeley Laboratory (LBL). The reference ballast settings for the new lamps were provided to the manufacturers along with samples of the new lamps. The reference ballast settings for the new lamps to obtain 1200 lumens are listed in Table I.

Table I

Reference Ballast Settings for EXP, F-17 CW, T-12 Fluorescent Lamps

Reference Ballast		Lamp Input	
Voltage	90.5 V	Voltage	59.1 V
Current	0.327 A	Current	0.327 A
Power	21 W	Power	17.9 W
Impedance	276.9 ohms		
Power Factor	0.071		
Volt-Amps	29.6 V-A		

The ballast manufacturers were to design the ballasts to obtain at least 92 1/2% of full light output (1200 initial lumens). The initial lumens of a lamp are a measure of the total light flux from the lamp after 100 hours of operation.

4.1 Quality Assurance of Ballasts

The quality assurance of the ballast is a measure of the uniformity of production. Variations in performance were measured for 20 Advance and 18 Universal efficient core ballasts, and compared with a standard Navy ballast manufactured by Starfield, measured four times. All the ballasts were measured in 25 $\pm$ 1°C ambient temperature with the same lamp (EXP, F-17, CW, T-12) to assure that any variation was due to differences among the ballasts. Several measurements with the same standard ballast demonstrated the experimental precision. Table II lists the results for the measurements at the center design voltage of 118 V.

Based on results, in which the mean variance in the parameters is 1% or less, the quality assurance of the efficient ballasts is acceptable.

The table also shows that the ballasts operate the lamp to produce at least 1200 initial lumens, i.e., the ballast factor is greater than 0.925.

Compared to the present ballast/lamp system efficiency of 50 lm/W, the new ballast/lamp system efficiencies are greater by factors of 1.24 and 1.21 for the Advance and Universal ballasts, respectively.

The other noteworthy feature of the new ballasts is the reduction in the third harmonics from 8.4% to 7.5 and 6.7%. The third harmonic is the only one that exceeded the 3% limit for both the standard and the new ballasts. After more than 5000 hours of operation, there have been no ballast failures.

Table II

Initial Performance of Ballasts with New Lamp (EXP, F-17 CW, T-12)

	Ballast		
Ballast Input	Starfield	Advance	Universal
Voltage (V)	118	118	118
Current (A)	0.364 ± 0.5%	0.303 ± 1%	0.328 ± 1.2%
Power (W)	2.54 ± 0.4%	19.4 ± 1.5%	20.9 ± 1.4%
Power Factor	0.59 ± 0.2%	0.54 ± 0.7%	0.54 ± 0.4%
Third Harmonic (%)	8.4 ± 1.5%	7.5 ± 2%	6.7 ± 2%
Ballast Output			
Voltage (V)	57.8 ± 0.3%	59.6 ± 0.3%	59.1 ± 0.5%
Current (A)	0.364 ± 0.5%	0.303 ± 1%	0.328 ± 1.2%
Power (W)	19.2 ± 0.5%	16.5 ± 0.6%	17.8 ± 1.1%
Ballast Factor (power ratio)	1.08 ± 0.6%	0.929 ± 0.9%	0.998 ± 1.1%
Lamp Output			
Initial Light Output (lm)	1350 ± 0.7%	1200 ± 0.9%	1270 ± 1.2%
Ballast Factor (light ratio)	1.08 ± 0.7%	0.959 ± 0.8%	1.01 ± 1.2%
Regulation of Light for ± 10% Voltage (%)	± 14 ± 7%	± 15 ± 4%	± 14 ± 4%
Flicker (%)	42 ± 3%	41 ± 2%	40 ± 3%
Lamp Efficacy (lm/W)	70.3 ± 1.2%	72.7 ± 1.5%	71.1 ± 2.3 %
System Efficacy (lm/W)	53.1 ± 1.2%	61.8 ± 2.4%	60.6 ± 1.9%

4.2 Quality Assurance of Lamps

4.2.1 Initial Light Output

The light output of 75 lamps (EXP, F-17, CW, T-12) as received was measured with the reference ballast in the integrating chamber. In the ambient temperature of 25 ± 1° C, the average light output was 1209 lumens with a mean variance of ± 1.6%. This is an acceptable product variance.

4.2.2 Lumen Depreciation

Lumen depreciation is a measure of the decrease in light output of a lamp with respect to length of operation. A total of 75 lamps were measured; 30 were operated with Advance ballasts, 30 with Universal ballasts, and 30 were operated with Starfield ballasts. A standard operating cycle of 3 hours on and 20 minutes off was used. The light output of the lamps was measured after 0, 100, 500, 1000, and 3000 hours of operation under standard ANSI conditions in the integrating chamber with the reference ballast.

The rate of lumen depreciation for this type of lamp is not expected to exceed 11% at 40% of rated life. The rated life of these lamps for this operating cycle is 9000 hours. Hence, the light output should be 89% of initial light output at 3600 hours.

The results of the lumen depreciation measurements are plotted in Fig. 1. The depreciations for lamps operated with the three different ballasts are shown. The large cross in the figure is the 89% level at 40% of life (3600 hours). The results show that the rate of lumen depreciation meets the manufacturers' ratings and there is no difference in rate of depreciation for lamps operated with the different ballasts.

The figure also shows the general depreciation curves for light-loaded and medium-loaded fluorescent lamps. The arc watts per phosphor area are ~ 0.1 watts per square inch (W/in.^{2}) for light-loaded lamps and ~ 0.25 W/in.^{2} for medium-loaded lamps. The loading for the EXP, F-17, CW, T-12 lamps is 0.15 W/in.^{2}. The general curves are based on the halophosphate-type phosphor. The results indicate that the phosphor used for the EXP, F-17, T-12 lamp exceeds the performance of the standard cool-white (CW) phosphor.

4.2.3 Lamp-Failure Rate

The lamps have been operating for more than 4650 hours, which is 52% of the rated-life (9000 hours). To date, five lamps and no ballasts have failed. The new lamps have been operated at a 3-hour-on/20-minute-off cycle. The times at which lamp failures have occurred have been monitored. Table III lists the times lamp failures have occurred and with which ballast the failed lamps were operated.

Table III

Lamp Failures

Operating Ballast	Time of Failure (h)	Percent of Life	Remaining Lamps		
			Advance	Universal	Starfield
	0	0	30	30	15
Universal	3410	38	29	30	15
Universal/Advance	3930	44	28	29	15
Universal	4270	47	27	29	15
Universal	4650	52	26	29	15

There have been several starter failures. No track of their failures has been made. When a failure is due to a starter, the starter is replaced and the lamp life test continued. The survival rates of lamps operated with different ballasts are listed in Table IV.

Table IV

Survival Rates of Lamps

Percent of Life (%)	Survival (%)				
	Universal	Advance	Standard	Universal and Advance	All Lamps
38	100	100	100	100	100
38	97	100	100	98	99
44	93	97	100	95	96
47	90	97	100	93	95
52	86	97	100	92	93

Figure 2 plots the survival rate of all the lamps (last column, Table IV). The solid curve in the figure is the general mortality curve for pre-heat start lamps operating at a 3-hour on/20-minute-off cycle. The survival rate is below the general mortality curve. However, the life tests are at 52% of life, where the mortality rate is low, and there is a large statistical variation.

Figures 3a, b, and c plot the data in Table IV on a more sensitive scale for different groupings of lamps. This figure shows that the survival rate of the new lamps operated with the Advance and Starfield ballasts are equal to or greater than predicted by the general mortality curve. If the excessive failure rate of lamps with the Universal ballast is real, we have identified no apparent reason for it from the data collected to date. One possible cause could be a slightly higher starting voltage which cannot be measured with the pre-heated starters. The data on starting at 70°C ambient shows that the input voltage at starting is less for the Universal system. This implies that the starting voltage across the lamp is greatest for these ballasts for the same input voltage to each type of ballast.

