LBL-12462
c.2

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

ENERGY & ENVIRONMENT DIVISION

JUN 30 1981
LIBRARY
DOCUMENTS

To be presented at the IEEE/IAS Annual Meeting, Philadelphia, PA, October 5-9, 1981; and to be published in the Proceedings

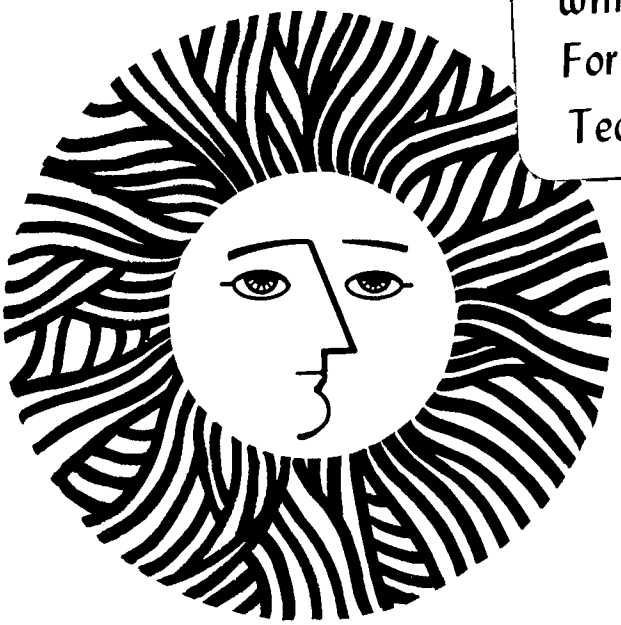
ELECTROMAGNETIC INTERFERENCE (EMI) MEASUREMENTS OF FLUORESCENT LAMPS OPERATED WITH SOLID-STATE BALLASTS

A. Arthur, R. Verderber, F. Rubinstein, and O. Morse

May 1981

TWO-WEEK LOAN COPY

This is a Library Circulating Copy which may be borrowed for two weeks. For a personal retention copy, call Tech. Info. Division, Ext. 6782



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

LBL-12462 c.2

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

LBL-12462
EEB-L-81-07

ELECTROMAGNETIC INTERFERENCE (EMI) MEASUREMENTS OF FLUORESCENT LAMPS OPERATED WITH SOLID-STATE BALLASTS

A. Arthur
R. Verderber
F. Rubinstein
O. Morse

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720
May 1981

Paper to be presented at the IEEE/IAS (Institute of Electrical and Electronics Engineers/Industry Applications Society) Annual Meeting in Philadelphia, Pennsylvania, October 5-9, 1981.

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings and Community Systems, Consumer Products Division of the U.S. Department of Energy under Contract No. W-7405-ENG-48 and by the Veterans Administration Office of Construction under Order No. 80-08-18.

ELECTROMAGNETIC INTERFERENCE (EMI) MEASUREMENTS OF FLUORESCENT LAMPS OPERATED WITH SOLID-STATE BALLASTS

A. Arthur
R. Verderber
F. Rubinstein
O. Morse

Lighting Systems Research
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

Abstract

Solid-state ballasts were placed in fluorescent lamps in various areas of a hospital to determine if these high-frequency systems would adversely affect any hospital operations. The general areas tested included a lobby and an office space. Potentially sensitive areas containing hospital diagnostic and monitoring equipment, including a computerized axial tomography (CAT) scanning room, an electroencephalograph (EEG) examination room, and a coronary ward were also tested. The measurement techniques are described and the results discussed with respect to the existing RFI environment and with respect to EMI radiated and conducted limits specified by the Federal Communications Commission and the Federal Drug Administration.

Introduction

The Veterans Adminstration (VA) Office of Construction has been actively evaluating new energy-efficient devices. When the VA first became interested in solid-state ballasts for fluorescent lamps, these components were in their final stages of development and not completely field-tested. One major concern of the VA staff was the emission of electromagnetic interference (EMI) from solid-state ballasted fluorescent lamps operated at high frequencies (20 to 30 kHz). This effect had been studied in a three-year solid-state ballast demonstration in the Pacific Gas and Electric Company's office building in San Francisco, CA.[1] During this time the ballasts showed no adverse effects on PG&E's data processing equipment or operations. However, a more stringent test of the EMI from these new ballasts was in order, specifically in a hospital environment that contains sensitive diagnostic and monitoring equipment. Towards this end the Veterans Adminstration Office of Construction supported a demonstration, one task of which was to assess the conducted and radiated EMI from fluorescent lamps operated with solid-state ballasts.

