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UNIVERSITY OF CALIFORNIA

ENERGY & ENVIRONMENT DIVISION

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ENERGY-EFFICIENT MANAGEMENT OF LIGHTING IN A
VETERANS ADMINISTRATION MEDICAL CENTER

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

March 1981

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MARCH 1981

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ABSTRACT

More than 200 solid-state fluorescent ballasts were installed in representative areas of the Veterans Administration Medical Center in Long Beach, California, to determine the cost-effectiveness of the installation and to measure levels of conducted and radiated electromagnetic interference (EMI).

The power, illumination, and EMI levels were measured first as the test sites initially existed, then after the fixtures were cleaned and relamped with energy-saving fluorescent lamps, and finally after the core-coil ballasts were replaced with solid-state ballasts. The annual energy savings for the complete retrofit was measured as 34%.

In the director's suite natural daylight was used to supplement the electrical illumination, saving an additional 20-25% in energy. Thus, in that area, the total annual energy savings amounted to 51%.

EMI levels were measured in general areas (lobby and director's suite), in diagnostic examination areas, and in a coronary care ward. The EMI levels, compared to existing levels, were not considered excessive.

All of the above data are analyzed on the basis of life-cycle costing. The analysis is presented on sets of curves relating the cost-effective price of a ballast to the cost of electrical energy.

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EXECUTIVE SUMMARY

Scope and Purpose of Study

This study was undertaken to determine the energy that could be saved by replacing standard core-coil, 60-Hz ballasts with new solid-state ballasts that operate fluorescent lamps more efficiently. The price of the new solid-state ballasts to the end-user is not definitive at this early stage of their commercial life. Thus, the data on these new ballasts, operated in both a dedicated and a dimmable mode, are analyzed to determine their cost-effective price. In order to permit the VA Office of Construction to apply these results to medical centers throughout the country, cost-effective prices are presented for a range of electrical energy costs.

During this study the ballasts' safety, reliability, and adaptability to different lighting applications were assessed. The experiments also included 1) measurement of the electromagnetic conducted and radiated power from these systems in comparison to standard core-coil ballasted systems and 2) installation of an automatic dimming system to make effective use of daylight for illuminating an office space.

Study Methodology

An on-site demonstration in a VA medical center was the means for testing the performance of the solid-state ballast. Several representative areas were selected for testing: a large lobby, an office area, and several diagnostic examination areas. Data (power, light levels, electromagnetic interference) were collected in these areas as they existed, after the fixtures were cleaned and relamped with energy-saving fluorescent lamps, and again after solid-state ballasts were retrofitted. The life-cycle cost analysis is used for the solid-state ballast to determine the cost-effective price of these ballasts for replacing standard core-coil ballasts.

Results

- Cleaning and relamping fixtures with 35-watt energy-efficient lamps will provide higher light levels and reduce energy by 11%.
- Dedicated solid-state ballasts with energy-savings lamps will provide higher light levels and reduce energy by 24%.
- Dimmable solid-state ballasts with energy-savings lamps can provide the same light levels and reduce energy by 34%.
- In areas where daylighting can be used, an additional 20-25% energy savings are possible with dimmable ballasts. In these areas energy use can be reduced by more than 51%.
- Dedicated solid-state ballasts can reduce the power and energy density for lighting from 3.1 w/ft^2 to 2.4 w/ft^2 and from 16.03 kWh/ft^2 to 12.18 kWh/ft^2 , respectively.

- Dimmable solid-state ballasts can reduce the power and energy density for lighting from 3.1 w/ft² to 1.8 w/ft² and from 16.03 kWh/ft² to 9.46 kWh/ft², respectively.
- Solid-state ballasts meet the safety requirements of a medical center and operate reliably.

Major Recommendations

- Dimmable solid-state ballasts should be specified for all new VA medical facilities that will start being constructed by 1982 or later.
- Dedicated or dimmable solid-state ballasts should be specified for all scheduled renovations occurring in 1982 or later.
- Dedicated or dimmable solid-state ballasts should be a standard replacement item for ballasts that fail in the field.
- The solid-state ballast, after a careful cost analysis, should be considered one of several viable options for reducing energy consumption for lighting, pursuant to VA mandates for reducing energy consumption in VA facilities.
- In following the above recommendations, a user should specify that a solid-state ballast meet the VA's requirements for safety, reliability, and efficient performance. In particular, the supplier's price should reflect the product's performance (UL Certification, high power factor, high efficiency, low EMI power generation, low third-harmonic wave distortion, record of performance, low flicker, and warranty).
- The VA Office of Construction should examine their outdoor lighting facilities and other areas where color rendition is not critical and consider the use of high-pressure sodium lamps operated with solid-state ballasts.
- New efficient light sources that can replace incandescent lamps should be assessed.

1 INTRODUCTION

The staff of the Veterans Administration (VA), through their Office of Construction, have been actively participating in programs to cost-effectively reduce the energy used in operating their buildings. The solid-state ballast, which has been shown to operate fluorescent lamps 20 to 25% more efficiently than core-coil ballasts,¹ represented another opportunity for the VA to meet these efficiency objectives. Using these ballasts in VA medical centers can significantly impact the buildings' energy use since lighting represents about 40 to 50% of the energy load. When the total performance of a solid-state ballasted fluorescent system is considered, the 'real' energy savings will exceed the measured intrinsic efficiency,² reducing a building's energy load by more than 20% while improving the illumination system.

At the time the VA expressed an interest in solid-state ballasts (mid-1979), the ballasts were in their final stages of development and not completely field-tested. A principal concern of the VA was the high-frequency (20 kHz to 30 kHz) operation of the ballast. Possible electromagnetic interference (EMI) associated with ballast operation might adversely affect sensitive hospital equipment. Although an extensive three-year test at the Pacific Gas and Electric Company's office building indicated no adverse effects,³ a more stringent test was in order to study the EMI from these new ballasts in a hospital containing sensitive diagnostic and monitoring equipment.

Toward this end the Veterans Administration Office of Construction supported a demonstration to qualify the use of solid-state ballasts in their buildings. The VA medical center in Long Beach, California, was selected as the demonstration site. In concert with the VA Office of Construction in Washington, D.C., and the engineering staff at the VA Long Beach Center, the Lawrence Berkeley Laboratory (LBL) Lighting Program staff developed a demonstration schedule. The program was designed to test the performance of solid-state ballasts in representative areas of a hospital in order to assess their safety, reliability, and cost-effectiveness. This report presents the results and conclusions of this solid-state ballast demonstration.

2 DEMONSTRATION DESIGN

2.1 Test Areas

The performance of the solid-state ballast was assessed in five areas of the hospital complex. These areas included a large space for general use, an office area, two diagnostic areas, and a coronary care ward with monitoring equipment. All of the tests in the latter two areas were conducted when no patients were present.

2.1.1 Outpatient Lobby

The outpatient lobby was selected as representative of a large, general-use space in a hospital. The layout of the floor is shown in Figure 2.1. The lobby is in a new wing of a building, and the lighting system has been operating less than twelve months (6000 hours). About 75% of the space is a sitting area where visual tasks are not critical, activities consisting of casual reading by visitors and waiting patients. A reception desk area, filling the remaining space, is the site of more critical visual tasks -- filing, typing, data processing, reading records, etc. The average light level is 415 lux (39 footcandles) in the sitting area, and 731 lux (68 footcandles) in the reception area. These lighting levels are within the recommended federal guidelines. In the perimeter areas of the lobby 132 40-watt, T-12, rapid-start cool white fluorescent lamps (66 ballasts) are used in enclosed two- and four-lamp (2' x 4') fixtures. The locations of these fixtures are shown schematically in Figure 2.1 as rectangles. They are of the non-air handling type. The minimum lamp wall temperatures of these lamps ranges between 46°C and 51°C. The connected load for the lighting system in this area is 1.37 watts per square foot.

A large grid of closely spaced bare lamps supplies illumination in the center of the lobby. The grid has no venting and contains 146 40-watt, T-12, rapid-start cool white fluorescent lamps. The minimum lamp wall temperature of these lamps is about 61°C. The coefficient of utilization of the grid is poor, and the connected load in this area is 4.2 watts per square foot.

The average lighting level and connected load for the lobby, including the reception area (4336 ft²), is 494 lux (46 footcandles) and 2.8 watts per square foot, respectively.

2.1.2 Director's Suite

The director's suite was selected as a typical office area. The floor plan of the three-office suite is shown in Figure 2.2. The suite is in an old wing that has received no scheduled lighting maintenance. That is, the lighting fixtures are not cleaned routinely and lamps are replaced only when they fail. The suite is illuminated by 72 40-watt, T-12, rapid-start cool white fluorescent lamps (36 ballasts) in enclosed, non-air handling, two-lamp (1' x 4') fixtures. The light levels in the executive offices are 695 lux (65 footcandles) and 603 lux (56 footcandles); the light level is 856 lux (80 footcandles) in the secretary's office.

The connected load for the suite (952 ft²) is 3.4 watts per square foot with an average light level of 718 lux (67 footcandles).

