Some Implications of Electronic-Ballast Fluorescent Lighting for Physics Laboratories

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ABSTRACT

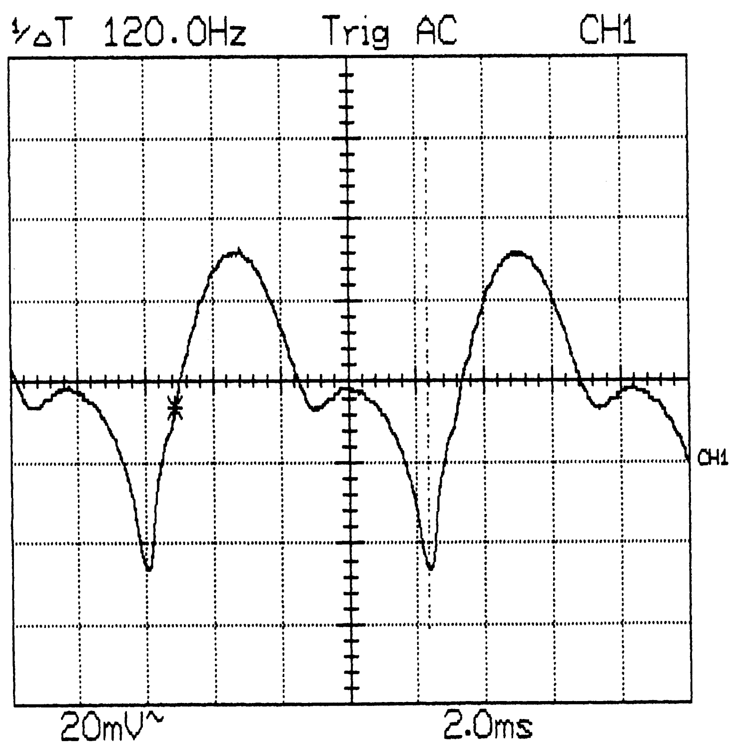
Recent construction and retrofitting of teaching and research laboratories frequently includes the installation of higher-efficiency fluorescent light fixtures, which incorporate electronic rather than inductive ballast units. Unlike the conventional tubes and circuits, which are synchronous with the 60-Hz utility frequency, the newer lighting contains oscillators that flash the lights, and radiate and conduct electromagnetic noise at much higher frequencies. Laboratory experiments and demonstrations that rely on the characteristics of the older lights will no longer work, and unanticipated interference may also occur in a variety of situations. We report examples and measurements which may be useful to teachers and researchers faced with past or pending lighting system conversions.

- Designing Olin Hall 1989-90:

  I had a general awareness of EMI-RFI problems from fluorescent lights equipped with electronic ballasts. At that time, these lights were beginning to make inroads into laboratory settings, and we didn't need more exotic sources of conducted noise and radiated emissions. [The now well-documented and commercially-addressed interference problems between IR remote controls and these lights were not part of my concern then, nor a focus now. See useful references at the end of this paper.]

  As department chair I extracted a written agreement from architects and our director of physical facilities that high-efficiency inductive-ballast 40-watt bulbs in 277-volt circuits would be the standard fixture, and that no electronic ballasts would be installed anywhere in the building. Except for the exit signs, that is what we got. My colleagues and I also didn't want to lose the useful "byproducts" of the inductive-ballast fixtures in several labs, as described next.

- All introductory oscilloscope labs include various transducers as input sources. One of these is an inexpensive solar cell, which students use to view the intensity as a function of time from the ceiling lights. A typical waveform is shown below.