The VA Hospital in Long Beach CA was selected as the demonstration site. In concert with the VA Washington, DC, office and the engineering staff at the hospital, the Lawrence Berkely Laboratory Lighting Program staff designed an EMI test schedule. This report presents the EMI test results of the solid-state ballast demonstration at the Long Beach VA Hospital.

EMI Tests and Results

Electromagnetic interference (EMI) data were taken prior to and after installation of solid-state ballasts in the following demonstration areas:

1. Director's Office Suite
2. Outpatient Clinic Expansion Lobby
3. Coronary Care Ward

In addition, solid-state ballast electromagnetic compatibility (EMC) tests were conducted at:

1. Computerized Axial Tomography (CAT) Laboratory
2. Electroencephalography (EEG) Laboratory

The outpatient clinic expansion lobby was chosen as a test site because of its significant area, utilizing more than 140 two-lamp fluorescent fixtures. Thus, it allowed us to examine the possible cumulative effects of a large number of fixtures, especially in terms of conducted EMI. The director's suite of offices was chosen to provide data for a typical office environment. There were 36 two-lamp fixtures in these three offices.

The remaining areas were chosen because of the possible sensitivity of the medical devices used therein.

EMI Test and Measurement Philosophy

Baseline data were taken prior to installing the solid-state ballasts to establish fluorescent EMI levels and hospital background levels.

When the solid-state ballasts were installed, our goals were: (1) to immediately insure that the ballasts in no way posed any safety or health hazard and presented no obvious equipment incompatibility problems, (2) to gather EMI data for levels exceeding normal hospital background, and (3) to provide for a sufficient demonstration period that would allow any unforeseen effects to come to light--possibly in the form of comments or complaints from the hospital staff or patients.

EMI Measurements

LBL engineers selected the test sites and test philosophy. The test procedures did not necessarily conform to any specific EMI standard applicable to a given class of devices. We were interested in the "real-world" EMI levels near a solid-state ballasted fixture that was one of many operating in an area. Therefore, the data collected cannot be directly compared to standards or specifications that isolate a single device for EMI testing.

A consulting EMI specialist (A&H Systems, Contract No. 4006100) provided and operated the EMI measuring equipment. All measurements were made within the normal hospital electromagnetic background and with all other fluorescent fixtures in the room turned on. All radiated EMI measurements were taken using a Tektronix 7L5 spectrum analyzer connected to a standard 41-inch monopole antenna having a ground plane. The antenna was positioned vertically and located directly under a central fixture in each room, the mid-point of the antenna being approximately one meter from the fixture. The conducted EMI measurements were taken using the same spectrum analyzer connected to a current probe clamped to the hot wire that provided power to the lighting in the demonstration area.

EMI Data

Conducted EMI. Figures 1 and 2 show the conducted EMI data.

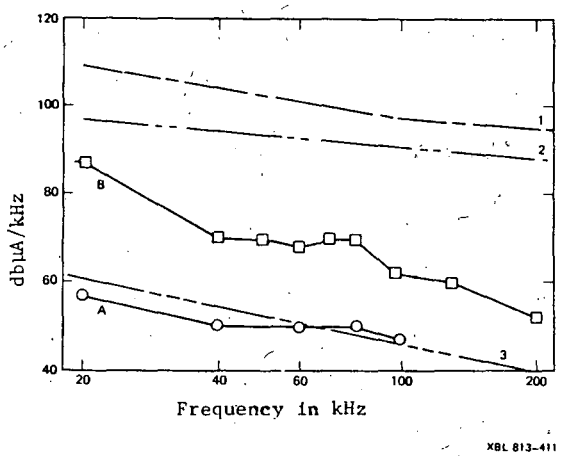


Figure 1. Conducted EMI Data for the Director's Suite with 36 Two-Lamp Fixtures: (A) Conventional Ballasts; (B) Solid-State Ballasts. (1) FDA Medical Device Susceptibility Limit; (2) FDA Narrowband Emission Limit; (3) FDA Broadband Emission Limit.

Shown with the data are Food and Drug Administration (FDA) limits that apply to individual medical device emissions and susceptibility.[2] It should be understood that the FDA specification does not apply to solid-state ballasts, but in the absence of any specific guidelines, we will use it for comparison.