2.1.3 Coronary Care Ward

A coronary care ward was selected because it contains equipment for monitoring patients. The test area included the nurses' station as well as the patient's room. The patient's room contained the usual

accessories (television, telephone, radio, etc.) as well as the standard equipment used to continually monitor a patient's vital signs. The effect upon an external pacemaker was also examined. Only EMI measurements were conducted in the coronary care ward.

2.1.4 Diagnostic Areas

Two diagnostic areas were selected in which to measure EMI. One was the Computerized Axial Tomography (CAT) scanning room and the other the Electroencephalograph (EEG) examination area. Both areas employ computer systems to process data. The EEG system was of particular interest because it measures and analyzes very low-level electrical signals of the brain.

These two areas are in a building that uses a 120-volt lighting system. The solid-state ballasts used in the test required 277 volts input. Since these ballasts could not be operated in the existing fixtures, the EMI was measured with a portable two-lamp 40-watt fixture. A transformer was used to increase the supply voltage to 277 volts. This portable fixture with the solid-state ballast was placed within one foot of the diagnostic equipment and its EMI compared with that of the core ballasts in the permanent fixtures.

2.2 Test Procedures

2.2.1 Electrical, Light Measurements

Appendix A lists the instruments used to measure electrical parameters and light levels. In the lobby and director's suite, where the performance of the solid-state ballasted systems was assessed, the lighting circuits were rewired to place all the test fixtures on the same branch circuit. This permitted us to connect the current and power transducers around one power line in the electric closet. Thus data could be collected without disturbing the occupants or the normal operation of the test areas. Electrical data were collected before and after the scheduled changes in the lighting system (see Section 2.3).

Light levels were measured with a Tektronix J-16 photometer and a J-6511 probe. This probe is both cosine- and color-corrected. Light levels were measured at several locations in each test area during evening hours. The positions at which the light levels were measured were precisely located to be certain that subsequent light measurements were taken at the same positions, assuring relevant comparisons. Figures 2.1 and 2.2 show the positions at which illumination was measured in the lobby and in the director's suite, respectively.

2.2.2 Daylight Instrumentation

The director's suite has windows that provide this area with natural illumination. To exploit this source of illumination, the light output of the fluorescent lamps was automatically controlled

with the solid-state ballasts, so they could be dimmed in response to prevailing natural illumination. A photocell was placed in the ceiling of each office to sense the level of illumination and send a signal to the ballasts, changing the light output of the lamps when the nighttime level of illumination was altered. The design goal of this dimming system was to obtain a constant illumination level on the tasks throughout the day.

A schematic of the complete dimming system is shown in Figure 2.3. The photocell senses the light level, and the photo-control module sends a signal to the ballasts to provide the prescribed illumination. In the director's suite one photocell and module in each office controlled all the fixtures in that office (from 18 to 30 lamps). The photo-control module could also be operated manually. That is, a user can set the lights to any level desired. When the automatic dimming system was installed, the maximum and minimum desired electric light levels were established. To measure the system's performance and to assess design goals, a photodiode was placed on the secretary's desk to continuously monitor the incident illumination on the desk throughout the day (see Figure 2.2). The amplified output signals from the photodiode (which measured the illumination) and the power transducer (which measured the power in the suite) were recorded continuously for several days with a two-pen strip-chart recorder.

2.2.3 Electromagnetic Interference Instrumentation

The radiated EMI measurements were obtained with a Tektronix 765 spectrum analyzer connected to a standard 41-inch monopole antenna having a ground plane. The antenna was positioned vertically, directly under a fixture in each room. The midpoint of the antenna was one meter from the fixture.

Conducted EMI measurements were taken using the same spectrum analyzer connected by a current probe clamped to the hot-wire that provided power to the lighting systems in the demonstration areas.

2.3 Test Schedule

The designed test schedule reflects LBL's attempt to accurately measure changes in the electrical load and energy consumption that resulted from introducing energy-efficient lighting concepts and products.

2.3.1 Baseline I Data

Prior to any changes in the test areas, the power, current, voltage, light levels, and conducted and radiated EMI levels were measured. The compiled information has been designated Baseline I Data. All measurements were made with the lighting system at equilibrium in the evening. Measuring the light levels at night assured us that only the electrical light levels were measured.

The lamp wall temperatures in several fixtures were also measured with thermocouples fixed to the midpoints of the lamps.

2.3.2 Baseline II Data

After Baseline I Data were collected and compiled, all the fixtures were cleaned and relamped. The 40-watt T-12 lamps were replaced with 35-watt, Type II energy-saving lamps. The lamps were operated for more than 1000 hours prior to any measurements. This allowed the lamps to pass through their initial large lumen depreciation (5%). Thus, for any subsequent changes (e.g., the installation of solid-state ballasts), the changes in light level due to lamp lumen depreciation would be so small they could be neglected.

The same data were collected and compiled as for Baseline I. These data were designated Baseline II Data. These data measured the changes in connected load and illumination due to cleaning and relamping with energy-saving lamps.

2.3.3 Experimental

Within three weeks after collecting Baseline II Data (~360 hours of operation), the core-coil ballasts were replaced by solid-state ballasts in the test areas.

The standard series of measurements was then repeated so that we could compare the data to the initial condition of the test site, as well as directly identify changes in performance due to the solid-state ballasts.

As for Baseline I, conducted and radiated EMI measurements were made to compare the EMI levels of the low- and high-frequency lighting systems.

2.3.4 Electromagnetic Interference Tests

In the coronary care ward and the diagnostic areas, measurements of conducted and radiated EMI for the core-coil and solid-state ballasts were made on the same date. This procedure was employed in case the solid-state ballasts showed excessively high EMI levels. If the levels were considered excessive, the ballasts could have been replaced with core-coil ballasts immediately after the measurements.

3 BALLAST MANUFACTURE

3.1 Specifications

After the design and scope of the demonstration had been established, a set of solid-state ballast specifications were generated. The features of a solid-state ballast needed for this qualification study included 277-volt input, automatic dimming capability, reliability, warranty, and the manufacturer's agreement to a set of acceptance criteria. The complete set of ballast specifications is given in Appendix B. Luminoptics Corporation was selected to supply the 250 solid-state ballasts and three photo-control modules.

3.2 Quality Assurance

There were no known established product lines of solid-state ballasts at the time of this study. Thus, acceptance criteria were established for the finished product (see Appendix B). The criteria consisted of a series of burn-in procedures at the Luminoptics plant and at the LBL Lighting Laboratory. While testing the delivered ballasts, the initial criteria were amended; the final set of burn-in procedures is given below.

At the manufacturing plant:

- A 48-hour burn-in for all ballasts.

At LBL (100% testing):

- Operate ballast at input voltages of 305, 249, and 277 (277 $\pm$ 10%)
- Operate 24 hours (3 hours on/20 minutes off) with one lamp removed;
- Operate 24 hours (3 hours on/20 minutes off) with both lamps in place;
- Replace lamps several times while power is being supplied to ballast.

At the LBL laboratory 25 ballast failures occurred during the above test schedule. At the test site (VA Hospital) 13 solid-state ballasts were found defective after passing the above test schedule. Seven of the 13 failed immediately after installation, suggesting shipping damage. At the time of preparing this report, about 200 solid-state ballasts will have been operating for more than eight months (4500 hours).

All of the failed ballasts were returned to Luminoptics and replaced. The manufacturer analyzed the modes of failure and submitted a report on their nature. The report is given in Appendix C. The Luminoptics report shows that all the failures can be explained and are not due to any shortcomings in the basic circuit design.

3.3 Reliability

The ballast failures that occurred during the burn-in schedule and at the test site reflect initial problems associated with a transfer of technology. The presently designed ballasts are commercial prototypes. Ballasts are now being mass-produced in-house and by potential suppliers, and manufacturing experience is being accumulated. The substitution of components and other unauthorized changes by the manufacturing line was the source of the defects.

The total failure count, to date, is the initial 38 units plus the 10 units that have failed at the test site since December, 1980. These units have been identified as having been delivered by the outside

supplier.

The 10 units that failed after several months show that the LBL burn-in test was not capable of detecting all defective ballasts. That is, a few ballasts will pass a short burn-in test with defects that manifest themselves only after several months. The above limitation reflects the importance of inspecting incoming components as well as in-line workmanship.

There is no doubt that the basic circuit design of these solid-state ballasts is reliable and will result in long life. The Long Beach Medical Center demonstration of these systems, in a limited and closely supervised area, contributed to identifying key components. These devices must be rigorously specified since sources of defects are difficult to identify in post-manufacturing testing. The on-site ballast defects that were not screened amount to a 9% failure rate of delivered products. This rate should be able to be reduced to 1% in the next few months thanks to the experience gained in this study. The target failure rate in the future is 0.5% (the same rate as the core-coil ballast). With mature product lines and the use of thick-film and integrate circuits this target should be achieved.

End-users of solid-state ballasts should obtain some evidence of a product's on-site performance. This requirement should be specified on the purchase agreement.