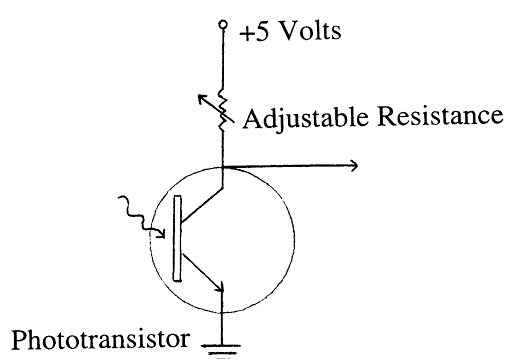


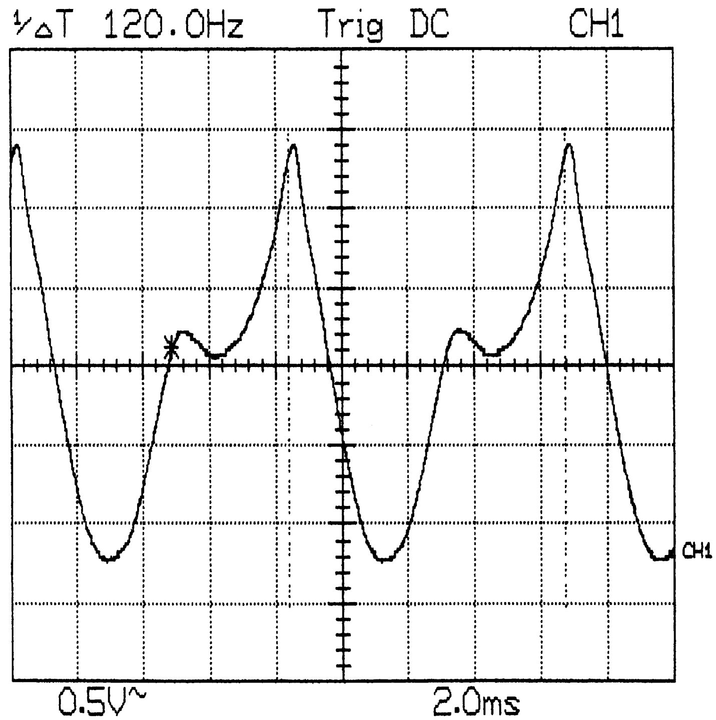
Note the 120-Hz fundamental frequency, which we discuss in the context of a simple model of the operation of the gas discharge tube and phosphor fluorescence. It's a practical illustration of the use of the scope and solar cell to learn something about a common device in our environment.

- However, after we moved to Olin Hall, some of us noticed that waveforms collected by students at two particular lab tables sometimes showed odd-shaped and small signals. I first guessed that one of the three tubes in these fixtures was somehow wired in opposite phase from the other two. It turned out to be more interesting. Depending on where the solar cell was held, it would receive a superposition of light from two or three ceiling fixtures. Three of the twelve fixtures in the room were on the emergency lighting circuit, and these were wired with opposite phase from the rest. Indeed, one could find a location roughly halfway between two fixtures where there was zero AC component to the illumination!

  [Dr. Robert Levin, Corporate Scientist in Osram Sylvania's R&D center in Beverly, Massachusetts told me that it was once standard practice in industrial settings that used three-phase power to mix the banks of each phase, in order to avoid the "strobe effects" on moving machinery.]

- In our second semester of electronics, students do wave shaping (Schmitt trigger, one-shots, etc.) on signals generated by a phototransistor exposed to various time-varying light sources, starting with the ceiling fluorescents. The input circuit and a typical waveform are shown below.