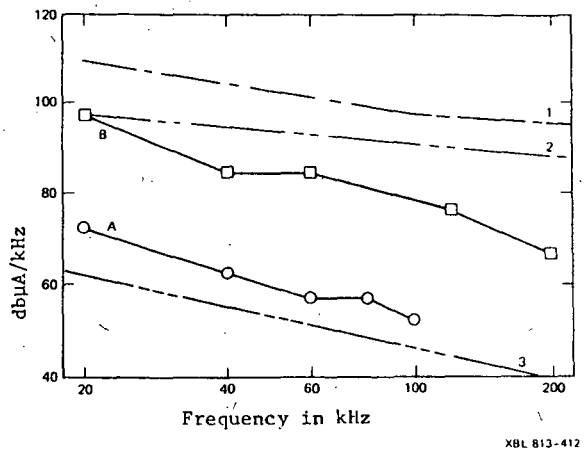


Figure 2. Conducted EMI Data for the Outpatient Clinic with 140 Two-Lamp Fixtures: (A) Conventional Ballasts; (B) Solid-State Ballasts. (1) FDA Medical Device Susceptibility Limit; (2) FDA Narrowband Emission Limit; (3) FDA Broadband Emission Limit.

Figure 1 shows the data for the director's office suite. The data were taken at the electrical closet supplying the lighting load for this area, and having been previously isolated from other lighting loads, represents the conducted EMI from the 36 two-lamp fixtures in this demonstration area. Curve A represents the baseline data for conventional ballasts; curve B represents the data for solid-state ballasts.

Figure 2 shows similar data for the outpatient lobby demonstration area. Included with the data are the FDA conducted limits. Curve 3 is the FDA device broadband conducted emission limit; (converted to dbμA/kHz); curve 2 the FDA device conducted narrowband emission limit, and curve 1 the FDA medical device susceptibility limit. The susceptibility limit has been converted to dbμA using the impedance of a 50μH, 50Ω line impedance stabilizer (LISN) in this frequency range.[3]

The FDA emission specifications are intended to apply to single devices. The data presented in Figures 1 and 2 are for 36 and 140 devices respectively, yet the conducted interference levels remain well below the FDA susceptibility limit. Most industrial lighting power is supplied at 277 Vrms AC; thus, a transformer exists between the lighting load and the 120 Vrms AC power normally used for medical devices. This transformer further attenuates the conducted interference. In light of the above, it appears unlikely that conducted interference would cause any incompatibility between these solid-state ballasts and general medical devices.

Radiated EMI. Figures 3 and 4 show a composite of radiated EMI data that is representative of data from many spectrum analyzer photographs taken in the four test areas.

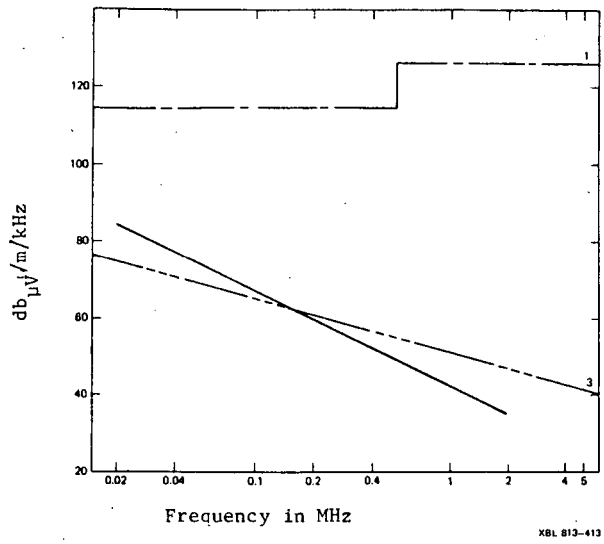


Figure 3. Typical Electric-Field Radiated EMI for a Four-Foot, Two-Lamp, Conventionally Ballasted Fixture: (1) FDA Radiated Susceptibility Limit; (3) FDA Broadband Radiated Emission Limited Converted to a One-Kilohertz Bandwidth.