4 RESULTS

4.1 Static Performance

4.1.1 Director's Suite

Table 4.1 lists the measurements of the connected load and light levels for the suite as it existed (Baseline I), after cleaning and relamping (Baseline II), and after replacing the core-ballasts with solid-state ballasts (Experimental). Illumination was measured in units of lux (10.7 lux = 1 footcandle). Power is given in terms of the total power for the suite and in terms of the average power per ballast (total power $\div$ number of ballasts).

To aid in presenting the relative changes in the important parameters (power, light level, and efficiency), the results listed under figure of merit are normalized with respect to Baseline I Data. In the last column (Experimental), the figures in parentheses reflect changes with respect to Baseline II Data. The differences in parameters (light, power, and efficiency) with respect to Baseline II show the changes due to replacing the core-coil ballasts with solid-state ballasts.

Table 4.1
ELECTRICAL & LIGHT MEASUREMENTS IN DIRECTOR'S SUITE

<u>DESCRIPTION</u>	<u>BASELINE I (1)</u>	<u>BASELINE II (2)</u>	<u>EXPERIMENTAL (3)</u>
ELECTRICAL			
POWER (WATTS)	3208	2870	2377
POWER PER BALLAST (WATTS)	89.1	79.7	66.
POWER FACTOR	.95	.95	.95
LIGHT LEVEL (LUX)			
DIRECTOR	695	981	952
ASST. DIRECTOR	603	1098	1038
SECRETARY	856	1057	1013
FIGURE OF MERIT			
AVERAGE LIGHT (LUX)	718	1045	1001
EFFICIENCY (LUX/WATT)	8.06	13.11	15.2
RELATIVE LIGHT	1	1.46	1.39(.96)*
RELATIVE POWER	1	.89	.74(.83)*
RELATIVE EFFICIENCY	1	1.63	1.89(1.16)*

- (1) CORE-COIL BALLASTS, 40-WATT LAMPS
- (2) CORE-COIL BALLASTS, 35-WATT LAMPS, CLEANED
- (3) SOLID-STATE BALLASTS, 35-WATT LAMPS CLEANED
- * WITH RESPECT TO BASELINE II

Baseline II Data show a 46% increase in light level. The improvement is due to cleaning the fixtures and refitting with new lamps. The 11% reduction in power results from using 35-watt lamps in place of 40-watt lamps.

By refitting with solid-state ballasts, the power is reduced 26%, while the light level is increased 39% with respect to initial conditions.

4.1.2 Lobby

Table 4.2 lists the results of static measurements in the lobby for the three lighting conditions (Baseline I, Baseline II, and Experimental).

Table 4.2
ELECTRICAL & LIGHT MEASUREMENTS IN LOBBY

DESCRIPTION	BASELINE I ⁽¹⁾	BASELINE II ⁽²⁾		EXPERIMENTAL ⁽³⁾	
		A	B	A	B
ELECTRICAL					
POWER (WATT)	12,130	5,168	10,448	4,825	9,108
POWER PER BALLAST (WATT)					
FIXTURE	90.0		80.0		64.9
GRID	84.8	70.8	70.8	66.1	66.1
POWER FACTOR	.89	.96	.96	.96	.96
LIGHT LEVEL (LUX)					
FIXTURE	731.		851.		818.
GRID	415.	417.	417.	520.	520.

(1) CORE-COIL BALLASTS, 40-WATT LAMPS

(2) CORE-COIL BALLASTS, 35-WATT LAMPS, CLEANED

(3) SOLID-STATE BALLASTS, 35-WATT LAMPS, CLEANED

* WITH RESPECT TO BASELINE II

FIXTURES: 66 BALLASTS; GRID: 73 BALLASTS

The ballasts in the enclosed fixtures and in the grid were measured independently. This was required because the lamp wall temperature in these two types of fixtures differed by as much as 10°C, resulting in a large change in input power per ballast. It is well known that lamp performance depends upon lamp wall temperature; a description of the difference is presented in Appendix D. The lower power per ballast in the grid is due to the higher lamp wall temperature (~61°C) compared to the temperature of the lamps in the enclosed fixtures (~50°C). However, as the results in Table 4.2 show, the light output of the lamps in the grid also decreases but still shows a net decrease in system efficiency.

The data in Table 4.3 are presented normalized with respect to the initial condition.

Table 4.3
RELATIVE SYSTEM PERFORMANCE IN LOBBY

FIGURE OF MERIT	BASELINE I (1)	BASELINE II (2)		EXPERIMENTAL (3)	
		A	B	A	B
EFFICIENCY (Lux/WATT)					
FIXTURE	8.12		10.6		12.6
GRID	4.89	5.88	5.88	7.87	7.87
RELATIVE LIGHT					
FIXTURE	1.00		1.16		1.12 (.96)*
GRID	1.00	1.00	1.00	1.25	1.25 (1.25)*
RELATIVE POWER					
FIXTURE	1.00		.89		.72 (.81)*
GRID	1.00	.83	.83	.78	.78 (.94)*
RELATIVE EFFICIENCY					
FIXTURE	1.00		1.31		1.55 (1.18)*
GRID	1.00	1.20	1.20	1.61	1.61 (1.34)*

(1) CORE-COIL BALLASTS, 40-WATT LAMPS

(2) CORE-COIL BALLASTS, 35-WATT LAMPS, CLEANED

(3) SOLID-STATE BALLASTS, 35-WATT LAMPS, CLEANED

* WITH RESPECT TO BASELINE II

FIXTURES: 66 BALLASTS; GRID: 73 BALLASTS

The light level in the lobby increased by 16%. This is much less than the increase measured in the director's suite, a fact we attribute to less lumen depreciation for these newer lighting systems. Under the grid the light level stayed the same (the grid had no diffusers that would accumulate dirt); thus, there was no appreciable dirt lumen depreciation. The lamp lumen depreciation for the 40-watt lamps in the grid apparently was small.

Because of the high lamp wall temperature, the solid-state ballasts provided a 34% increase in efficiency compared to core ballasts operating the fluorescent lamps in the grid. This shows that the total system efficiency is maintained over a wider range of lamp wall temperatures (30°C to 61°C) in a solid-state ballasted system than in a core-coil system. That is, the system efficiency for a core-coil system is drastically reduced when the lamp wall temperature exceeds 50°C. This excellent regulation by solid-state

ballasts is also shown by comparing the input power of the two types of ballasts in the two sections of the lobby (fixtures and grid). Input power for the solid-state ballasts is virtually the same for both stations (64.9 and 66.1 watts), while the core-coil ballasts differ by nearly 10 watts for both the 40-watt lamps (90 and 80 watts) and for the 35-watt lamps (80 and 70 watts). Table 4.4 lists the power per ballast in the two sections.

Table 4.4
POWER PER BALLAST IN THE
GRID AND FIXTURES

BALLAST TYPE	POWER PER BALLAST (WATTS)	
	GRID (LAMP TEMP. 61°C)	FIXTURES (LAMP TEMP. 50°C)
CORE-COIL	84.8 (1)	90.0 (1)
	70.8 (2)	80.0 (2)
SOLID-STATE	66.1 (2)	64.9 (2)

(1) 40-WATT LAMPS

(2) 35-WATT ENERGY-EFFICIENT LAMPS

4.2 Daylighting

Figures 4.1 and 4.2 show the continuous power consumption for the director's suite and the illumination on the secretary's desk for two days in mid-October (the 11th and 12th). The 11th was a cloudy day, while the 12th was clear. For a 10-hour day (8 a.m. to 6 p.m.), the energy consumption was 23.8 kWh with a dedicated solid-state ballasted system. The energy used on the 11th and 12th was 19.1 and 17.8 kWh, respectively. This shows that an energy savings of 20-25% is possible by using daylighting. The annual savings for this small area would be 1392.3 kWh. At \$.07 per kWh, this would be an annual savings of \$97.46

The dimming system's good design (placement of the photocell sensors and operation of the module) is reflected by the fact that the task light level was maintained at between 940 and 960 lux ($\pm 1\%$), while the electrical illumination fluctuated as much as 40%.

The dimming system was adjusted so that the electric light level could be reduced to only 60% of its maximum output. This conservative

approach was taken because 35-watt lamps are generally more difficult to dim than the standard 40-watt lamps. One author (RRV), however, has a dimming system in his office which satisfactorily operates 35-watt lamps over a light output range from 100% to less than 50%.

The sensitivity of the dimming system to the natural ambient light is shown by the greater reduction of energy on the clear day than on the cloudy day, as one would anticipate. In addition, because most of the windows face the west, more natural illumination was available in mid-afternoon. The data indicate that the least electrical lighting energy was used in the afternoon between 2 pm and 5 pm.

4.3 Electromagnetic Interference (EMI) Data

4.3.1 Conducted EMI

Figures 4.3 and 4.4 show the conducted EMI data. Shown with the data are the Food and Drug Administration (FDA) limits that apply to individual medical device emission and susceptibility. 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 4.3 shows the conducted EMI 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 4.4 shows the data for the outpatient lobby demonstration area. Shown with the data are FDA limits ⁵ (see Appendix F) that apply to individual medical device emissions and susceptibility. Curve 3 is the FDA device conducted broadband emission limit (converted to $\text{db}/\mu\text{A}/\text{kHz}$); curve 2 the FDA device conducted narrowband emission limit; and curve 1 the FDA medical device susceptibility limit converted to $\text{db}/\mu\text{A}$ using the standarding line impedance stabilizer (LISN) impedance in this frequency range.