However, the life tests have not reached the sensitive portion of the mortality curve, 80 to 120% of rated life (7200 to 10,800 hours of operation). The present data for all the lamps provide some confidence that the survival rate will meet the Navy's requirements. The actual life of lamps on board ships will be considerably longer than measured with the standard testing cycle. Figure 4 shows the additional life expectancy of pre-heat fluorescent lamps for longer burning times per start. The Navy operates lamps almost continuously, thus lamp life is extended by a factor of 1.9 with respect to the 3-hour burning cycle.

4.3 Thermal Performance

4.3.1 Minimum Lamp Wall Temperature

The performance of a fluorescent lamp/ballast system is sensitive to the minimum lamp wall temperature (MLWT) at which the lamp is operated. This minimum temperature determines the mercury pressure in the lamp. The MLWT for the present lamp/ballast system (F-40 lamp and Starfield ballast) and the new lamp/ballast systems has been measured for one-lamp and three-lamp Naval fixtures. Table V lists the results.

Table V

Minimum Lamp Wall Temperature

Fixture	Starfield F-20 Lamp (°C)	Advance EXP F-17 Lamp (°C)	Universal EXP F-17 Lamp (°C)
One-lamp	46	44	45
Three-lamp	58	57	57

The table shows that on ships the MLWT for lamps in the fixture ranges from 46° C to 58° C, which is considered a relatively high operating temperature. The new ballast/lamp system will operate 1 or 2 degrees centigrade lower.

4.3.2 Comparison of 40 and 50°C MLWT Operation

All of the data collected on the present and new systems were measured at a MLWT of either 40°C or 50°C. Table VI shows the results of the various lamp/ballast systems at the two temperatures. The optimum operating condition for a fluorescent lamp occurs at an MLWT of 40°C. The table indicates that maximum efficacy is at 40°C. However, at the high MLWTs, the relative increase in efficacy of the new systems with respect to the present system (Starfield, F-20 lamp) is greater. As shown in Table V, this is the region in which lamps operate on ships.

Table VI

Performance at a 40 and 50°C MLWT

System Ballast	System Lamp	MLWT (°C)	Power (W)	Light Output (lm)	Efficacy (lm/W)	Relative Efficacy
Starfield	F-20	40	25.5	1220	48.1	1.00
Starfield	F-17	40	25.4	1350	53.1	1.10
Advance	F-17	40	19.0	1230	64.6	1.34
Universal	F-17	40	20.4	1300	63.8	1.32
Starfield	F-20	50	25.6	1130	44.1	1.00
Starfield	F-17	50	25.1	1330	52.9	1.20
Advance	F-17	50	18.7	1160	62.1	1.41
Universal	F-17	50	20.0	1250	62.5	1.42

4.4 Starting

The standard F-20, CW, T-12, fluorescent lamp/ballast system is specified to ignite in an ambient temperature from 10°C (50°F) to 70°C (158°F) at the center design input voltage. The new and present lamp/ballast systems were tested to measure the minimum starting voltage at 0° and 70°C. The measurements were taken in a thermal chamber capable of providing these ambient temperatures. Table VII lists the average starting voltages for the three types of ballasts for five EXP, F-17 lamps and three F-20 lamps in ambients of 0°C and 70°C. The table includes the input voltages at which the starter was fired and shows that the starting voltage was not limited by the starter, i.e., the lamp firing voltage always exceeded the starter firing voltage.

Table VII
Starting Voltage at 0° and 70°C

	Ballast Type					
	Starfield		Advance		Universal	
	Firing Voltage (V)		Firing Voltage (V)		Firing Voltage (V)	
	Starter	Lamp	Starter	Lamp	Starter	Lamp
EXP F-17 - 0°C	87	134	86	145	86	142
F-20 - 0°C	88	116	84	121	86	113
EX F-17 - 70°C	80	84	82	87	81	84
F-20 - 70°C	80	90	84	89	81	83

At 70°C ambient, the voltages at which the F-20 and EXP F-17 lamps will start are about the same. At 0°C, the new lamp requires a substantially greater input voltage. Since the Navy specification is based on the ANSI standards, these lamps are required to start at 10°C ambient. The low-temperature test was repeated, in which the center design voltage was applied while the ambient temperature was slowly increased from 0°C. At every 5°C interval, the lamp was tested to determine whether it would start. Table VIII lists the average starting temperature at which the lamps were ignited for five new lamps and three F-20 lamps.

Table VIII

Average Starting Temperature at 118 Volts

Lamp Type	Ballast		
	Starfield (°C)	Advance (°C)	Universal (°C)
EXP F-17	9	10	9
F-20	0	0	0

The average starting temperatures for the lamps meet ANSI standards for all the ballasts. The starting temperature is greater for the new lamps relative to the F-20 lamp, which suggests that the gas mixes in the lamps are different.

4.5 Harmonic Content

The Navy requires all electrical components on ships to limit any single harmonic peak to 3% of the fundamental frequency. Fluorescent lamps/ballasts were in use prior to these regulations, and they generated a third harmonic above this limit. Table IX lists the results of the three types of ballasts with the EXP, F-17 lamp.

Table IX

Magnitude of Third Harmonic

	Ballast		
	Starfield	Advance	Universal
Percent of Fundamental	8.4 ± 1.5%	7.5 ±2%	6.7 ± 2.1%

The results show that the new ballast systems still do not meet the 3% limit. However, they are an improvement over existing systems.

For each ballast type and an EXP, F-17 lamp, all harmonics up to the 32nd were measured. Table X lists the results for one ballast of each type.

Table X

Harmonic Magnitude

Harmonic	Starfield Peak	Starfield %	Advance Peak	Advance %	Universal Peak	Universal %
Fundamental (60 Hz)	17800	100	14900	100	15300	100
2	64	0.4	56	0.4	55	0.4
3	1490	8.4	1070	7.2	1160	7.6
4	13	0.1	12	0.1	13	0.1
5	164	0.9	191	1.3	202	1.3
6	26	0.1	19	0.1	24	0.2
7	18	1.1	104	0.7	113	0.7
8	7	-	6	-	5	-
9	17	0.1	24	0.2	28	0.2
10	3	-	2	-	3	-
11	62	0.3	35	0.2	35	0.2
12	9	0.1	5	-	8	0.1
13	8	-	23	0.2	24	0.2
14	8	-	4	-	4	-
15	39	0.2	29	0.2	28	0.2
16	7	-	3	-	3	-
17	12	0.1	12	0.1	15	0.1
18	12	0.1	8	0.1	7	-
19	24	0.1	18	0.1	19	0.1
20	11	0.1	4	-	5	-
21	11	0.1	14	0.1	14	0.1
22	7	-	8	0.1	7	-
23	22	0.1	9	0.1	8	0.1
24	9	0.1	11	0.1	10	0.1
25	17	0.1	6	-	8	0.1
26	9	0.1	9	0.1	12	0.1
27	9	0.1	8	0.1	7	-
28	8	-	9	0.1	11	0.1
29	5	-	6	-	7	-
30	6	-	6	-	8	0.1
31	5	-	2	-	2	-
32	9	0.1	1	-	3	-

Table X shows that all harmonics of the 60-Hz fundamental, except the third, meet Navy requirements.

4.6 Radiated and Conducted Electromagnetic Emissions

4.6.1 Experimental Procedures

The radiated electromagnetic fields (E-fields) from a single lamp/ballast system were measured in a screen room. Figure 5 is a schematic layout of the experiment. The spectrum analyzer was positioned outside the screen room. The lamp-antenna distance was one meter. Broadband measurements were taken with an impulse bandwidth of 150 Hz up to one MHz and with an impulse bandwidth of 1500 Hz above one MHz.

The conducted EM emissions were measured with the experimental setup shown schematically in Fig. 6. A current probe was employed to detect EMI levels. The high-pass filter was used to prevent overloading of the spectrum analyzer. Narrowband measurements were made over the frequency range of 60 to 20 kHz. Broadband measurements were made with an impulse bandwidth of 1550 Hz over a range of frequencies from 300 to 10 kHz.