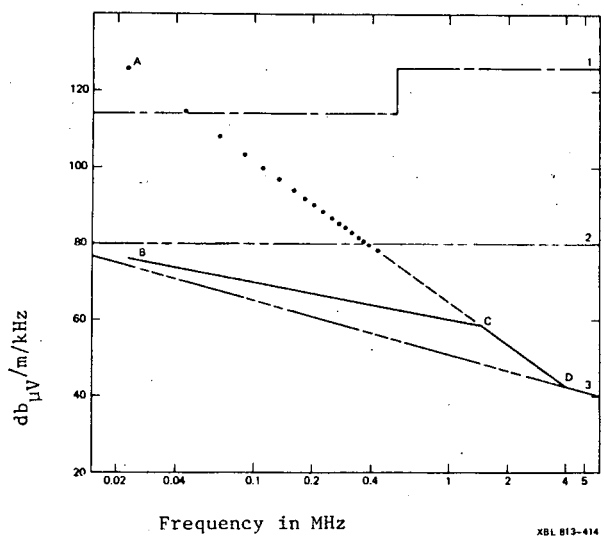


Figure 4. Typical Electric-Field Radiated EMI for a Four-Foot, Two-Lamp, Solid-State Ballasted Fixture: (AC) Narrowband Peaks of 23 kHz and Harmonics; (BCD) Broadband Background Noise. (1) FDA Susceptibility Limit; (2) FDA Narrowband Limit; (3) FDA Broadband Limit.

Typical spectrum analyzer photographs are shown in Figures A1 and A2 of the Appendix . Included with the data in Figures 3 and 4 are the FDA radiated limits. Curve 3 is the FDA device broadband radiated emission limit (converted to dbμV/m/kHz); curve 2 is the FDA device radiated narrowband emission limit; and curve 1 is the FDA device radiated susceptibility limit.

The data in Figure 3 show the broadband radiation measured from the conventionally ballasted fixtures prior to our ballast retrofit. It compares favorably to the FDA broadband limit. Data are given only to 2 MHz, where the radiation disappears into the ambient hospital EMI.

The curves in Figure 4 represent the data taken on the radiated emission from a typical solid-state ballasted fixture. The dotted curve segment AC represents the locus of narrowband peaks of the 23-kHz fundamental and its harmonics, and curve segment BC represents the broadband background radiation underlying these peaks (refer to photographs, Figure A2 in the Appendix). Each individual solid-state ballast in the demonstration area operates on a slightly different frequency; therefore, the high-order harmonics begin to disperse. When measured with a one-kHz spectrum analyzer bandwidth, the narrowband emissions from all sources at the higher frequencies tend to become broadband. The above effect and the fact that the amplitudes of the harmonics decrease with frequency (about 35 db/decade) cause the narrowband peaks to merge with the background gas discharge noise at point C.[4] Curve segment CD then continues to drop in amplitude until it also disappears into the hospital ambient EMI at about 4 MHz. Again, the broadband component of the EMI from the solid-state ballasted fixtures compares quite favorably with the FDA broadband radiated emission limit. However, the narrowband peaks for the solid-state case exceed the FDA narrowband radiated limit in the frequency range of 23 kHz to 400 kHz, and slightly exceed the device minimum susceptibility limit for the 23-kHz fundamental and the 46-kHz second harmonic.

Figure 5 shows the VA Hospital EMI data plotted with that of Clark,[5] indicating reasonably good agree-

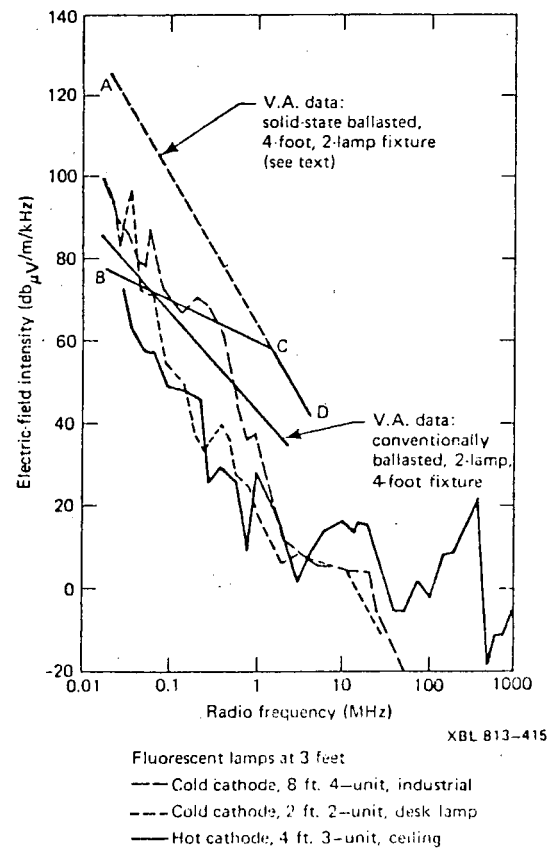


Figure 5. VA Demonstration Data Compared to that of Clark.[5]

ment for the broadband component of the electric field emission.