The FDA emission specifications are intended to apply to individual devices. The data presented in Figures 4.3 and 4.4 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 before it appears in the 120-volt circuit. In light of the above, it is unlikely that conducted interference would cause any incompatibility between solid-state ballasts and general medical devices.

4.3.2 Radiated EMI

Figures 4.5 and 4.6 show a composite of radiated EMI data derived from spectrum analyzer photographs taken in the four test areas. Typical spectrum analyzer photographs are shown in figures E.1 and E.2 of Appendix E. Included with the data in figures 4.5, 4.6, and E.2 are the FDA radiated limits. Curve 3 is the FDA device radiated broadband emission limit (converted to $\text{db}/\mu\text{V}/\text{m}/\text{kHz}$; curve 2 is the FDA device radiated narrowband emission limit; and curve 1 is the FDA device radiated susceptibility limit. The data in Figure 4.5 show the broadband radiation measured from the conventionally ballasted fixtures prior to the ballast retrofit. The curve compares favorably to the FDA broadband limit. Measurements are shown only to 2 MHz, where the radiation disappears into the ambient hospital EMI.

The curves shown in Figure 4.6 represent 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, (each dot representing a narrowband peak), and curve segment BC represents the broadband background radiation underlying these peaks (see Appendix E, Figure E.2). 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 tend to merge at the higher frequencies and 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.⁹ Curve segment CD then continues to drop in amplitude until it also disappears into the ambient hospital EMI at about 4 MHz. The broadband component of the EMI from the solid-state ballasted fixtures compares quite favorably with the FDA radiated broadband emission limit. However, the narrowband peaks for the solid-state case exceed the FDA radiated narrowband 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 4.7 shows the VA demonstration data plotted with that of Clark,⁴ indicating reasonably good agreement for the broadband component of the electric field emission.

4.3.3 Electromagnetic Compatibility Tests

In addition to the direct measurement of EMI 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 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 17-V, 2-millisecond pulse occurring at a 1-second period. This produces a broadband burst of power when viewed on a spectrum analyzer with a 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 set, 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 E.4 of Appendix E).

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, a hand-held fluorescent fixture having a solid-state ballast and two fluorescent lamps was devised 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 in close proximity to the sensitive equipment. No interference was observed.

Electroencephalograph (EEG) Examination Area. This area is also in an older portion of the hospital, and for the same reasons as given above, EMI had to be investigated using the hand-held fixture. This area is divided into two parts, that containing the measuring equipment, and a section 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, the recorders registered interference. The EEG operator explained that it is mandatory to conduct EEG examination with the conventionally ballasted fluorescent lights turned off since they also cause interference with the sensitive EEG equipment.

4.4 Impact of Solid-State Ballast Performance

In order to determine the potential impact that the solid-state ballast can have upon connected load and energy consumption for the medical center, specific results will be generalized.

In 1976, the typical lighting load for a medical center was 3 to 4 watts per square foot.⁹ The average initial power density in the lobby and the office was 2.8 watts/ft² and 3.4 watts/ft², respectively. The average power density at the Long Beach Medical Center is 3.1 watts/ft², assuming these two areas represent the "average." Lights are used 6000

hours annually in the lobby and 3000 hours annually in the offices. Since most areas of the medical center are in operation more than the office hours, we will give double the weight to the lobby's hours in averaging usage hours. The average hours of use are thus 5170 hours. Thus, the average annual energy density of lighting consumption for the medical center is $3.1 \text{ w/ft}^2 \times 5170 \text{ h} \times 10^{-3} = 16.03 \text{ kWh/ft}^2$.

Using the efficiency improvements we have measured for the efficient lamps and solid-state ballasts, operated in the dedicated or the dimmable mode, we can predict average savings for the entire Long Beach Medical Center.

The average reduction in power from dedicated solid-state ballasts was 24% (see Tables 4.1 and 4.3). That is, both power and energy density can be reduced by 76%, or 2.36 w/ft^2 and 12.18 kWh/ft^2 .

The average reduction in power from dimmable ballasts was 37% and, where daylighting could be used, was 53%. In a 100-foot by 100-foot building (10,000 square feet per floor), the outer ten feet (3600 square feet per floor) can use natural illumination. This represents 36% of the total building area. To be conservative we assume 25% of the medical center area can use daylighting effectively. Thus, the average power reduction for the facility is $(75\% \times .37 + 25\% \times .53) = .41$; average power consumption is reduced 41%. Thus, the average power density and energy density reduction is 1.83 watts/ft^2 and 9.46 kWh/ft^2 , respectively. The general expression to determine the above is the following:

$$P_{D2} = P_{D1} \left[1 - \frac{P_1 - P_2}{P_1} \right], \quad (4.1)$$

and

$$E_{D2} = E_{D1} \left[\left(\left[1 - \left(\frac{P_{i1} - P_{i2}}{P_{i1}} \right) \right] \times \alpha_i + \left[1 - \left(\frac{P_{e1} - P_{e2}}{P_{e1}} \right) \right] \alpha_e \right) \right], \quad (4.2)$$

where:

P_{D1} = initial power density
 P_{D2} = final power density
 P_1 = initial power per ballast
 P_2 = final power per ballast (solid-state)
 E_{D1} = initial energy density
 E_{D2} = final energy density
 P_i = power per interior ballast
 P_e = power per exterior ballast
 $\alpha_{i,e}$ = proportion of total floor area with i and e type of ballasts.

5 LIFE-CYCLE COST ANALYSIS

A life-cycle cost method that considers initial, operating, and installation costs, and discounts capital investment, is used to calculate the total cost of presently used lighting systems. If any new lighting system that provides the same function costs less than the total cost of the present system, that new system is "cost-effective." The initial cost of solid-state ballasts to the end-user is not well defined at this stage of their commercial life since the ballast manufacturers' costs are high due to the small unit volume of production. Thus, their price will be based upon whatever the market will bear. The goal in this section is to determine the maximum initial cost of the new solid-state ballasts which will result in a total cost that is "cost-effective". If the new system is cost-effective it will be the soundest investment. Note that the cost-effective price for a particular system will differ, depending upon whether it is used in a retrofit or a new construction.

Tables 5.1 and 5.2 present the basic parameters from which we determined the cost-effectiveness of the various energy-conserving strategies (cleaning and relamping; the use of dedicated or dimmable solid-state ballasts.)

Table 5.1
POWER PER BALLAST

SITE	BASELINE I		BASELINE II		EXPERIMENTAL					
	(40-WATT LPS)		(35-WATT LPS)	REDUCED POWER	DEDICATED (WATT)			DIMMABLE (WATT)		
	(CORE/BALLAST)		(CORE/BALLAST)	(BLI)	(35-WATT LPS) REDUCED POWER			(35-WATT LPS) REDUCED POWER		
	(WATT)		(WATT)	(WATT)	(SOLID-STATE BALLAST)	BLI	BLII	(SOLID-STATE BALLAST)	BLI	BLII Exp Ded.
OFFICE	89.1		79.7	9.4	66.0	23.1	13.7	53.5	35.6	26.2 12.5
LOBBY										
FIXTURE	90.0		80.0	10.0	64.9	25.1	15.1	61.2	28.8	18.9 3.7
GRID	84.8		70.8	14.0	66.1	18.7	4.7	56.0	28.8	14.8 10.1

Table 5.2
OPERATION OF DEMONSTRATION AREAS

SITE	ANNUAL USE (HRS)	NUMBER OF LAMPS	NUMBER OF BALLASTS
DIRECTOR'S SUITE	3500	72	36
LOBBY			
FIXTURE	6000	132	66
GRID	6000	146	73

The power per ballast is obtained from Tables 4.1 and 4.2. The reduction in power is with respect to the major column heading. For example, the reduction in power for the dedicated, Experimental condition compared to the Baseline I condition is listed under the column entitled Experimental, dedicated BLI (23.1, 25.1, and 18.7 watts).

The power per ballast listed for the dimmable solid-state ballast was calculated from Tables 4.1 and 4.2. It is the power that would be needed for the solid-state ballasted system to provide the same light level as was measured initially (Baseline I light levels). This is simply the power per ballast at Baseline I divided by the relative efficiency in the Experimental column. The values in Table 5.1 for the dimmable ballasts are corrected to account for lumen depreciation, based upon a two-year scheduled maintenance program. We have used a 10% lamp lumen depreciation rate for the two-year schedule. Thus, the average power per ballast for the dimmable ballasts is increased by 5% when adjusted to provide the initial light levels. We increased this power by an additional 5% to account for the non-linearity of the dimming.

Table 5.2 lists the estimated hours of operation as well as the number of lamps and ballasts in each test area. The director's office is used six days a week and 11 hours a day. The lobby is used 17 hours a day throughout the year.

5.1 Cleaning and Relamping

Table 5.3 lists the cost of cleaning and relamping the area. We have used the list price of \$3.00 per energy-efficient lamp and have estimated a cost of \$2.00 to clean and relamp each fixture.