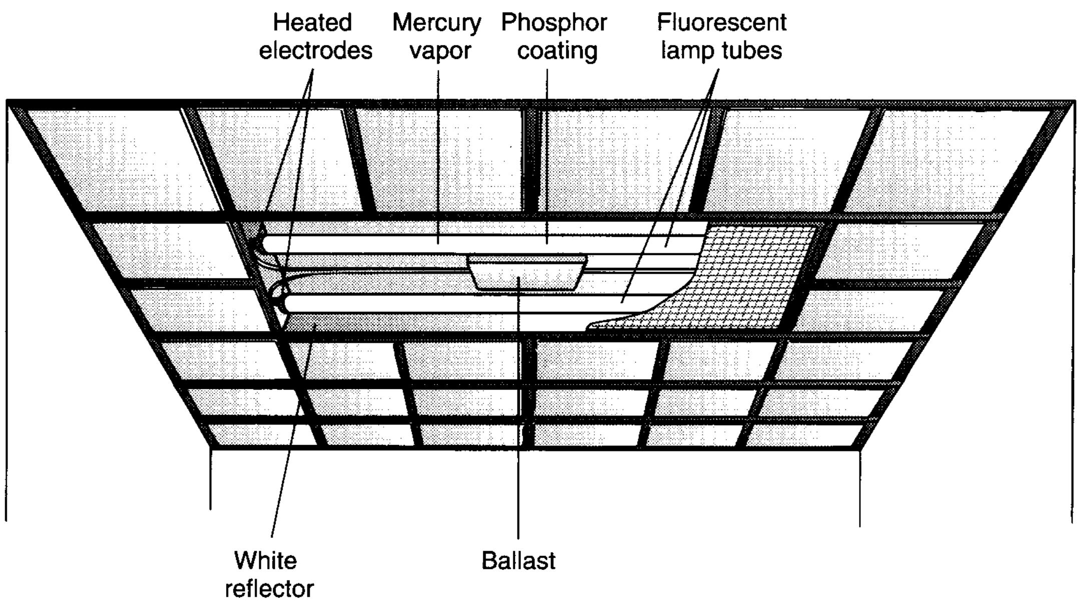
Note the much larger signal amplitude than from the solar cell, as would be expected from this active device.

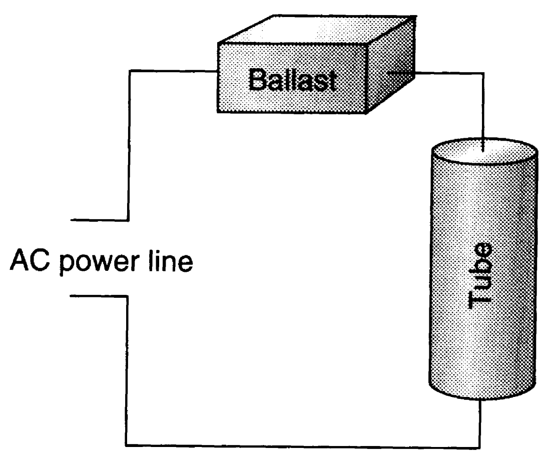
- All was well until 1996, when I discovered outside electricians going through our building room-by-room, tearing out the almost–new fluorescents, and replacing them with 32-watt electronic ballast fixtures. There was no consultation or supervision whatsoever. I quickly found that our new director of physical facilities (whom I had helped select) had been convinced by a lighting vendor of the economics of changing out all inductive-ballast lights, campus-wide. I raised all kinds of hell, and got a freeze on such conversions in our building, pending discussions and investigation of the issues.

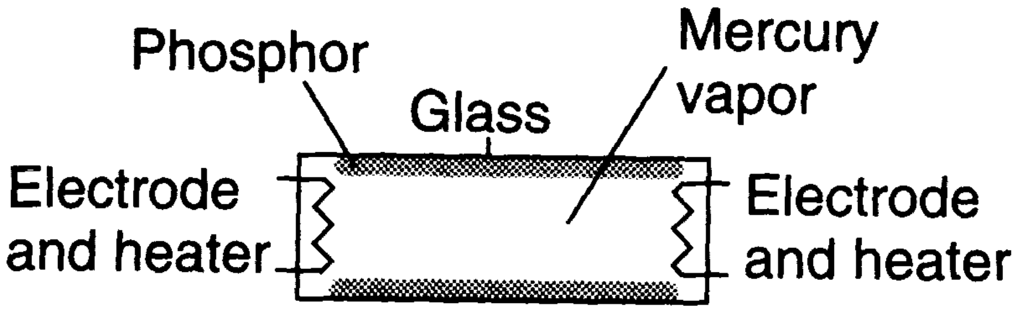
- The next year, he and I met with Sylvania sales engineers, and I started collecting information to bolster my case against the conversion. While it was true that the newer fixtures used energy at a somewhat lower rate, the cost savings and return on investment were inflated by faulty data on room usage, and other assumptions. It is true that electronic ballasts have a power factor (cosine δ) closer to unity than do the inductive ballasts. Electric utilities sometimes charge an extra "kvar" (kilovolt-amp- reactive) fee for substandard power factor. This is to compensate for the costs of generating and transmitting the "wattless power", which is not measured by watt-hour meters. However, our institution was not paying an extra charge for these "kvars", anyway. There turned out to be a lot better places to invest such capital than in our building, and we dropped to the bottom of the list, until last year.