4.6.2 Radiated EMI Results

The radiated electromagnetic interference (EMI) spectrum from the lamp/ballast system was broadband. Measures were made at 14, 33, 55, 100, 300, 500, and 800 kHz; 1 and 2 mHz results are plotted in Fig. 7. Measurements were also made at 2 and 20 mHz. The high-frequency data were below the instrument noise level. The measured data are presented in terms of dBμV/m/MHz so they can be compared to the Navy broadband (RE02) limit expressed in the same units. The limit is shown as a solid line in the figure. The dotted line is the measured instrument noise level and shows discrete changes because the instrument sensitivity had to be changed to prevent overloading of the spectrum analyzer.

The radiated broadband limit (RE02) is exceeded below 1 mHz and merges into the instrument noise level at 2 mHz. However, above 1 mHz, the RE02 limit is met. These results are similar to those that would be obtained with present lamp/ballast systems.

4.6.3 Conducted EMI Results

Figures 8 and 9 show results for narrow- and broadband conducted EMI, respectively. The broadband data have been plotted in units of dBμa/20 kHz in order to compare with the CE01 broadband limits. The conducted EMI meets the CE01 limits over the entire range of frequencies, 60 Hz to 20 kHz.

5.0 Advanced Lamp/Ballast Systems

In the course of the present Navy-supported effort, additional components (lamps and ballasts) were submitted for evaluation. Table XI lists the results that were obtained with an F-20, T-8 (1-inch-diameter) lamp, an advanced efficient core-coil ballast, and solid-state ballasts. The advanced lamp/ballast systems are compared to the present Navy system and the efficient-core ballast EXP, F-17 lamp system assessed in this report.

Table XI

Summary of Advanced Lighting Systems

System			Efficacy (lm/W)				
Number	Ballast	Lamp	Lamp	System	Relative	Power Factor	Third Harmonic (%)
1	Starfield	F-20	61	49	1.00	0.6	8
2	Efficient-Core	EXP F-17	66	60	1.22	0.6	6
3	Advanced Efficient-Core	EXP F-17	66	62	1.27	0.95	3
4	Advanced Efficient-Core	F-20 T-8	82	77	1.57	0.95	3
5	Solid-State	F-20 T-8	86	8.4	1.71	0.97	2

The systems are listed in order of the likelihood of their application. System 1 is in current use. System 2 has been tested and is ready for application. Advanced efficient-core ballasts have passed through advanced development and require the testing carried out for this report. The F-20, T-8 lamp is a laboratory prototype and requires initial evaluations such as those done with the EXP, F-17 lamp. Operating lamp specifications must be developed for the ballast design. The solid-state ballast is in the prototype stage for this particular Navy application. Thorough evaluation must be conducted to test its reliability, and its cost must be reduced.

The table shows that significant advances have been achieved in the development of a reliable, more efficient lighting system for ships. The relative efficacy has been increased by a factor of more than 1.2 with some reduction in the third harmonic. Near at hand is a more advanced efficient-core ballast that should be reliable, prove nearly 30% more efficient than the present system, and increase the power factor to over 90%, as well as reduce the third harmonic to meet Navy requirements. A 60% additional improvement in efficacy can be realized with the T-8 lamp. This system should also be as reliable as the present system. The solid-state ballast, which requires further development to reduce costs and establish a record of reliability, will nearly double system efficacy, reduce weight, obtain a near 100% power factor, and reduce the third harmonic well below the Navy's upper limit.

6.0 CONCLUSION

A total of 50 efficient core-coil ballasts submitted by Advance Transformer and Universal Manufacturing, and 100 EXP, F-17, CW, T-12 lamps developed by GTE lighting were tested according to Navy MIL-SPEC requirements (see section 2.0). The results show that these efficient ballasts equal or exceed the performance of the F-20 lamp/ballast system presently used on ships. The number tested and the reputation of the companies that submitted these short-run samples demonstrate that the units can be manufactured in large quantities. The uniform performance of the products is evidence that they can be manufactured to close tolerances so that they can meet Navy requirements.

Based on our results, we recommend that Navy procurement accept these products as equivalent replacements for existing equipment.

7.0 ACKNOWLEDGEMENT

This study was supported by the U.S. Department of the Navy under subcontract No. 0167784RC00009 and partially supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Energy Research and Development, Buildings Equipment Division, Energy Conversion Equipment Branch of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

The tests for this study were designed by Dr. Oliver Morse and measured by Mr. C. Dumm and Mr. C. Green.

Figure 1.