Table 5.3
COST OF CLEANING AND RELAMPING

SITE	INITIAL LAMP COST (\$)	INITIAL LABOR COST (\$)	TOTAL COST (\$)	ANNUAL COST (\$)
DIRECTOR'S SUITE	216	72	288	
LOBBY				
FIXTURE	396	132	528	
GRID	438	146	584	
		TOTAL	1,400	806.7

The total initial cost is \$1400. In order to determine the annual cost we employ a two-year maintenance schedule and discount the initial investment by 10% annually. We used the uniform capital recovery equation⁶:

$$A = P \times UCR = P \times \frac{i(1+i)^n}{(1+i)^n - 1} \quad (5.1)$$

where A is the installment amount,
P is the initial investment,
i is the discount rate,
n is the equal periodic installments, and
UCR is the uniform capital recovery.

Table 5.4 lists the energy saved annually in both areas by using the energy-saving lamps (11,276 kWh).

Table 5.4
ENERGY SAVED AFTER CLEANING AND RELAMPING

SITE	REDUCED POWER (WATTS/BAL.)	ENERGY SAVED (KWH/YR.)	ANNUAL SAVINGS(\$)	
			AT \$0.05KWH	\$0.10KWH
DIRECTOR'S SUITE	9.4	1,184	59.2	118.4
LOBBY				
FIXTURE	10	3,960	198	396
GRID	14	6,132	306.6	613.2
	TOTAL	11,276	563.8	1,127.6

This reduces annual energy consumption by 13%. Cleaning fixtures increases the light output but does not affect the connected load or energy consumption. Figure 5.1 is a plot of energy cost versus initial cost of the fluorescent lamp. This curve permits a user to determine the cost-effective price of a lamp depending on the cost of energy. The curve is generated from Tables 5.2, 5.3, and 5.4. It is a conservative estimate since it discounts the initial lamp and labor investment but assumes a constant cost for energy.

5.2. Solid-State Ballasts

5.2.1. Dedicated Operation

The costs for ballasts and installation are listed in Table 5.5.

Table 5.5
COST OF SOLID-STATE BALLASTS

SITE	LABOR COST (\$)	BALLAST COST (\$) AT			
		\$20/BAL.	\$30/BAL.	\$40/BAL.	\$50/BAL.
DIRECTOR'S SUITE	360	720	1,080	1,440	1,800
LOBBY					
FIXTURE	660	1,320	1,980	2,640	3,300
GRID	730	1,460	2,190	2,920	3,650
TOTAL	1,750	3,500	5,250	7,000	8,750
ANNUAL COST	285	570	854	1,139	1,424
LABOR		285	285	285	285
CLEAN & LAMP		806.7	806.7	806.7	806.7
TOTAL ANNUAL COST		1,661.7	1,945.7	2,230.7	2,515.7

The labor cost to change one ballast is estimated to be \$10.00. Initial ballast costs are considered in the range of \$20 to \$50 each. Annual costs are obtained by considering a 10-year life and using a 10% discount rate in Equation 5.1. The total annual cost is the sum of the ballasts, labor, cleaning, and relamping.

The energy saved from having the solid-state ballasts operating in a dedicated mode is given in Table 5.6. The savings are determined using the conditions in Tables 5.1 and 5.2. The annual savings is 21,090.8 kWh, providing a 25% reduction in energy consumption.

Table 5.6
ENERGY SAVINGS WITH DEDICATED SOLID-STATE BALLASTS

SITE	REDUCED POWER (WATTS/BAL.)	ENERGY SAVED (KWH/YR)	ANNUAL SAVINGS(\$)	
			AT \$0.05/KWH	\$0.10/KWH
DIRECTOR'S SUITE	23.1	2,910.6	145.53	291.06
LOBBY				
FIXTURE	25.1	9,939.6	496.98	993.96
GRID	18.7	8,190.6	409.53	819.06
TOTAL		21,040.8	1,052.04	2,104.08

Two cost-effective curves are shown in Figure 5.2, relating the initial cost of the ballast and the cost of energy. The curves are generated using Tables 5.5 and 5.6 and a cost of \$1 or \$3 per lamp.

In order to compare the relative merits of a solid-state and a core-coil ballast, Table 5.7 lists the energy savings obtained solely by refitting the core ballast with a solid-state ballast operated in the dedicated mode.

Table 5.7
ENERGY SAVED WITH SOLID-STATE BALLAST
RELATIVE TO CORE BALLASTS

SITE	REDUCED POWER (WATTS/BAL.)	ENERGY SAVED (KWH/YR)	ANNUAL SAVINGS(\$)	
			\$0.05/KWH	\$0.10/KWH
DIRECTOR'S SUITE	13.7	1726.2	86.31	172.62
LOBBY				
FIXTURE	15.1	5979.6	298.98	597.96
GRID	4.7	2058.6	102.93	205.86
	TOTAL	9764.4	488.22	976.44

The annual energy savings is 9764.4 kWh, meaning that the solid-state ballasts use 14% less power than do core-coil ballasts.

Figure 5.3 is the cost-effective curve one can use when considering the purchase of a standard core-coil ballast or a dedicated solid-state ballast. The premium cost of the solid-state ballast is plotted--i.e., the initial cost of the ballast is the premium cost plus the cost of a standard core-coil ballast. (The cost of a replacement core-coil ballast to an end-user is about \$10.) The curve shows that if a decision has been made to clean, relamp, and change the ballast, a cost-effective premium price for a dedicated solid-state ballast would be \$18 for an energy cost of \$0.05 per kWh. The total initial cost-effective price of the ballast, if a standard ballast costs \$10, would be \$28.

5.2.2. Dimmable Operation

The previous sections indicate that the factors that reduced connected load were both energy-efficient lamps and solid-state ballasts. Cleaning fixtures and installing new lamps provided higher light levels. With the use of dimming ballasts, connected load can be further reduced by lowering the final light levels to initial levels of illumination, which were considered acceptable by the occupants.

Table 5.8 lists the total energy saved by using dimmable solid-state ballasts after cleaning and relamping, and adjusting light levels to initial (Baseline I) levels.

Table 5.8
TOTAL ENERGY SAVED WITH
DIMMABLE SOLID-STATE BALLASTS

SITE	REDUCED POWER (WATTS/BAL.)	ENERGY SAVED (KWH/YR)	ANNUAL SAVINGS(\$)	
			AT \$0.05/KWH \$0.10/KWH	
DIRECTOR'S SUITE	35.6	4,485.6	224.28	448.56
LOBBY				
FIXTURE	28.8	11,404.8	570.24	1,140.48
GRID	28.8	<u>12,614.4</u>	<u>630.72</u>	<u>1,261.44</u>
	TOTAL	28,504.8	1,425.24	2,850.48

The power per ballast is corrected to account for a 10% lamp lumen depreciation over a two-year maintenance schedule. Figure 5.4 is the cost-effective plot relating initial ballast cost and the cost of energy. Two curves have been generated, for lamp costs of \$1 and \$3.

Table 5.9 presents the energy savings from a dimmable solid-state ballast relative to a standard core-coil ballast.

Table 5.9
ENERGY SAVED WITH DIMMABLE SOLID-STATE BALLAST
RELATIVE TO CORE BALLAST

SITE	REDUCED POWER (WATTS/BAL.)	ENERGY SAVED (KWH/YR)	ANNUAL SAVINGS(\$)	
			AT \$0.05/KWH \$0.10/KWH	
DIRECTOR'S SUITE	26.2	330.12	165.06	330.12
LOBBY				
FIXTURE	18.9	7484.4	374.22	748.44
GRID	14.8	<u>6482.4</u>	<u>324.12</u>	<u>648.24</u>
	TOTAL	17,268.0	863.40	1,726.80

The cost-effective curve for the price of the solid-state ballast compared to a core-coil ballast is plotted in Figure 5.5. Note that ballast cost is given as premium cost. Initial ballast cost is the premium cost plus the cost of a standard core-coil ballast (approximately \$10).

Finally, Table 5.10 lists the energy saved by operating the solid-state ballast in the dimmable as opposed to dedicated mode. The cost-effective curve for this comparison is plotted in Figure 5.6.

Table 5.10
ENERGY SAVED WITH DIMMABLE SOLID-STATE BALLAST
RELATIVE TO A DEDICATED SOLID-STATE BALLAST

SITE	REDUCED POWER	ENERGY SAVED	ANNUAL SAVINGS(\$)	
			AT	
			\$ 0.05/kWH	\$ 0.10/kWH
DIRECTOR'S SUITE	12.5	1575	78.75	157.5
LOBBY				
FIXTURE	3.7	1465.2	73.26	146.52
GRID	10.1	4423.8	221.19	442.38
	TOTAL:	7464	373.2	746.4

5.3 Decision Criteria

5.3.1 Site Characteristics

The collection of data at the VA Medical Center was designed to establish the prices at which lamps and solid-state ballasts would be cost-effective. The initial lighting in the two test areas, director's suite and lobby, can be characterized as follows:

- a. Director's Suite - lamps in enclosed fixtures; lamps have experienced considerable lamp and dirt lumen depreciation.
- b. Lobby - one group of lights in fixtures that have very little lamp and dirt lumen depreciation; another group of closely spaced lamps in a grid, which are operating at a high lamp wall temperature, resulting in a light output about 25% below anticipated manufacturer's rated output.