- No records were kept of which rooms had already been converted, some only partially. I began a study with sophomore Marissa Lingen, and we observed some of the differences between the intensity waveforms. The campus rebuilding after the March 29, 1998 tornado shut down work until senior Carrie Ginder joined the study in the fall of 1998. [Carrie is completing the B.S. and M.S. in E.E. at the University of Minnesota. Her work with me has led to internships in EMC (electromagnetic compatibility) labs doing measurements.]

- Let's do a quick review of fluorescent light basics: [Drawings from How Things Work: The Physics of Everyday Life, Louis A. Bloomfield (Wiley, 1997), reproduced by permission of the author.]







- The electronic ballast contains a rectifier, filters, and an oscillator that drives the fluorescent lights at a frequency of 18-100 kHz, depending on the design. There are many families of such lights, varying in ballast factor, harmonic distortion of the line frequency (typically 10-20%), color rending index, inrush current, and many more specifications.

- Compatibility problems, based on these and other characteristics, exist for room occupancy detectors, ground fault interrupt protection, and harmonic currents in neutral wires. These are primarily issues for architects and design engineers.

- The two principal sources of improved "lighting efficacy" (defined as lumens per watt) from high-frequency as compared with 60-Hz fluorescent tube fixtures are:

a) Higher average electron density around the anode; [This saves about 4.5 watts for a 40-watt F40T12 tube.]

b) Higher average phosphor fluorescence due to phosphor persistence. [This effect has already been largely optimized by 25 kHz.]

- In addition to the previously-cited category of optical interference with infrared remote controls, there are potential problems of conducted interference, such as between power line carrier systems (e.g. synchronized clocks in schools).

- Two examples of radiated interference with circuits and equipment in upper-level physics labs are:

a) An advanced lab experiment: "Undergraduate Laboratory experiment on quantized conductance in nanocontacts", by Foley, Candela, Martini and Tuominen in **AJP** Vol. 67 No. 5 May, 1999, p. 391]

b) Carrie Ginder and lab partner Nelson Kottke, doing a project in a lab room equipped with the new lights, encountered false triggers in a breadboard circuit that used phototransistors and one-shot multivibrators to time a Kater's pendulum. (It is not clear whether the interaction was optical, or due to E-field coupling, but we suspect the latter.)

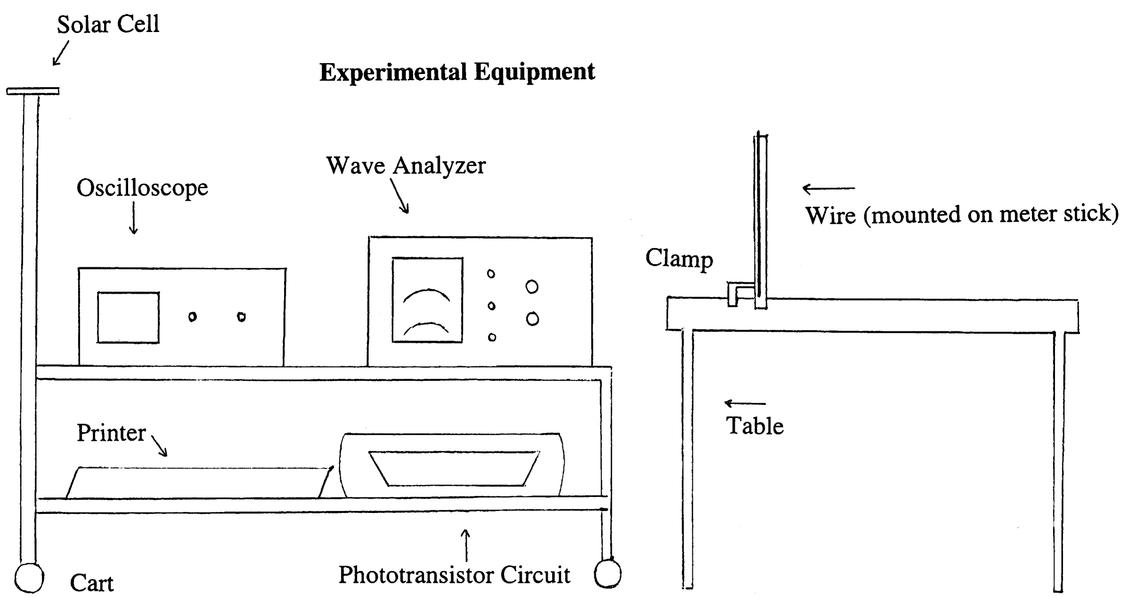
- We collected data on the light intensity waveforms and the E-field coupled noise voltages in rooms with both types of fixtures. Principal equipment, in addition to the solar cell and phototransistor circuit previously mentioned included:

  Hewlett-Packard 3581A Wave Analyzer (a tunable microvoltmeter with adjustable bandwidth, covering 1 Hz to 50 kHz)

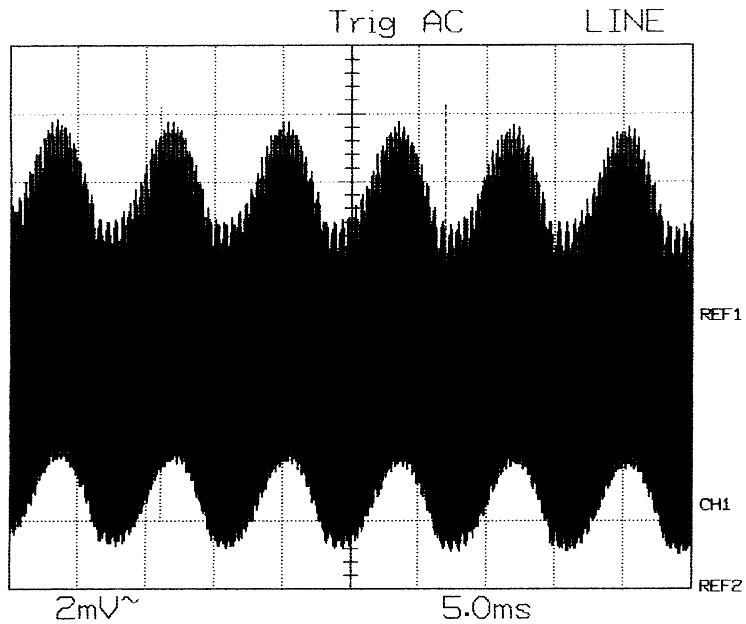
  Tektronix 2212 A/D storage oscilloscope with attached Canon bubblejet printer.

  Fluke 45 digital DMM (with frequency measurement)