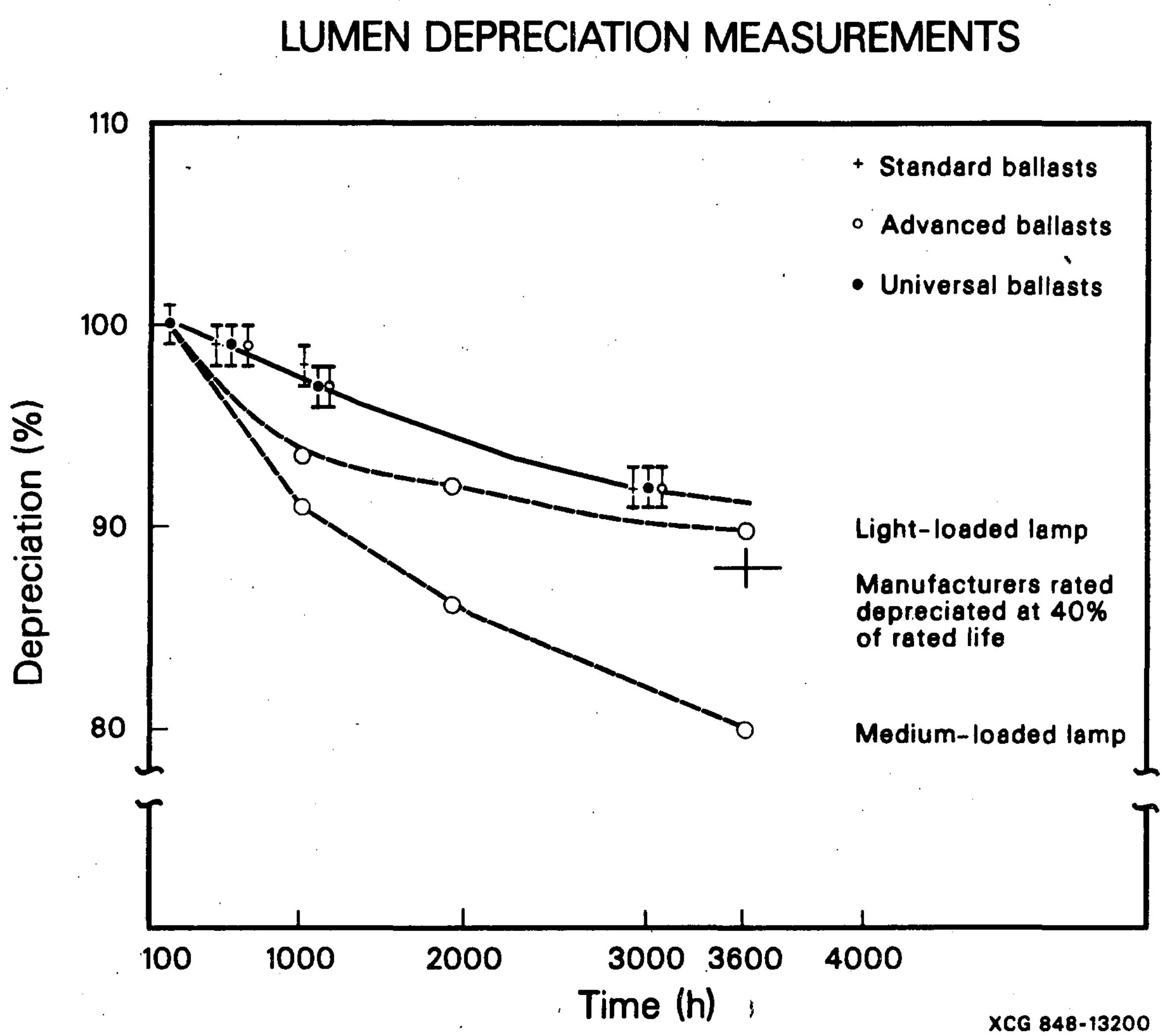
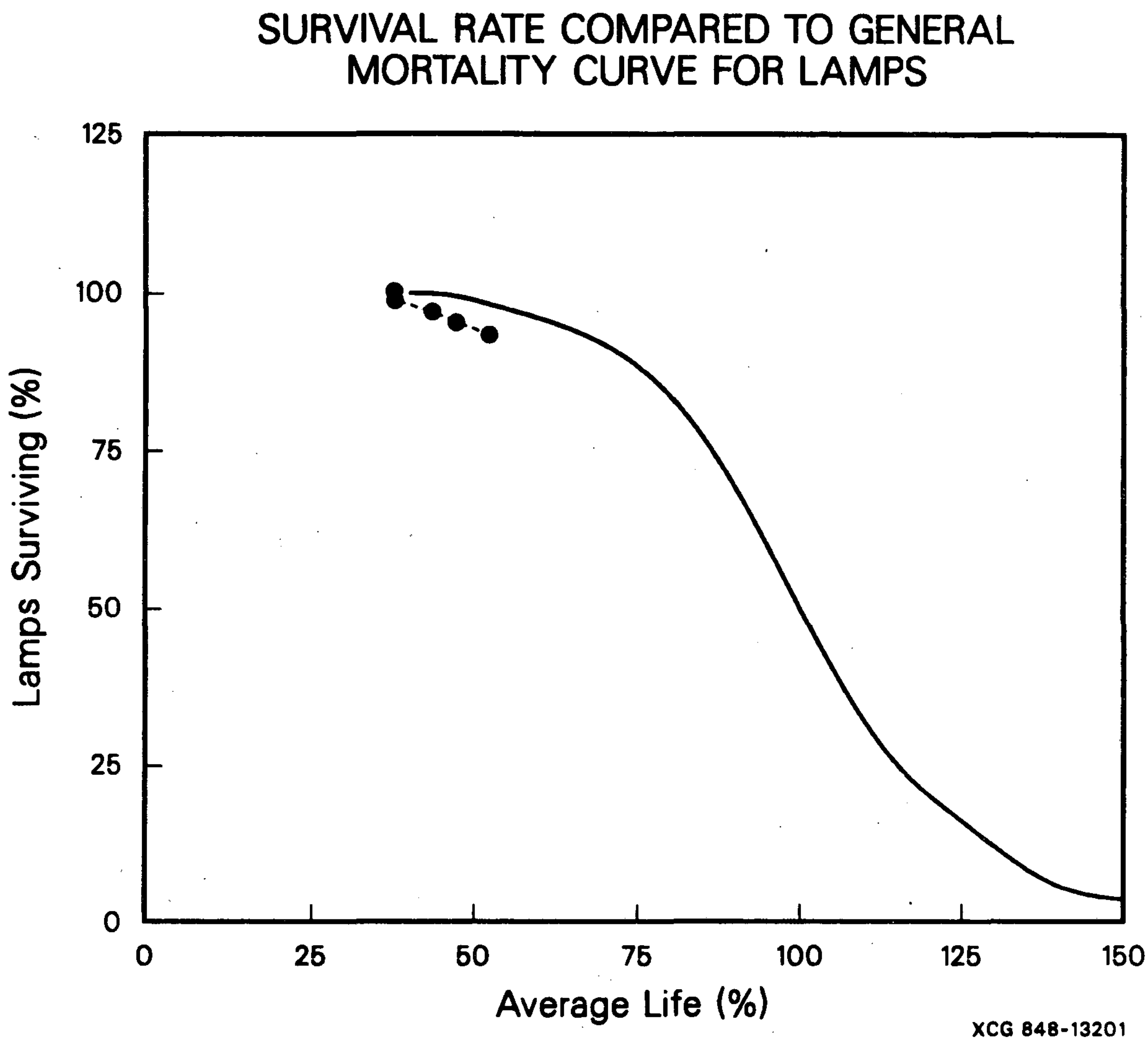
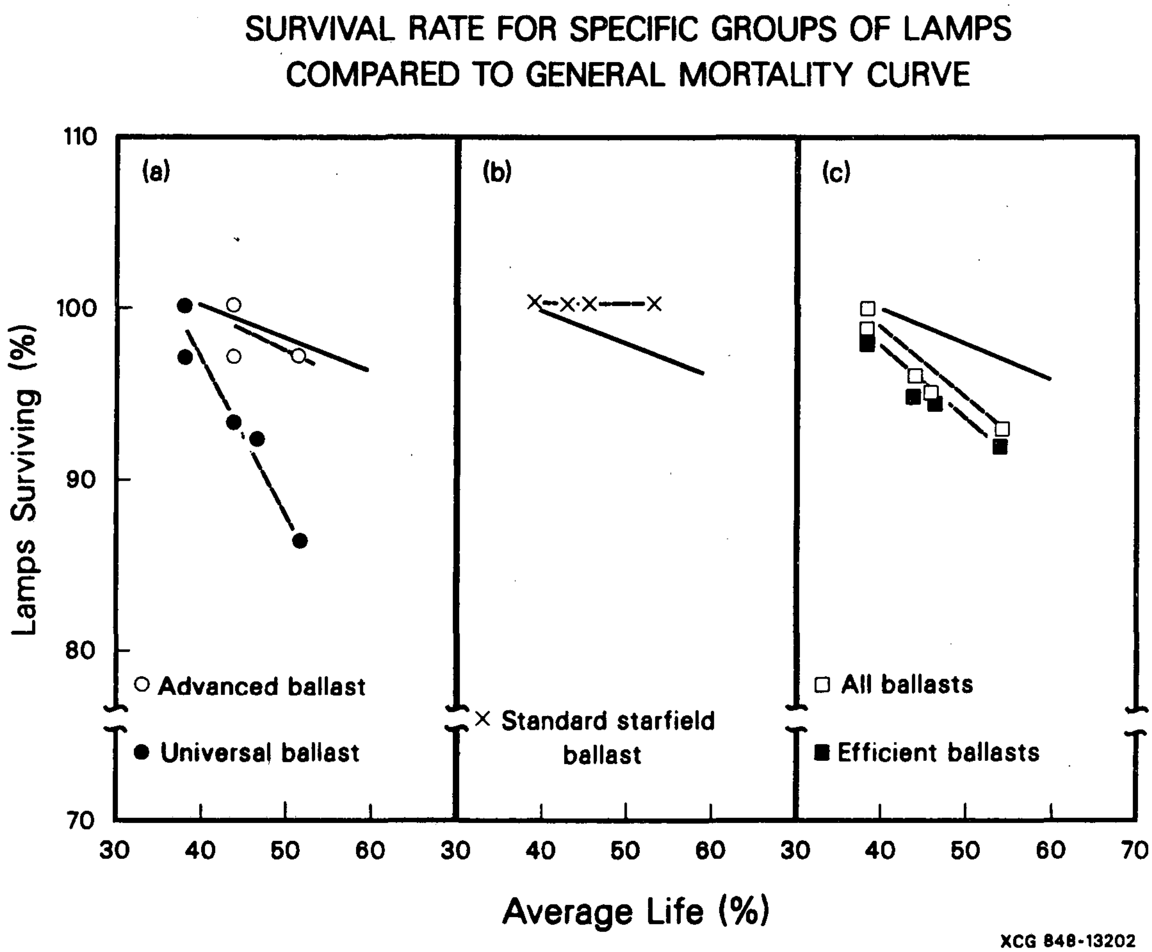

LUMEN DEPRECIATION MEASUREMENTS
110
100
90
80
Depreciation (%)
+ Standard ballasts
o Advanced ballasts
• Universal ballasts
Light-loaded lamp
Manufacturers rated depreciated at 40% of rated life
Medium-loaded lamp
100
1000
2000
3000
3600
4000
Time (h)
XCG 848-13200

Figure 2.