5.3.2 Ballast Design

The solid-state ballasts selected for this qualification were the Luminoptics Corporation architectural dimming ballasts. These have been shown to achieve efficiencies of 90 lumens per watt and

improvements to efficiency, relative to a core-ballasted system, as high as 25%. Since they are dimmable ballasts, a design decision was reached to operate them at full filament power. These improvements in reliability, plus lowering the component count to reduce product cost, resulted in a decrease in intrinsic efficiency. However, we operated this ballast in a dedicated mode to collect data to examine this condition. Solid-state ballasts designed to operate in a dedicated manner⁷ can and should achieve efficiency improvements, relative to a core ballast, above 20%.

In analyzing ballasts operated in the dimmable mode, we have considered only one of several available energy-saving strategies, manually setting the lighting level to match the initial illumination level. In the preceeding section (4.2) we showed that daylighting allows an automatically controlled dimming system to save an additional 20-25% in energy. Another independent energy-saving strategy is 'tuning' the lighting system to each area's visual requirements. In aisles, halls, and other non-critical areas the solid-state ballast makes it possible to lower the level of illumination and still maintain safe and comfortable visual conditions. Thus, because of reasons given above as well as our use of a constant cost for energy, the effective target prices that are presented in the cost-effectiveness figures for dimmable ballasts (5.4 through 5.6) are conservative.

5.3.3 Ballast Cost Targets

Table 5.11 lists target costs for solid-state ballasts above which it is no longer cost-effective for the designated application in the test areas of the Long Beach VA Medical Center.

Table 5.11
EFFECTIVE SOLID-STATE BALLAST COST

COST OF ENERGY (\$ KWHR)	LAMP COST (\$)	DEDICATED SOLID-STATE BALLAST		DIMMABLE SOLID-STATE BALLAST		
		INITIAL COST ¹ (\$)	PREMIUM COST ² (\$)	INITIAL COST ¹	PREMIUM COST ²	PREMIUM COST ³
0.050	1.00	<10	<18	<27	<32	<15
0.075	1.00	<30	<28	<54	<50	<23
0.100	1.00	<50	<35	<80	<64	<29

1. INITIAL COST OF BALLAST FOR REFIT STRATEGY (CLEANING, RELAMPING AND REFITTING CORE BALLAST).
2. PREMIUM COST OF BALLAST FOR CORE BALLAST REPLACEMENT ON NEW CONSTRUCTION STRATEGY (INITIAL COST = PREMIUM COST + COST OF CORE-COIL BALLAST).
3. PREMIUM COST OF BALLAST FOR DEDICATED SOLID-STATE BALLAST REPLACEMENT ON NEW CONSTRUCTION STRATEGY (INITIAL COST = PREMIUM COST + COST OF DEDICATED SOLID-STATE BALLAST).

The reader should notice that when the solid-state ballast is compared to the initial condition, after cleaning and relamping, an initial cost is cited. The total cost used includes lamp cost, cleaning cost, and ballast installation cost, as well as initial ballast cost. This situation simulates the basis for a management decision to retrofit a lighting system. The table shows that a \$10 dedicated solid-state ballast is cost-effective at energy rates of \$.05 per kWh. At energy rates of \$.10 per kWh, dedicated ballasts are cost-effective at \$50.

The other columns that cite premium costs directly compare the cost-effectiveness of the two types of dedicated ballasts as well as comparing the dimmable solid-state ballast with both types of dedicated ballasts. However, in these comparisons we use the premium cost; that is, including the additional cost required to obtain the superior performing system. This situation simulates the basis for a management decision to select a new lighting system or renovate an existing one. It also simulates a management decision to replace a failed ballast with the same type of ballast or with a new energy-efficient solid-state ballast. In all the above decisions the labor cost, lamp cost, and cost of a core-coil ballast will be incurred; one is concerned with the net worth that the additional expenditure (premium cost) will provide through reducing energy consumption.

5.3.4 Application of Decision Targets

The data and analysis have been presented in the above manner to permit the VA Washington Office of Construction to use the tables

as a guide for all their installations. By plotting the information as a function of energy cost and ballast cost, decisions can be made about which strategy and product is most cost-effective for any location in the United States.

When a ballast price is quoted and the price of energy known, one can select the most appropriate cost-effectiveness curve (Figure 5.1., 5.2., 5.3, 5.4., or 5.5). If the strategy is cost-effective the return on investment (ROI) can be determined in order to compare two or more cost-effective strategies. The ROI is defined by the equation:

(5.2)

$$\text{ROI} = \frac{\text{monies saved in energy cost for strategy}}{\text{investment in energy-saving system}}$$

where: money saved = actual cost of energy minus
cost-effective energy price
and

investment = cost-effective energy price.

For example, if one pays \$0.85 per kilowatt-hour and a dimmable solid-state ballast is priced at \$50, at \$1 per lamp the ROI is $(\$0.085 - \$0.0070) \times 100 \div (\$0.070) = 21.4\%$.

6 DISCUSSION OF EMI DATA

In the presentation of the EMI data taken on-site at the Long Beach VA facility, we have in each case compared it to the FDA guidelines.⁵ Appendix F contains excerpts from that document which indicate its scope and rationale.

Our data show that the radiated narrowband 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 minimum susceptibility limit set by the FDA at 23 kHz to 46 kHz. In our demonstration at the Long Beach VA Medical Center, we found no instance in which solid-state ballasted fixtures caused difficulty where conventionally ballasted fixtures did not. In the EEG laboratory, for instance, neither system could be operated.

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 the basis for the standard, and in setting reasonable guidelines. We especially agree with the need to control the steadily growing ambient EMI.

Table 6.1
FCC SPECIFICATION FOR
ULTRASONIC EQUIPMENT (PART 18C)

<u>Radio Frequency</u>	<u>Distance (Feet)</u>	<u>Field Intensity</u>
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

Table 6.2
MEASURED FIELD INTENSITIES VERSUS
EXTRAPOLATED FCC-ALLOWED EMI INTENSITIES

<u>Frequency</u>	<u>Allowed Field Intensity</u>	<u>Measured Field Intensity</u>
(kHz)	(db _{μV/m})	(db _{μV/m})
20	190	126
200	165	90
400	148	80
1000	116	66

However, these limits were established based upon the levels of EMI that existed at the time in several hospitals. Had solid-state (high-frequency) ballasts been common at the time of the FDA field studies, it is likely that the susceptibility limit would have been raised in the 10-kHz to 550-kHz range. (See Figure E.5 in Appendix E for the ambient levels measured in the FDA study and the resultant susceptibility limits.)

At this time we know of no FCC regulation that applies specifically to solid-state ballasts. Nevertheless, it is informative to compare our data with typical FCC-allowed radiation emissions. Such a comparison is

somewhat complicated by the fact that the FCC specifies measurement distances of 100 feet, 1000 feet, and sometimes one mile. According to ANSI C63.12 Draft,⁸ a conservative method for translating measurement distances (given certain boundary conditions that specify the proper measurement distances with respect to the size of the EMI source and the 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 $\lambda/2\pi$ (where λ is the wavelength of the radiation).

The specification for ultrasonic equipment (FCC Part 18C), which is somewhat typical of radiated emissions allowed in other sections of the regulations, is shown in Table 6.1.

All the measured field intensities for the solid-state ballasted systems are less than the allowable EMI levels that have been extrapolated to the near field (see Table 6.2). Therefore, it appears that the solid-state systems would comply with FCC radiated emission specifications. Even in the proposed revision to Part 18,⁸ the ISM out-of-band limits would allow 136 dB/ μ V/m up to 4.85 MHz (translated to one meter by the method described), which the present system meets.

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 or at the input of branch circuits. 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 four-foot, T12, fluorescent lamp requires 105 VAC to operate, the near field along the axis of the lamp is approximately 100 volts per meter (180 dB/ μ 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 high-frequency systems.^{10,11,12}

7 CONCLUSIONS

Connected load can be reduced and light levels increased by cleaning fixtures and replacing existing fluorescent lamps with energy-saving lamps. Power reductions of 11% result in an annual energy savings of 13.4%, or 11,276 kWh for the director's suite and lobby.

By retrofitting the cleaned and relamped areas with dedicated solid-state ballasts, the higher light levels are maintained while further reductions in connected load are achieved. Compared to initial conditions, the power is reduced by 26.7%, resulting in an annual energy savings of 25% or 21,040.8 kWh for the director's suite and lobby.

By using dimmable solid-state ballasts to restore light levels to initial acceptable levels, the connected load is reduced still further. The power is reduced by a total of 36.7%, resulting in an annual energy savings of 34%, or 28,504.8 kWh for the director's suite and lobby. The inequality between power reduction and energy savings is due to the different usage in the two areas.