Electromagnetic Compatibility Tests

In addition to the direct measurement of EMI emissions in the four main demonstration areas, electromagnetic compatibility (EMC) tests were conducted on specific devices that could be potentially sensitive.

External Pacemaker. In the coronary care ward, spectrum analyzer measurements were made on the output of an external pacemaker before and after installing the solid-state ballasts. The pacemaker was placed on a bed directly below the fluorescent fixture. The spectrum analyzer was connected to the pacemaker output coax tip using a 10:1 voltage probe with a 10-megohm impedance. The output of the pacemaker was a 17V, 2-millisecond pulse occuring at a 1-second period. This produces a broadband burst of power when viewed on a spectrum analyzer with 1-kHz bandwidth setting. Buried 50 db below the broadband signal we observed at 15.75 kHz the horizontal drive signal from the television set in the room located approximately 8 feet from the pacemaker. After installing the solid-state ballasts, the 23-kHz ballast fundamental was observed about 20 db lower in amplitude than the T.V. signal.

We believe that most of the EMI observed in the pacemaker output was induced in the spectrum analyzer probe and the probe ground lead and, therefore, is not indicative of the true EMI susceptibility of the external pacemaker. Since the induced effect from the solid-state ballasts was extremely small and always less than that from the room television, and since pacemakers are routinely used in close proximity to T.V. sets, we are confident that there is no EMI incompatibility in this case.

This investigation did reveal the fact that the television sets used throughout the hospital are a significant source of EMI in the 15-kHz to 1.5-MHz frequency range. See Figure A3 in the Appendix.

Computerized Axial Tomography (CAT) Examination Room

This area is in an older section of the hospital that uses 120 VAC for its lighting power. Since the ballasts used in this demonstration required 277 VAC, the proposed ballast retrofit could not be done. Instead, we devised a hand-held fluorescent fixture having a solid-state ballast that could be powered by a special 120 VAC to 277 VAC step-up transformer. This was then taken to the CAT scan area and held approximately one foot from the sensitive equipment. No interference was observed.

Electroencephalograph (EEG) Examination Area

This area was also in an older portion of the hospital, and for the same reasons as given above, the EMC had to be investigated using the hand-held fixture. This area is divided into two parts, that containing the measuring equipment, and an area with a bed for the patient being examined. No interference was noted in the equipment area. When the fixture was taken into the patient area, and held within a meter of the patient leads, interference was noted on the recorders. The EEG operator explained that it was mandatory to conduct EEG examination with the conventionally ballasted fluorescent lights turned off since they also cause interference with the signals (typically tens of microvolts) measured by the sensitive EEG equipment.

Discussion of EMI Data

We have in each case compared the EMI data taken on site at the Long Beach VA facility to the most appropriate FDA guidelines available. It should be noted again, however, that the FDA standard does not pertain to fluorescent lamps and ballasts.

Our data show that the narrowband radiated EMI from a fixture powered by a solid-state ballast supplying energy at a fundamental frequency of 23 kHz has the potential to interfere with medical devices that marginally meet the susceptibility limit at 23 kHz and 46 kHz. In our demonstration at the Long Beach VA Hospital, we found no instance in which solid-state ballasted fixtures caused difficulty while conventionally ballasted fixtures did not.

We agree wholeheartedly with the purpose and rationale for the FDA standard. FDA did a creditable job in identifying the need for a standard, establishing a basis for the standard, and in setting reasonable guidelines. We especially agree with the need to control the steadily growing ambient EMI.

The FDA guidelines were based on a survey of existing EMI levels in hospitals, and had solid-state (high-frequency) ballasts been commonplace at the time of the FDA field studies, it is most like that the susceptibility limit would have been raised in the 10-kHz to 550-kHz range (see Figure A5 of the Appendix for the ambient levels measured in the FDA study and the resultant susceptibility limits).

At this time we know of no FCC regulation applying specifically to solid-state ballasts. Nevertheless, it is informative to compare our data with typical FCC allowed radiated emissions. Such a comparision is somewhat complicated by the fact that the FCC specifies measurement distances of 100 feet, 1000 feet, and sometimes one mile. According to Draft ANSI C63.12,[6] a conservative method for translating measurement distances (given certain boundary conditions that specify the proper measuring distance with respect to the size of the EMI source and receiving antenna) is to use an attenuation factor of $1/d^3$ in the near-field region where both measuring distances are less than $\lambda/2\pi$, to use an attenuation factor of

$^1/d$ in the far-field region where both measuring distances are greater than $\lambda/2\pi$, and to use a straight-line approximation over the transition region where one measuring distance is greater and one is less than $\lambda/2\pi$.