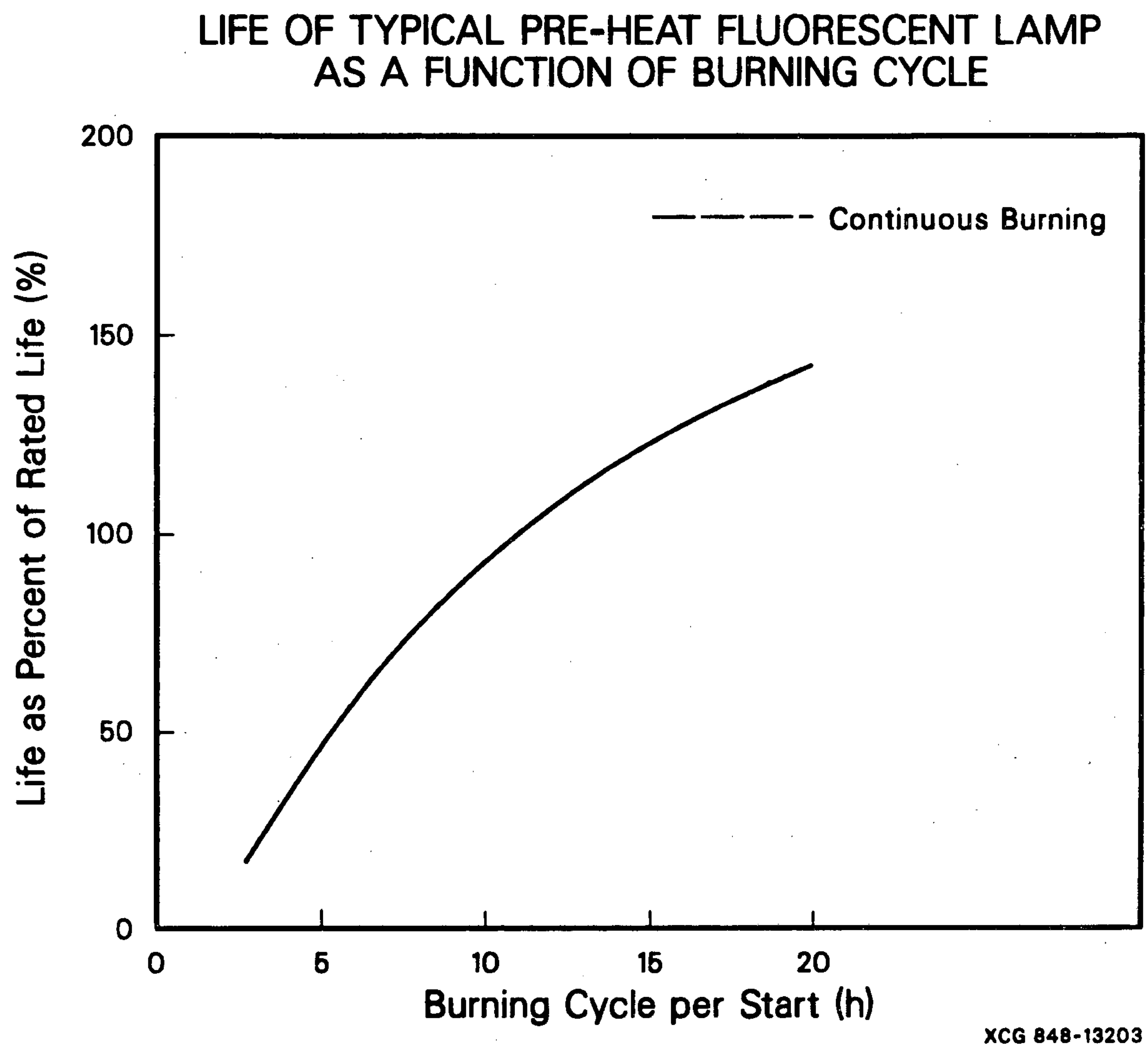
SURVIVAL RATE COMPARED TO GENERAL MORTALITY CURVE FOR LAMPS
Lamps Surviving (%)
125
100
75
50
25
0
0
25
50
75
100
125
150
Average Life (%)
XCG 848-13201

Figure 3.

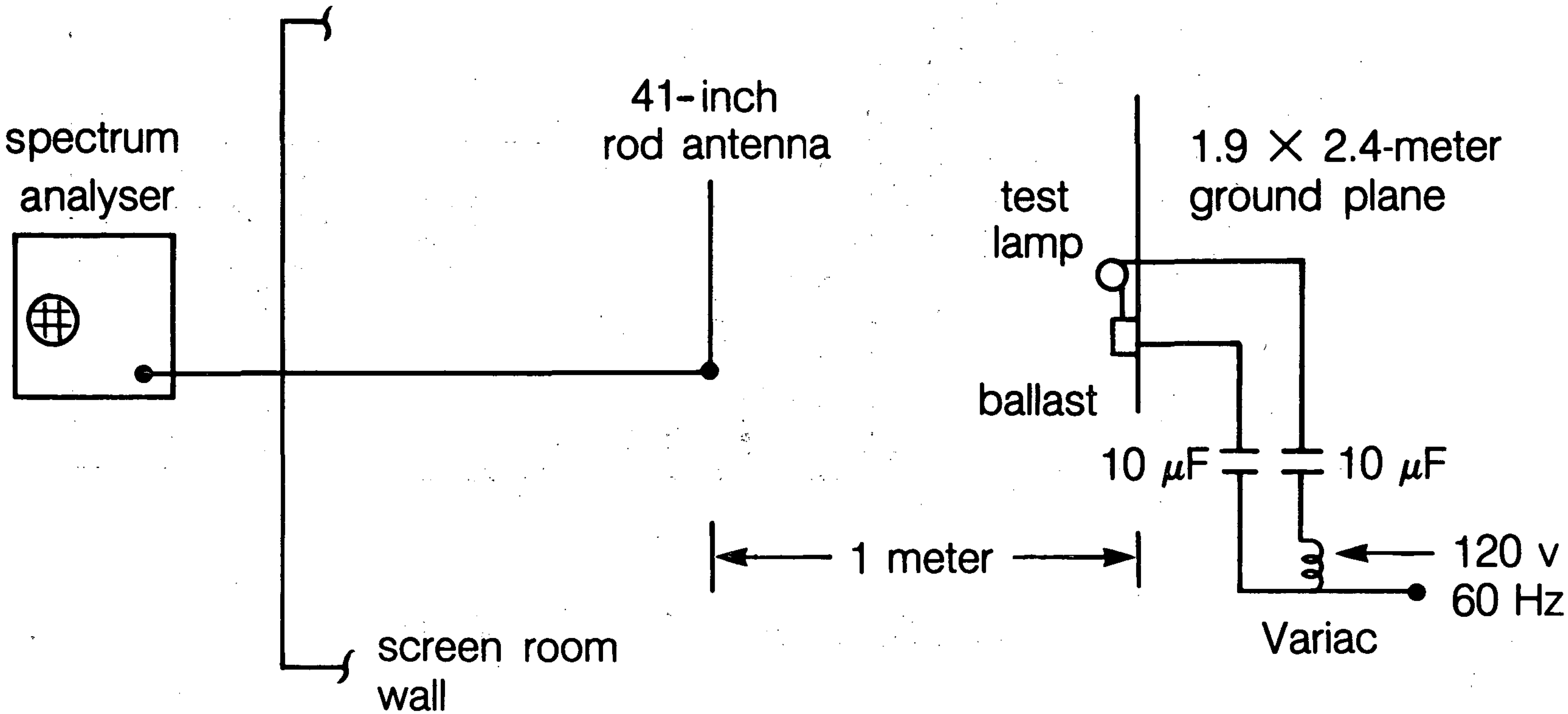


SURVIVAL RATE FOR SPECIFIC GROUPS OF LAMPS
COMPARED TO GENERAL MORTALITY CURVE
110
100
90
80
70
(a)
(b)
(c)
Lamps Surviving (%)
○ Advanced ballast
● Universal ballast
× Standard starfield ballast
□ All ballasts
■ Efficient ballasts
30
40
50
60
70
Average Life (%)
XCG 848-13202

Figure 4.