For new construction and renovation in areas where energy costs are \$0.05 to \$0.10 per kWh, the premium price for dedicated and dimmable solid-state ballasts can be as high as \$18 to \$35 and \$32 to \$64, respectively. Solid-state ballasts are available at those premium prices.

For refitting with energy-saving strategies in areas where energy costs are \$0.075 per kWh, the initial price for dedicated and dimmable solid-state ballasts should be less than \$30 and \$54, respectively. Solid-state ballasts are available at these initial costs. In areas where energy costs are more than \$0.10 per kWh, both dimmable (\$80) and dedicated (\$50) solid-state ballasts are available at cost-effective prices for all the energy-saving strategies.

The conducted and radiated EMI levels from solid-state ballasted systems exceed the levels from core-coil ballasted systems. However, the measured levels are within the proposed FCC standards and less than the FDA-specified susceptibility levels for hospital equipment over most of the frequency range.

8 PROGNOSIS

8.1 Solid-State Ballast Costs

The present level of sales for solid-state ballasts is low, resulting in a relatively high cost for these systems. Yet this report indicates that there are many areas in the nation where current solid-state ballast prices are cost-effective. Existing solid-state ballast circuit designs lend themselves to standard cost-reduction techniques (thick-film circuits, power-hybrid circuits, and integrated circuits), which became attractive when the unit volume of demand increases. Astute ballast developers are currently working on these cost-reduction techniques. We envision a range of original equipment manufacturers' (OEM) prices of \$8 and \$16 for dedicated and dimmable ballasts, respectively, in the near future. This would suggest retail costs of no more than \$16 and \$32. These prices, and anticipated increases in energy costs, will dictate the universal selection of solid-state ballasts gas-discharge lamps.

8.2 Electromagnetic Interference Levels

From the results of these studies and a previous test at the Pacific Gas and Electric Company's office building in San Francisco, the LBL staff conclude that solid-state ballasts can be used safely in offices and hospitals. Part of our confidence is due to existing commercial and industrial building codes that require the power lines in a building to be run in metal conduits. This prevents the possible emission of EMI

radiation from the conducted EMI through the long lengths of power line, which are efficient antennas at these high frequencies.

However, the industry must quantify allowable EMI levels for solid-state ballast designers and manufacturers to make certain they will prevail in all sectors, including the residential. We anticipate a large increase in the use of solid-state ballasted gas-discharge lamps in the residential sector. Residential wiring is not required to be run through metal conduits and could therefore be a significant source of stray EMI. In addition, the emerging solid-state ballast industry must provide systems that do not adversely affect radio, TV sets, or other household appliances. Working seminars with the ballast industry are being planned at LBL in the near future to address this problem. The LBL staff wish to assist the industry in assuring that solid-state ballasted systems having safe EMI levels become widely available, thereby fulfilling all potential applications.

9 ACKNOWLEDGEMENTS

The LBL staff appreciate the timely support for our solid-state ballast program by the Research and Electrical Engineering staff of the Veterans Administration Office of Construction. The successful execution of this study was made possible by the cooperation of the VA Medical Center, Long Beach CA, including the Director's Office and the Engineering Department. The contributions of Mr. Tom Millhouse, of the VA Medical Center's Engineering Department, throughout all stages of this study (design, site preparation, refitting, and compiling data) is also recognized.

The continuing support of the Assistant Secretary for Conservation and Solar Energy, Office of Buildings and Community Systems, Consumer Products Division of the U.S. Department of Energy under Contract No. W-7405-ENG-48 is gratefully acknowledged, and indicates their contribution to other agencies' conservation programs.

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Figure 2.1
Floor Plan of Lobby Lighting

XBL 813-407

Figure 2.2
Floor Plan of Director's Suite Lighting

XBL 813-406

Figure 2.3
Automatic, Photo-Controlled Dimming System

XBL 813-401

Figure 4.1

Light Level, Power on Cloudy Day
in Director's Suite

XBL 813-409

Figure 4.2

Light Level, Power on Clear Day
in Director's Suite

XBL 813-408

Figure 4.3

Conducted EMI Data for the Director's Office Suite with 36 Two-Lamp Fixtures: A) Conventional Ballasts; B) Solid-State Ballasts.

XBL 813-411

Figure 4.4

Conducted EMI Data for the Outpatient Clinic Lobby with 140 Two-Lamp Fixtures: A) Conventional Ballasts; B) Solid-State Ballasts.

XBL 813-412

Figure 4.5

Typical Electric-Field Radiated EMI for a
4-Foot, Two-Lamp, Conventionally
Ballasted Fixture.

XBL 813-413

Figure 4.6

Typical Electric-Field Radiated EMI for a
4-Foot, Two-Lamp, Solid-State Ballasted
Fixture. (Refer to text for detailed explanation.)

XBL 813-414

Figure 4.7

V.A. Demonstration Data Compared to that of Clark⁴

Fluorescent lamps at 3 feet

- Cold cathode, 8 ft. 4-unit, industrial
- Cold cathode, 2 ft. 2-unit, desk lamp
- Hot cathode, 4 ft. 3-unit, ceiling

XBL 813-415

Figure 5.1

Cost-Effectiveness of Cleaning and Relamping

XBL 813-399

Figure 5.2

Total Cost-Effectiveness with Dedicated Solid-State Ballasts

XBL 813-404

Figure 5.3

Cost-Effectiveness of Dedicated Core and Solid-State Ballasts

XBL 813-403

Figure 5.4

Total Cost-Effectiveness with Dimmable Solid-State Ballasts

XBL 813-405

Figure 5.5
Cost-Effectiveness of a
Core and Dimmable Solid-State Ballast

XBL 813-402

Figure 5.6
Cost-Effectiveness of
Dedicated and Dimmable Solid-State Ballasts

XBL 813-400

APPENDIX A

LIST OF TEST AND MONITORING EQUIPMENT

1. <u>Voltage</u>	Data Precision 248-voltmeter
2. <u>Current</u>	TIF Clamp On
Ohio Semitronics CTIRV
3. <u>Power</u>	Ohio Semitronics PC5-59C
4. <u>Light</u>	Tektronix J16 Photometer
Tektronix J-6511 Probe
UDT-PIN 10 DP Photodiode
United Defector Technology UDT-101A Amplifier
5. <u>Temperature</u>	API Pyrometer, Type J Thermocouple
6. <u>EMI</u>	Tektronix Spectrum Analyzer Model 765
41-inch monopole antenna

APPENDIX B

BALLAST SPECIFICATION AND ACCEPTANCE CRITERIA

INPUT

AC Input Voltage	249-305 Volts, AC, 60 Hz (277 Volts Nominal)
Minimum Starting Voltage	235 Volts AC
Maximum RMS Operating Current @ 6300 Lumens +0-7.5% (per ANSI Lamp Specifications)	.300 Amps
Maximum Starting Current	.350 Amps
Power Factor	.90 Leading Minimum at full light output
Third Harmonic Distortion	Negligible
Surge Withstand Capability	Shall be capable of withstanding surge from a 6000V, 50kHz damped sinewave, 50 ohm impedance source.

OUTPUT

Lamp Drive Frequency	(20 to 30) kHz
Lamp Operating Voltage	200 Volts Nominal (100 per lamp)
Open Circuit Voltage	Open circuit voltage is 350 volts RMS for a maximum of 4 seconds or until lamp ignites. After 4 seconds if lamp has not ignited, open circuit voltage drops to 250 VRMS maximum.
Lamp Lumens	As Rated by Lamp Manufacturer
Heater Voltage	2.5 to 4 Volts, proportional to inverter power.
Lamp Crest Factor	$1.48 \pm 10\%$
Dimming Range	30 to 100%
Flicker Index	Zero
Percent Flicker	Zero
EMI	Projected to meet FCC Part 15
Lamp Type	F40T12 RS or F40T12 Low Energy (35-Watt)

DIMMING

The ballast shall have the capability of being dimmed either manually or automatically. Local dimming shall be accomplished with a simple adjustment on the ballast proper. Remote dimming shall be accomplished via a pair of low-voltage wires connected to a simple potentiometer. For U.L.-specified operation, an isolator module in the fixture is required. "Level of Service" dimming shall be accomplished with the proportional photocell module located appropriately. All external control signals shall be low voltage (under 36 volts), two-wire control. Dimming shall be over a 30 - 100% range and shall

be smooth in operation with no noticeable flicker or other objectional effects.

ENVIRONMENT

The ballast shall operate over a temperature range of 20 - 60°C. The ballast shall be interchangeable with conventional core-coil ballasts and will not adversely affect the building environment or power distribution systems.

RELIABILITY

The Luminoptics ballast shall have a minimum rated life of 30,000 hours or ten years when installed and operated in accordance with the manufacturer's recommendation.

LAMP LIFE HEALTH & SAFETY

Lamp life shall not be reduced by virtue of operation from the ballast. The ballast shall meet the functional intent of all recognized National codes including UL and ANSI.

SIZE

The ballast shall be mounted in a standard fluorescent ballast 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.

WARRANTY

The seller will provide a one-year replacement warranty for all ballasts.