The specification for ultrasonic equipment (FCC Part 18C), which is somewhat typcial of radiated emissions allowed in other parts of the regulations, is given in Table I.

TABLE I

Radio Frequency	Distance (Feet)	Field Intensity
Up to and including 490 kHz	1000	2400/F (kHz)
More than 490 kHz up to and including 1600 kHz	100	24000/F (kHz)
More than 1600 kHz	100	15

Shown in Table II are field intensities allowed under Part 18C which have been translated to one meter by the method described, along with measured field intensities for solid-state ballasted lamps.

TABLE II

Frequency (kHz)	Allowed Field Intensity ($db_{\mu v/m}$)	Measured Field Intensity ($db_{\mu V/m}$)
20	190	126
200	165	90
400	148	80
1000	116	66

Since in each case the measured intensities are well below the translated limits, it appears that there would be no problems with existing FCC radiated emission specifications. Even in the proposed revision to Part 18,[3] the ISM out-of-band limits would allow 136 $db_{\mu V/m}$ up to 4.85 MHz (translated to one meter by the method described).

The solid-state ballast designer can control the conducted EMI level of his product by providing adequate filtering at the AC input of the device. He has little or no control over the radiated EMI level. To provide an energy-efficient product, he must excite the fluorescent lamps at 10 kHz or greater. To insure that audible noise is not a problem, he must go to at least 20 kHz. The radiated levels are strictly a function of the lamp/fixture combination. Since a 4-foot T12 fluorescent requires 105 VAC to operate, it stands to reason that close to and along the axis of the lamp are approximately 100 volts per meter (180 $db_{\mu V/m}$) at the fundamental excitation frequency, whether it be 60 Hz or 20 kHz.

If there is need to reduce the radiated EMI from the lamps, methods have been proposed for the 60-Hz ballasts that could be applied to the high-frequency system.[7]

Acknowledgement

The LBL staff appreciate the support of the Veterans Administration Office of Construction under Order No. 80-08-18 through Mr. Samuel Levinrad, and the continuing support of the Department of Energy, Assistant Secretary for Conservation and Renewable Energy, Office of Buildings and Community Systems, Consumer Products Division under Contract No. W -7405-ENG-48.

We would also like to thank Mr. Bert Mc ee and Mr. Tom Millhouse of the Long Beach VA Hospital Maintenance Department, without whose help this task would have been most difficult, and Mr. Art Cohen of A & H Systems for his help and guidance in the EMI measurement.

References

(1) Jewell, J.E., Selkowitz, S., and Verderber, R.R., "Solid-State Ballasts Prove to be Energy Savers," Lighting Design & Application 10 (10):36 (January 1980).

(2) U.S. Food and Drug Administration, Electromagnetic Compability Standard for Medical Devices. BMD publication number MDS-201-0004. U.S. Food and Drug Administration, Silver Spring MD, (October 1979).

(3) Federal Communications Commission, Second Notice of Proposed Rule Making, FCC Docket No. 20718, "In the Matter of Overall Revision of Part 18 Governing Industrial, Scientific, and Medical Equipment: Adopted January 18, 1979." Released January 29, 1979, FCC 79-29, 44 FR 9771.

(4) Culp, J.W., "Noise in Gaseous Discharge Lamps," Journal of the Illuminating Engineering Society: 37(January 1952).

(5) Clark, D.B., "Evaluation of Interference Suppression of Fluorescent Lamps," U.S. Naval Civil Engineering Laboratory, Technical Report 166, (October 1961).

(6) American National Standards Institute, Draft American National Standard C63.12, "Recommended Procedures for Control of System Electromagnetic Compatibility," July 20, 1979.

(7) Walters, G., "Suppression of Radio Interference in Fluorescent Lighting Installations," Journal of the Illuminating Engineering Society XVII: 295 (June 1954).

Appendix : EMI Reference Material

Typical EMI Data

Figures A1 through A4 show spectrum analyzer photographs of the EMI data taken during the Long Beach VA Hospital solid-state ballast demonstration. All EMI data were taken under the following conditions:

1. Tektronix Spectrum Analyzer Model 7L5 using a one-kHz bandwidth setting.

2. Radiated electrical field data were taken with a 41-inch monopole antenna the ground plane of which was positioned vertically and located directly under a centrally located fixture in the demonstration area. The midpoint of the antenna was approximately one meter from the fixture.