LIFE OF TYPICAL PRE-HEAT FLUORESCENT LAMP
AS A FUNCTION OF BURNING CYCLE
Continuous Burning
Life as Percent of Rated Life (%)
200
150
100
50
0
0
5
10
15
20
Burning Cycle per Start (h)
XCG 848-13203

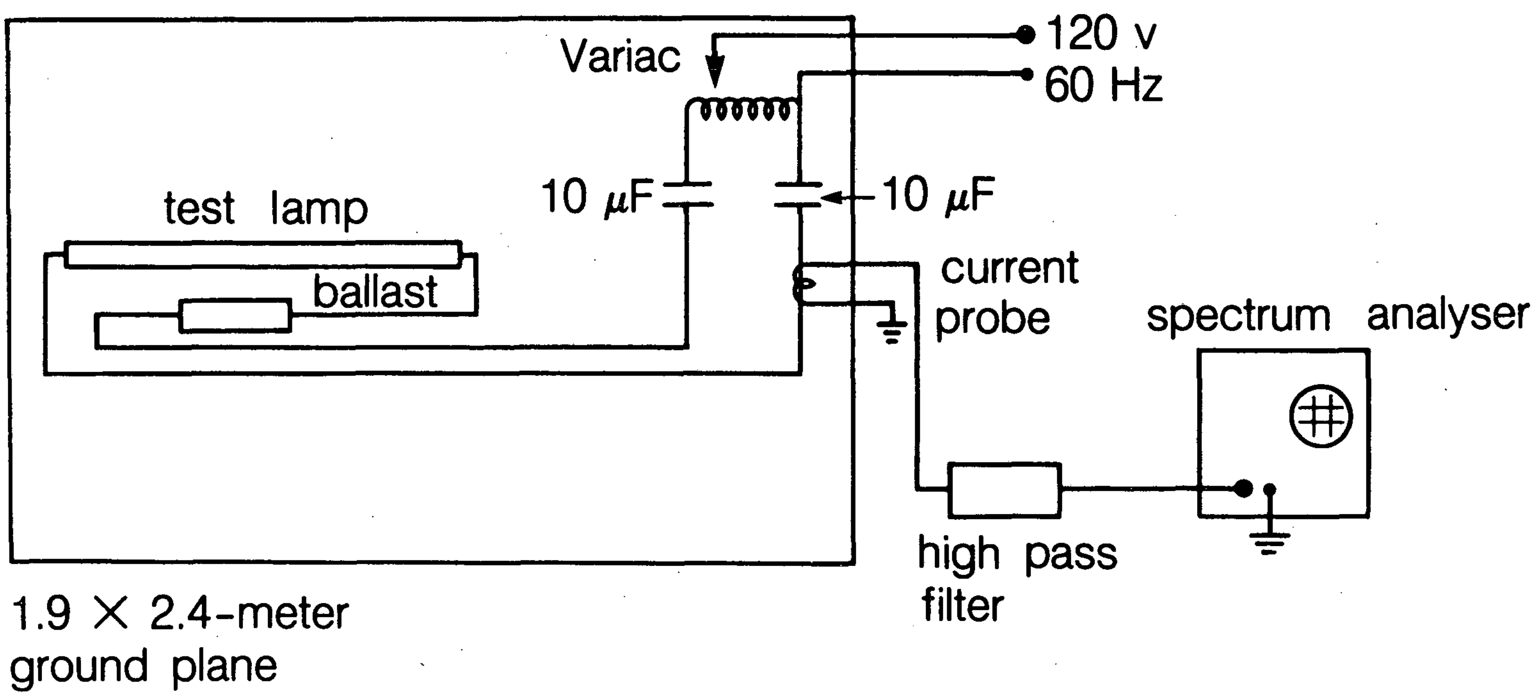
RADIATED EMI TEST CIRCUIT



XBL 849-3723

Figure 5.

CONDUCTED EMI TEST CIRCUIT



XBL 849-3724

Figure 6.

Figure 7.

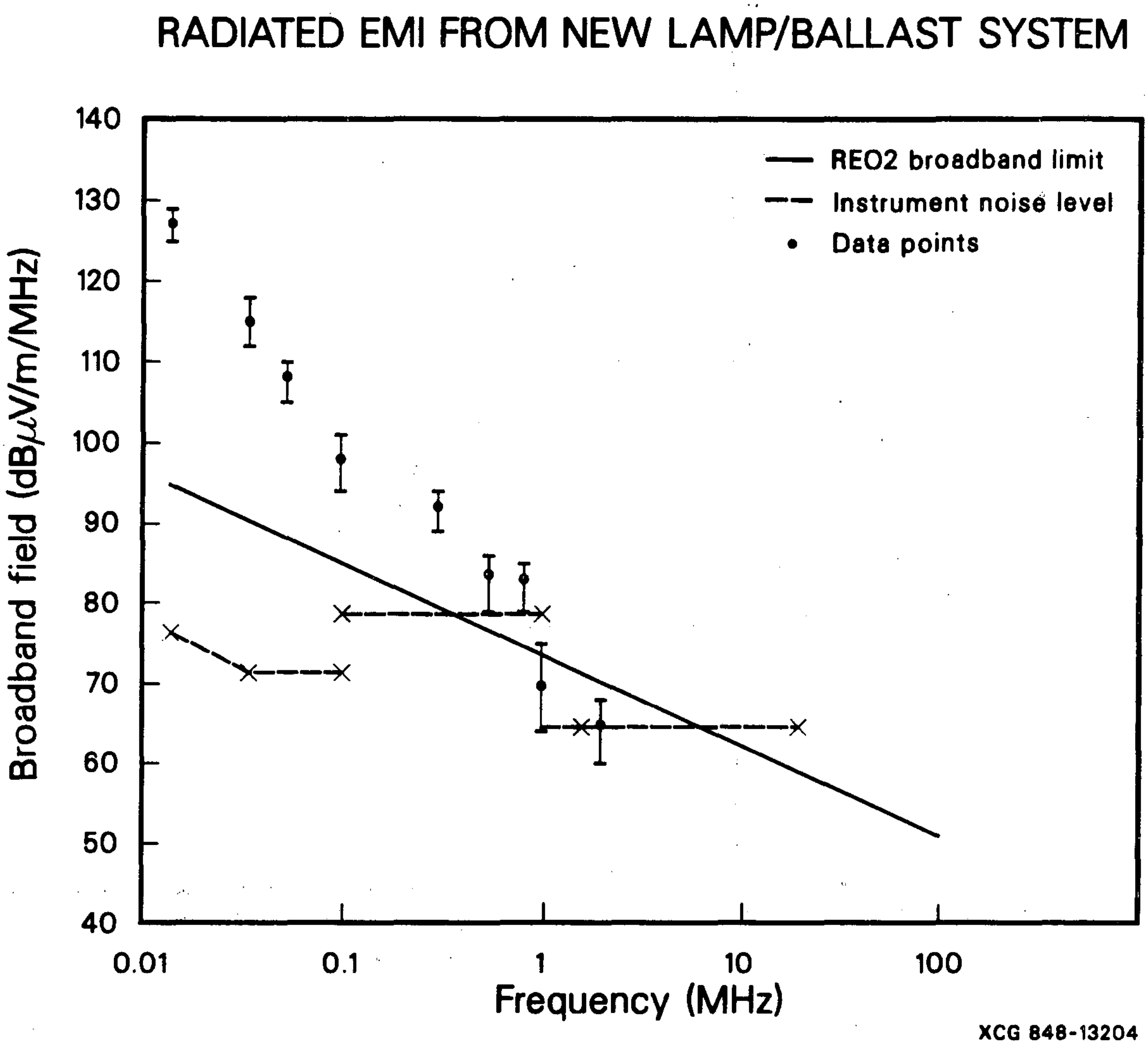

RADIATED EMI FROM NEW LAMP/BALLAST SYSTEM
REO2 broadband limit
Instrument noise level
Data points
Broadband field (dBμV/m/MHz)
140
130
120
110
100
90
80
70
60
50
40
0.01
0.1
1
10
100
Frequency (MHz)
XCG 848-13204

Figure 8.