ACCEPTANCE CRITERIA

A representative sample (10% or more) will be subjected to and must pass the following tests:

1. One week operation (3 hours on and 20 minutes off cycle) on the LBL life-test rack.
2. Operation at high and low input voltage limits.
3. Surge test (see Input Surge Withstand Capability specification).
4. One-day operation with one lamp disconnected.

APPENDIX C

LUMINOPTICS BALLAST FAILURE ANALYSIS REPORT

MEMORANDUM

TO: BILL ALLING

FROM: ROB CARLSON

January
23, 1981

C.C.: RUDY VERDERBER

SUBJECT: Dual 35w/277 V Ballast failure report (ref. Memo same 3/Nov/80)

1. The four LBL units returned (140, 171, 285, 228) are still running. Have shown no intermittent operation or failure to date.
2. The 13 VA hospital units as well as some additional (25) units returned to us from various sources fall into roughly four categories.

A) Broken dim potentiometer due to pressure or accidental blows to the extended shaft. This can cause improper drive to transistor Q3, destroying it in due time.

CORRECTION: Future units will have the area where the shaft protrudes recessed 1/8 of an inch and the length of shaft tooled as to be flush with the top surface.

B) Broken leads on the dim pot, inductor leads L2, L3, L4, and other various miscellaneous workmanship problems due "mostly" to the difficulty of placing the PCB assembly into the can. Litz wire leads (5 strands) would have broken strands and cause excessive heating and failure of the inductors.

CORRECTION: A complete new package concept has been developed at Luminoptics whereby the PCB assembly slides directly into the open face can base with the lead wires dropping into slots at each end and being insulated and strain-relieved via U.L. approved Heyco devices. The cover then simply pops in place and is pop riveted in place. The dim pots have now been mounted directly on the PCB with the plastic shaft extending up through the recessed cover. This also prevents high-pot breakdown between the pot-element and cover, the weakest link so far.

- C) Failure in assembly, during life test; and in the field of Transformer T5. The ZX company designed this core unit using 40 and 42 guage wire which was prone to breakage during soldering temperature stressed and as well as insulation breakdown during open-voltage surge operation. A new Luminoptics design utilizing a larger core assembly, with wire guage #36 on the primary and increased spacing between the primary start and finish is now being incorporated. The secondary heater windings are now being wound with Kynar insulated wire with 5000 VRMS rated breakdown.
- D) The fourth and most elusive problem was that of the unexplainable failure of the T0-220 cased, power transistor Q3. It turns out that both transistor Q3 and Q5 are type XX 13007 devices. However, ZX company purchased XX transistors devices at a much lower cost than the Y brand and assigned them for use as Q3. The Y (original designer) transistor and preferred Q3 device being used exclusively for Q5.

Opening up the case on both type units began to unravel the mystery. First the XX transistor chips were found to be considerably smaller in die-area than the Y device. Second, the XX die removed itself from the frame heat sink almost every time the plastic case was removed. It appears that the die may be epoxy bonded to the lead frame or that the eutectic process is such that the die becomes unattached during heat cycling and stress.

Observing the "on" state of the devices at which time they are supposed to be in saturation revealed the horror that some of the XX devices were coming out of saturation after initial turn-on, causing the devices to run excessively hot and fail early. (Vce-6-10 volts)

Increasing the base drive (forced-beta) did not reduce the saturation voltage. This was normally not noticeable since the collector waveform is 500 volts peak, the technician not catching small changes in the baseline.

Normally, an expensive special oscilloscope with a special plug-in offset amplifier is required to read small voltages (1-10 volts) in the presence of large amplitude signals (500 V) and not readily available. A simple method, however, was developed for this test in house.

All units in house were recycled and the area directly adjacent to the heat sink of Q3 was observed. The units running hotter than normal were disassembled and Q3 removed and checked. In all the cases the transistor Q3 was found defective by the new screening test. These devices are being returned for investigation. They all come from one production run and purchase lot of 1000 devices by ZX company.

NOTE: Failure of Q3 to the shorted mode can place an excessive stress on Q5 and eventually cause it to fail. This was the conclusion reached in the case of both Q3 and Q5 being shorted. No cases of Q5 only failing have been reported in approximately 10 months since the addition of the 2nd MOV to the input filter circuit and use of the proper* MOV. Relocation of L1 in the input circuit as a result of line transient testing carried out with LBL results in further protection of the input bridge rectifier without going to higher voltage devices at increased costs.

*(improper unit substituted by ZX company)

APPENDIX D

POWER VARIATIONS OF CORE-COIL BALLASTS WITH LAMP WALL TEMPERATURE

The input power for the normal operation of two 40-watt, T12, rapid-start fluorescent lamps with standard core-coil ballasts is 96 watts. The above condition prevails when the bulb wall temperature is 104°F(40°C). Measurements of the variation of input power with bulb wall temperature for different types of lamps and core-coil ballasts have been reported.¹³ The results of this study are shown in Figure D.1. As the lamp wall temperature increases, the input power decreases. However, the light output also decreases more rapidly above 104°F, thereby decreasing the efficiency of the system.

Figure D.1
System Wattage
versus Bulb Wall Temperature ⁽¹¹⁾

Where

- A - F40 lamp on standard ballast
- B - Improved 35W lamp on waveform modified ballast
- C - 35W lamp on standard ballast
- 1 - Sphere (two lamps)
- 2 - Two-lamp industrial fixture
- 3 - Two-lamp strip
- 4 - Four-lamp troffer
- 5 - Four-lamp wrap-around

All fixtures at 77°F ambient

XBL 813-410

APPENDIX E

OSCILLOSCOPE TRACES OF EMI MEASUREMENTS

TYPICAL EMI DATA

All EMI data were collected under the following conditions:

1. Tektronix Spectrum Analyzer Model 765 using a one-kHz bandwidth setting.
2. 41-inch monopole antenna with ground plane 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. All lamps in the demonstration area were on during the data measurement. All lamps were turned off for the ambient measurement.

TOP TRACE:

Lamps On

BOTTOM TRACE:

Ambient Noise

(Lamps Off)

TOP TRACE:

Lamps On

BOTTOM TRACE:

Ambient Noise

(Lamps Off)

Figure E-1. 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 E-2. 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 Range 0 - 200 kHz

Figure E-3. Conducted EMI Spectrum Analyzer Photographs
For Areas with Solid-State Ballasts.
Top: Director's Suite
Bottom: Outpatient Clinic Lobby

Figure E-4. Electric-Field Radiated EMI Spectrum Analyzer Photograph for Room Television Set Located about 6 Feet Away.

Figure E.5

Composite Radiated Electric Field Level

APPENDIX F

EXCERPTS FROM "ELECTROMAGNETIC COMPABILITY STANDARD FOR MEDICAL DEVICES" FDA, BMD NO. MDS-201-0004 AND NEW FEDERAL COMMUNICATION COMMISSION REGULATIONS

SECTION 1 INTRODUCTION

1.1 Scope

This standard establishes maximum levels of electromagnetic emissions which medical devices are allowed to produce and it establishes minimum levels of electromagnetic interference to which medical devices must not be susceptible. A section containing test methods is included to provide a consistent means of verifying compliance with the requirements. Appendix A contains a rationale which provides technical support for the requirements and test methods incorporated into this standard.

This standard does not address signal line or patient lead conducted emissions and susceptibility. In addition, the radiated susceptibility limits in this standard do not reflect the severity of the environment which is encountered near electrosurgical units.

1.2 Purpose

The purpose of this standard is two-fold:

- 1) To serve as a reference document for FDA-promulgated regulations and guidelines in which electromagnetic compatibility requirements are included. In this capacity, the regulations or guidelines which reference this standard must supplement the requirements of this standard by defining the susceptibility degradation criteria and the details of test configuration and test methods for the subject device.
- 2) To serve as guidance for other devices. In this capacity, this standard must be used with a degree of judgment, bearing in mind that the requirements of this standard are general and do not specify susceptibility degradation criteria or the details of test configuration which may be unique to each device.

1.3 Voluntary Use of this Standard

Manufacturers and users of medical devices are encouraged to utilize and reference this standard. However, this standard cannot be used casually. Manufacturers are cautioned not to make unqualified statements that their products conform to or meet this standard. Any claim of conformance must be accompanied by supplementary information which is described in paragraph 3.1. Users or purchasers of medical devices, similarly, should not require conformance to this standard unless the supplementary information of paragraph 3.1 is either specified by the purchaser or required of the manufacturer as a condition of the sale.

A3.2 Emissions

A3.2.1 General

The primary purpose of this standard is to establish a reasonable level of assurance that medical devices will operate safely and effectively in the electromagnetic environments expected in use. However, hardening medical devices against EMI is a losing strategy unless some attempt is made to limit the steadily growing ambient. Therefore, emission limits were established, the desired effect being to halt the growing ambient at present levels. Since this standard is explicitly intended for medical devices, it is obvious that many of the major contributors to the electromagnetic environment will remain uncontrolled. However, it is hoped that this standard will serve notice to users that electromagnetic compatibility should be considered when purchasing nonmedical equipment. Any such equipment which emits electromagnetic energy at levels in excess of the limits presented in this standard is a potential source of interference for medical devices, even if those medical devices conform to the susceptibility requirements of this standard.

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