3. Conducted emission data were taken using a current probe clamped to the hot wire that was providing power to the demonstration area lighting.

4. All lamps in the demonstration area were on during data measurement. All lamps were turned off for the ambient measurement.

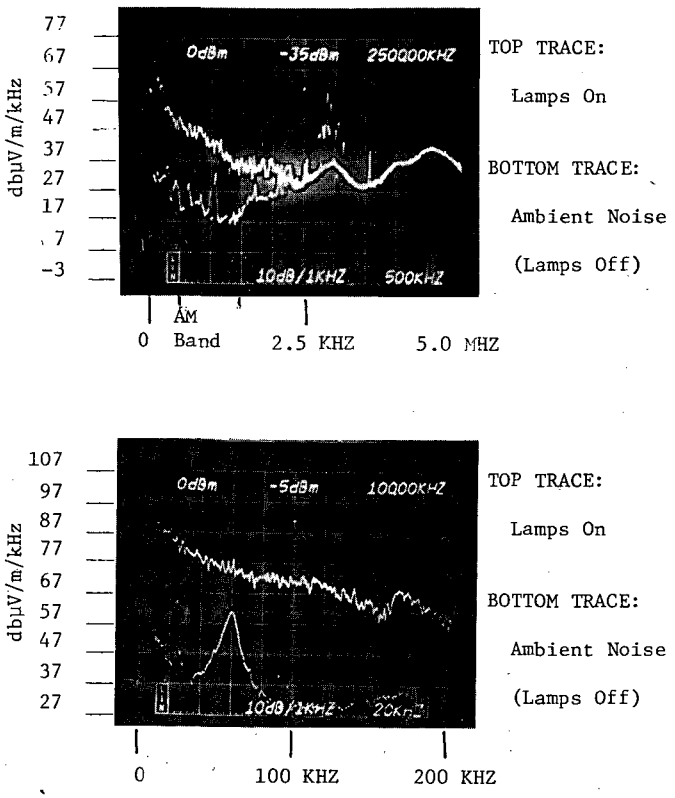


Figure A1. TYPICAL ELECTRIC-FIELD RADIATED EMI SPECTRUM ANALYZER PHOTOGRAPHS FOR CONVENTIONALLY BALLASTED 4-FOOT, 2-LAMP FIXTURES.
TOP: FREQUENCY RANGE 0 - 5 MHZ
BOTTOM: FREQUENCY RANGE 0 - 200 KHZ.

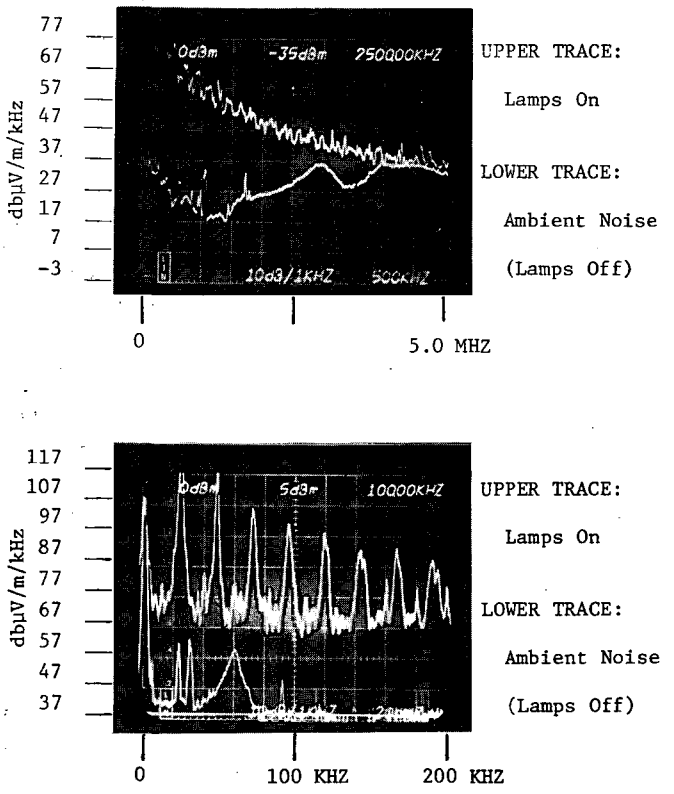
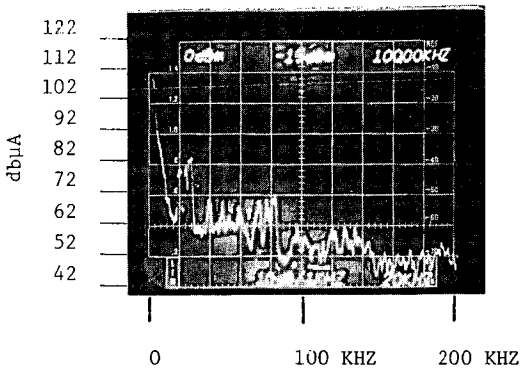