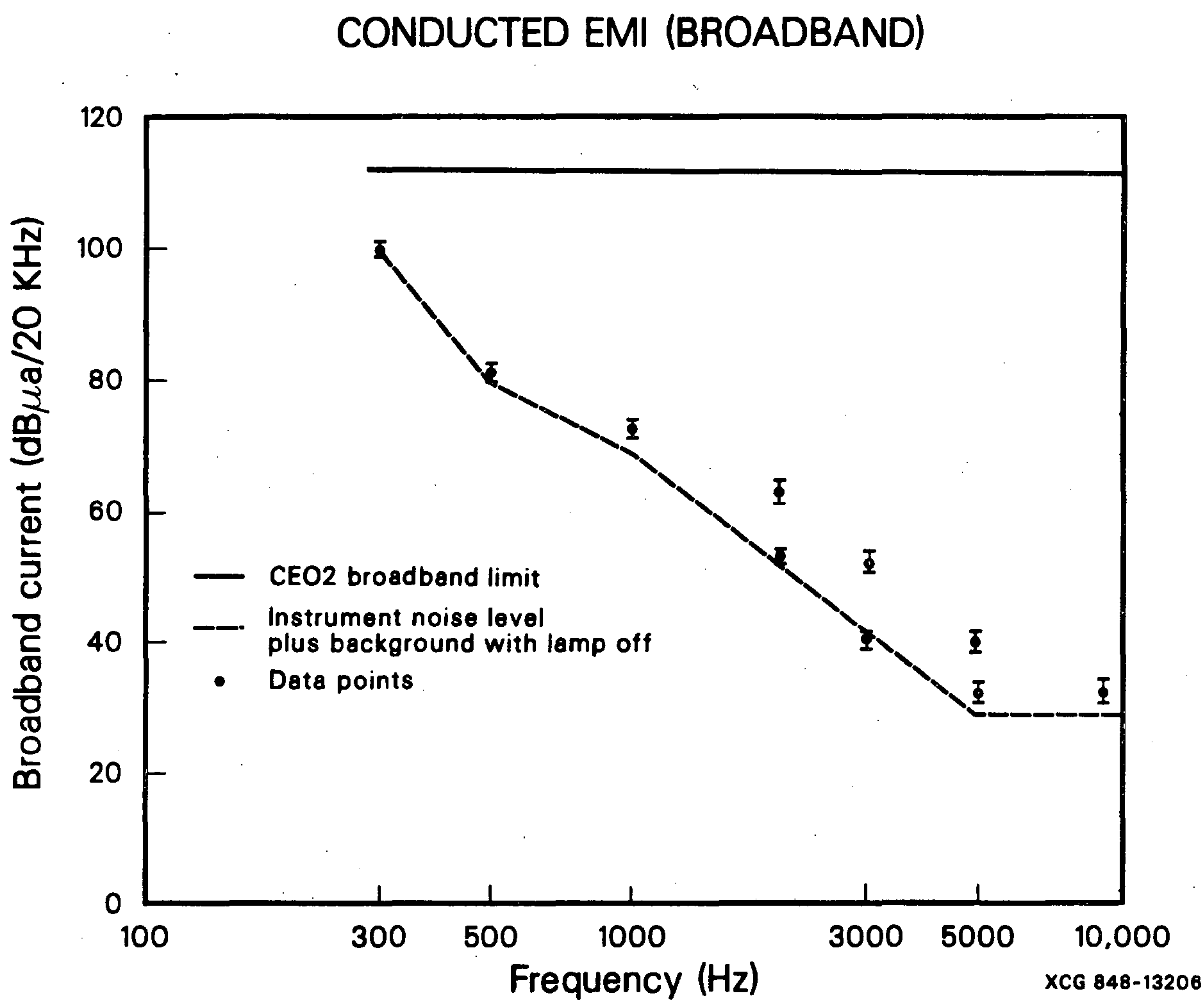
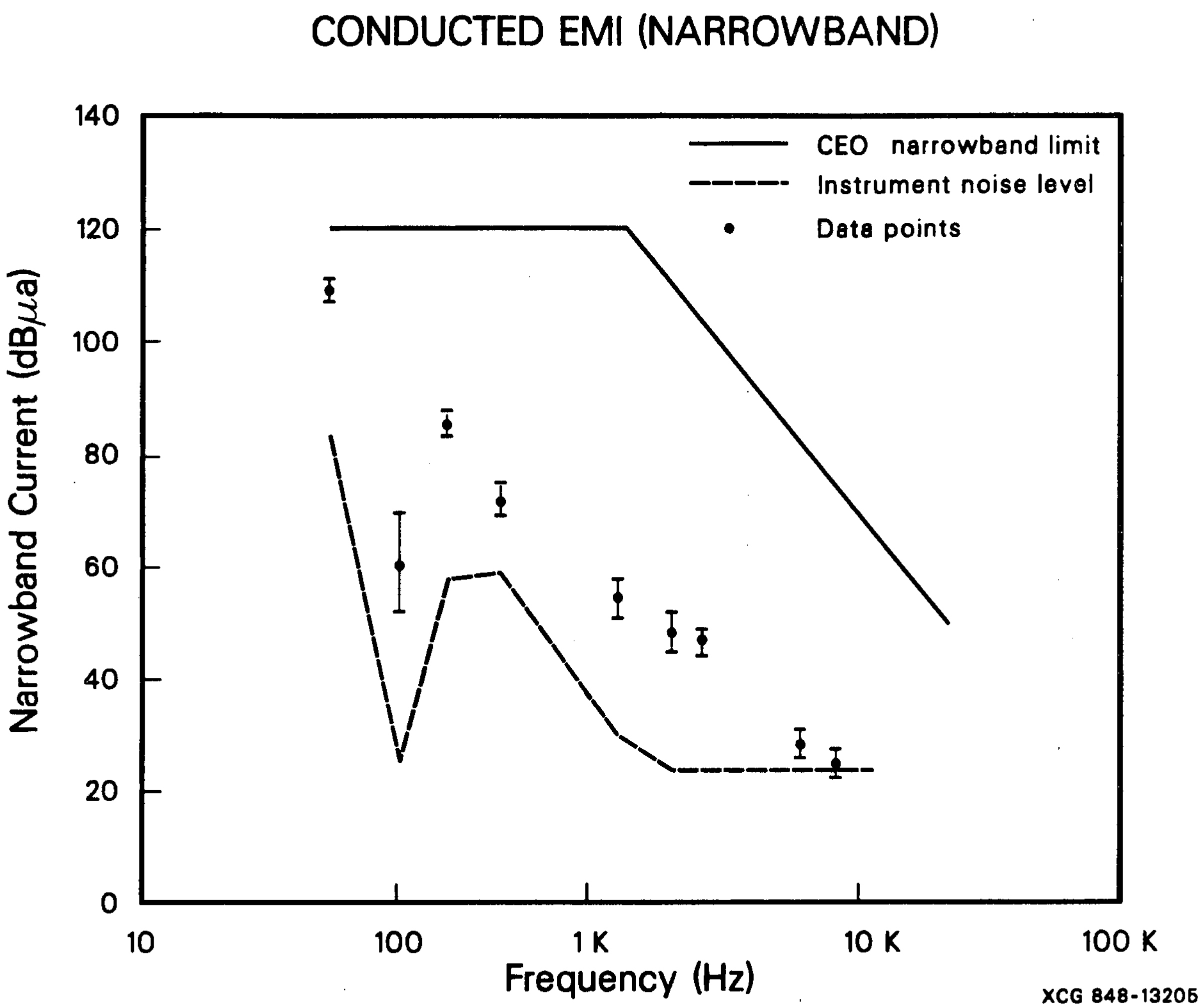

CONDUCTED EMI (BROADBAND)
120
100
80
60
40
20
0
Broadband current (dBμa/20 KHz)
CEO2 broadband limit
Instrument noise level
plus background with lamp off
Data points
100
300
500
1000
3000
5000
10,000
Frequency (Hz)
XCG 848-13206

Figure 9.