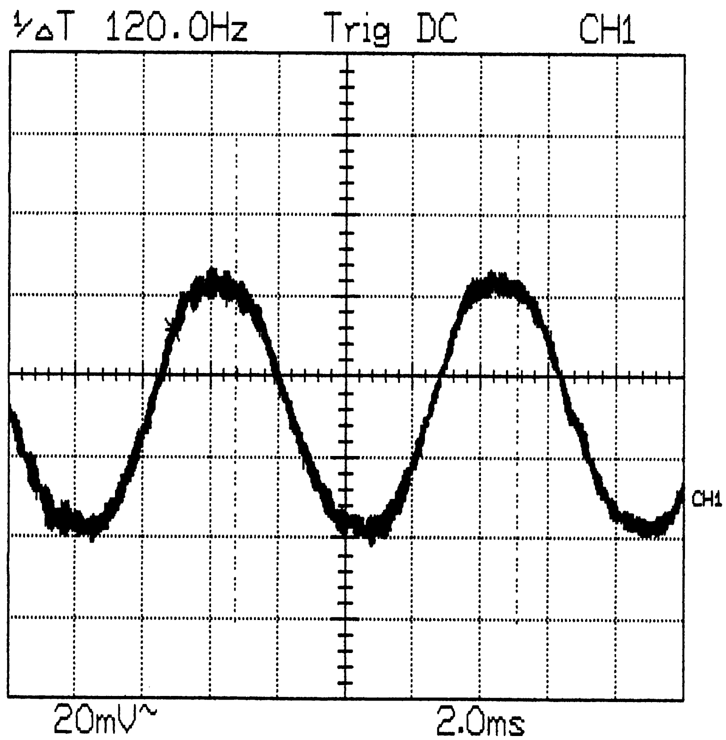
Experimental Equipment

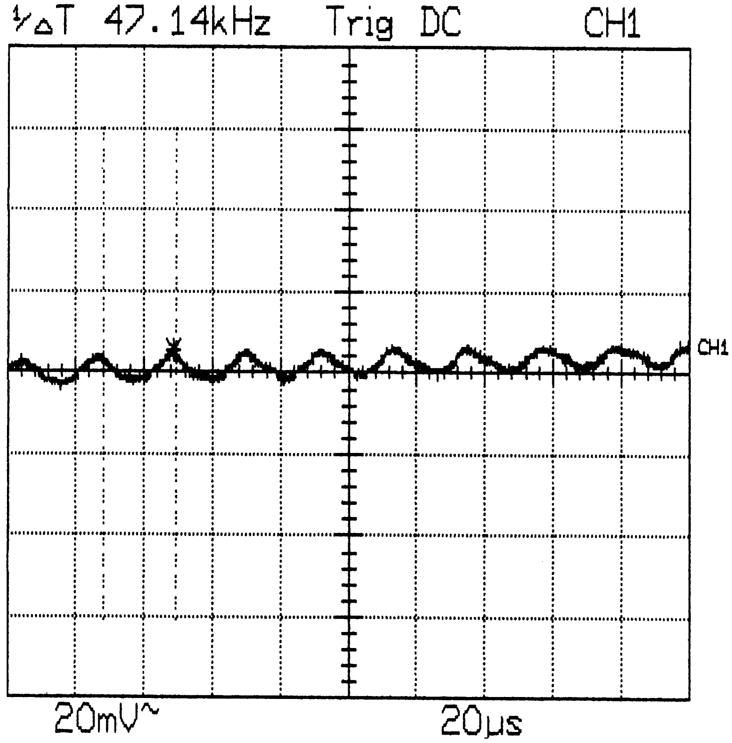


- The AC *optical* pickup from electronic ballast lights is small compared to that from inductive-ballast tubes. A solar cell placed within 25 cm of a pair of tubes shows a small amplitude-modulated waveform, with the envelope at 120 Hz and "carrier" at about 48 kHz, which is twice the ballast frequency of this fixture. At lab-table distances, the signal is too small to be viewed on most scopes, and therefore too small for use in our lab exercises.



- We used a phototransistor (for its greater inherent sensitivity) at a typical ceiling-table distance of about 1.8 m. The two principal frequency components in the intensity waveform are shown below.





- We made measurements of the E-field coupled noise using the HP Wave Analyzer and a straight vertical (y) or horizontal (x) .96m-wire arranged below each type of light fixture (inductive and electronic ballast).

f (Hz)	BW (Hz)	Induct. x(mV)	Induct. y(mV)	Elect. x(mV)	Elect. y(mV)
60	3	.395	3.4	1.1	2.5
120	3	.015	0.1	0.008	0.002
180	3	.45	3.8	0.008	0.002
23.3k	30	<.001	<.001	3.	8.6

While even the largest of these noise components looks modest, throw in a gain of 1000, typical breadboard wiring, and unshielded cables, and some of them aren't. We're used to dealing with 60 Hz "hum" and its low harmonics. The ballast frequency noise pickup may very well be unexpected, and troublesome in some situations.

CONCLUSIONS:

Electronic-ballast fluorescent lights have become the norm for new construction, and for program retrofits in commercial and institutional buildings. Physics faculty and staff who have concerns for teaching and research labs should become aware of the different characteristics of the two families, and share these concerns with those administrators who make facilities decisions.

ACKNOWLEDGMENTS

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ADDITIONAL REFERENCES

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