Figure A2. TYPICAL ELECTRIC-FIELD RADIATED EMI SPECTRUM ANALYZER PHOTOGRAPHS FOR SOLID-STATE BALLASTED, 4-FOOT, 2-LAMP FIXTURES.
TOP: FREQUENCY RANGE 0 - 5 MHZ
BOTTOM: FREQUENCY RANGES 0 - 200 KHZ.



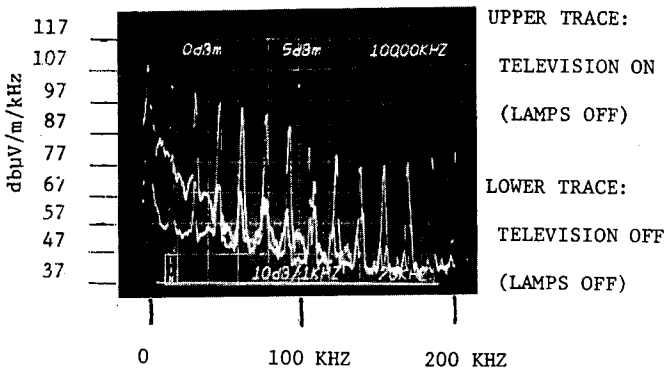


FIGURE A4. ELECTRIC-FIELD RADIATED EMI SPECTRUM ANALYZER PHOTOGRAPH FOR ROOM TELEVISION SET LOCATED ABOUT 6 FEET AWAY.

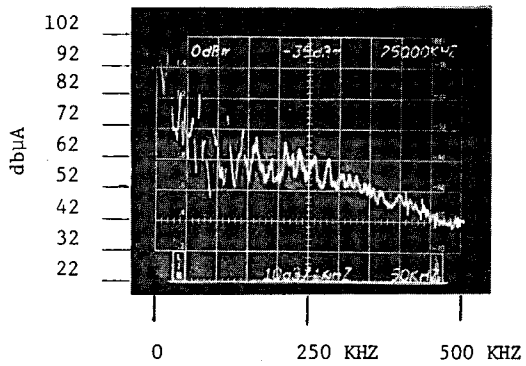


FIGURE A3. CONDUCTED EMI SPECTRUM ANALYZER PHOTOGRAPHS FOR AREAS WITH SOLID-STATE BALLASTS.

TOP: DIRECTOR'S SUITE

BOTTOM: OUTPATIENT CLINIC LOBBY.

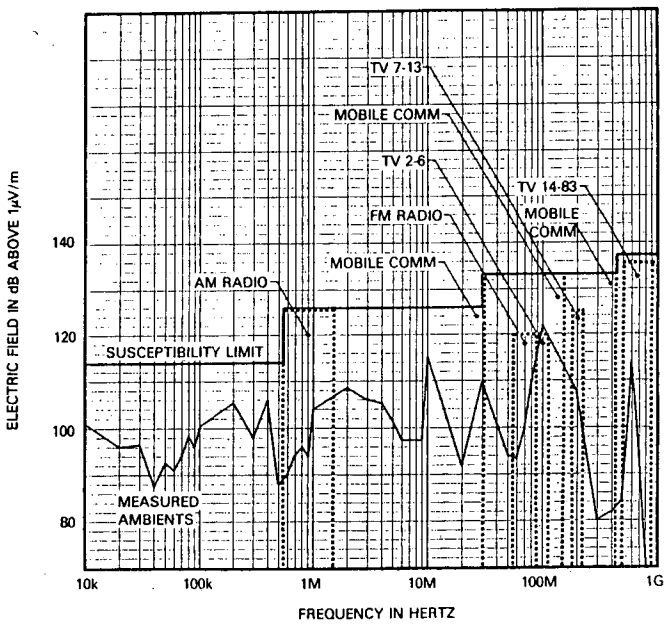


FIGURE A5. COMPOSITE RADIATED ELECTRIC FIELD LEVEL.

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.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

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