CONDUCTED EMI (NARROWBAND)
CEO narrowband limit
Instrument noise level
Data points
Narrowband Current (dBμa)
140
120
100
80
60
40
20
0
10
100
1 K
10 K
100 K
Frequency (Hz)
XCG 848-13205

1.0 INTRODUCTION

This addendum is an extension of the preceeding final report that described the performance of an efficient F-20 fluorescent lamp system and an advanced efficient core-coil ballast. Compared to other efficient core-coil ballasts, the advanced concept improved the power factor and reduced the third harmonic. In this report, we assess 14 prototypes of the advanced ballast. The measurements are compared to the present Navy ballast and the efficient ballasts submitted to replace them. The new Navy F-17 fluorescent lamp is used throughout the study.

2.0 EXPERIMENTAL PROCEDURES

The tests for these advanced ballasts are the same as those described in the original report. Since time is of the essence, the life test is shorter and the lumen depreciation less than reported in the original report. However, these tests will continue. Since there is no change in the concept, the EMI tests are deleted in this study.

3.0 RESULTS

3.1 Input-Output Characteristics

Table I lists the results of the measurements on 14 of the advanced efficient ballasts operating the new F-17 fluorescent lamp. The values in the table are the average for the 14 ballasts. At the center design voltage, these ballasts meet all Navy specifications. However, at 129.8 volts the third harmonic exceeds the Navy limit. The other improvement is the high power factor. The ballast factor is 1% below the required light output.

Table II compares the results of the advanced efficient ballast with the standard and efficient ballasts. Ballasts 1 and 2 are the Advance and Universal submissions, respectively. The advanced efficient ballast design has been submitted by IOTA Engineering. The H and R types were development models submitted by IOTA for initial testing. The prototype tested in this study is comprised of the fourteen units subsequently delivered for assessment. The IOTA prototype provides about 7 to 13% less light than the efficient ballasts. However, the line current is reduced by 40 to 47%, since the power factor is improved.

3.2 Starting

The starting voltage with the advanced ballast types was measured at 10^{o} and $70^{o}C$ ambient temperature. When 92 volts were applied the lamps ignited. Thus, the lamps will start at ambient temperatures from 10^{o} to $70^{o}C$ with the rated applied voltage.

3.3 Life Tests

The lamp life tests have been run for 600 hours and there have been no lamp or ballast failures. The lumen depreciation is 0.9% at 500 hours. However, the short time of the tests does not permit any conclusions, and the work will continue.

4.0 DISCUSSION

Performance of the advanced efficient core-coil ballast submitted by IOTA Engineering is generally equivalent to that of the efficient core-coil ballasts submitted by Advance and Universal. The ballast is 8% more efficient than the standard Navy ballast. Compared with the performance of the standard lamp/ballast system (48 lumens per watt lm/W), and the new F-17 lamp/ballast system (59 lm/W), there is nearly a 20% improvement in system efficacy.

Table III lists the most significant advances in the lamp/ballast system on ships: a power reduction of 25%, an improvement of 53% in the power factor, a decrease in the third harmonic from 8 to 1%, and a 51% decrease in line current.

The new ballast is 8% more efficient because of its improved magnetics and the lower ballast current. The new F-17 lamp is 13% more efficacious than the F-20 lamp. The system efficacy improvement is 23%.

The life tests have not been carried out long enough to estimate the failure rate. However, no problems are anticipated with this ballast design.

5.0 CONCLUSIONS

The advanced efficient ballast meets all of the requirements for use on Naval ships. This latest design dramatically improves the third harmonic contents as well as the power factor. This latter attribute reduces the copper size for the lighting distribution network.

The use of this ballast F-17 lamp system will reduce the power requirements for the lighting system by over 20%.

TABLE I. AVERAGE PERFORMANCE OF FOURTEEN ADVANCED BALLAST PROTOTYPES

BALLAST INPUT	INPUT VOLTAGE			LAMP WALL TEMPERATURE	
	-10%	center	+10%	40°C	50°C
Voltage (V)	106.2	118	129.8	118	118
Current (A)	0.158	0.176	0.197	0.176	0.175
Power (W)	16.3	19.0	21.9	19.0	18.4
Power Factor	0.971	0.915	0.856	0.920	0.891
LAMP INPUT					
Power (W)	13.7	15.7	17.6	15.7	15.0
Current Crest Factor	1.4	1.5	1.5	1.5	1.5
LAMP OUTPUT					
Initial Flux (lumens)	983	1116	1241	1120	1083
Ballast Factor		0.893			
Percent Regulation (%)	-12		+11		-3.4
Flicker (%)	41	41	41	41	42
SYSTEM					
Ballast Efficiency (%)	0.843	0.827	0.805	0.823	0.817
Lamp Efficacy (lm/W)	71.6	71.1	70.5	71.1	72.2
System Efficacy (lm/W)	60.4	58.8	56.7	58.8	59.0
LINE CURRENT HARMONICS					
2nd	0.7	0.9	1.6	0.9	0.7
3rd	2.4	1.3	3.3	1.3	1.2
5th	1.2	1.1	2.2	1.1	1.5
7th	0.6	0.6	0.9	0.5	0.5
9th	0.3	0.3	0.7	0.4	0.4
Higher Harmonics	negligible				

TABLE II. COMPARISON OF BALLAST SYSTEMS

	BALLAST TYPE					
	Standard	Efficient		Advanced Efficient		
		1	2	H	R	Prototype
BALLAST INPUT						
Voltage (V)	118	118	118	118	118	118
Current (A)	0.364	0.303	0.328	0.161	0.172	0.176
Power (W)	25.4	19.4	20.9	18.0	18.8	19.0
Power Factor	0.59	0.54	0.54	0.95	0.93	0.92
LAMP INPUT						
Voltage (V)	57.8	59.6	59.1	60.2	60.5	60.1
Current (A)	0.364	0.303	0.328	0.288	0.281	0.282
Power (W)	19.2	16.5	17.8	16.0	15.7	15.7
LAMP OUTPUT						
Initial Flux (lm)	1350	1200	1270	1132	1135	1116
Ballast Factor	1.08	0.96	1.01	0.91	0.91	0.89
Regulation (%)	±14	±15	±14	±10	±12	±12
Flicker (%)	42	41	40	39	39	41
SYSTEM						
Ballast Efficiency (%)	76	85	85	89	84	83
Lamp Efficacy (lm/W)	70	73	71	71	72	71
System Efficacy (lm/W)	53	62	61	63	60	59
Third Harmonic (%)	8	6	6	2	2	1.3

TABLE III. PERFORMANCE ADVANCES WITH THE NAVY BALLAST-LAMP SYSTEM

	Standard Ballast (F-20 Lamp)	Advanced Efficient Ballast (F-17 Lamp)	Relative Change
INPUT			
Voltage (V)	118	118	
Current (A)	0.362	0.176	-51%
Power (W)	25.4	19.0	-25%
Power Factor	0.60	0.92	+53%
OUTPUT			
Light Flux	1220	1120	- 8%
Third Harmonic (%)	8	1	-88%
SYSTEM			
Ballast Efficiency (%)	76	83	+ 9%
Lamp Efficacy (lm/W)	63	71	+13%
System Efficacy (lm/W)	48	59	+23%

LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720