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Can we save energy used to power traffic signals without disrupting the flow of traffic?

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The Energy Problem of Signalized Intersections

About one quarter million intersections in this country had, as of 1996, been fitted with traffic control signals. That number is increasing annually as urban sprawl and increased crowding lead to more traffic and to the need for more vigorous traffic control capability. Each intersection has an average of 40 such signals using either 69 or 150 watt incandescent lamps. Half of these are on at a given time, and due to the existence of protected left turns, the red traffic signals are on the most, perhaps 55 – 60% of the time. This a large energy burden though of course, the sight seer gazing down on a clear evening at the San Francisco Bay area from the surrounding hills, would not see these as a predominant source of lighting. Nonetheless, these are an important economic burden to the agencies that maintain them, for those agencies are governmental and a trend in the 1990's towards increasing economic pressure has require them to explore any avenue of cost savings that is available. Of course, seeking efficiency is often prescribed by governmental authorities¹ and thus stands as a required and desirable product of day-to-day operations.

Aside from energy cost, incandescent lamps have an inherent maintenance cost, their life cycle requiring preventative replacement annually.

The emergence of energy-saving solutions

The 1990's have seen the emergence of a number of solutions to the energy problem described above. For example, vendors have developed neon tube replacements for incandescent lamps, a reflectorized incandescent bulb is now available for purchase, a fiber-optic fixture using a halogen bulb can also be obtained. These technologies each promise some meaningful energy savings, and possibly maintenance savings as well. The most promising technology, however, is actually a family of technologies resting upon the light emission properties of semiconductor materials, the so-called light emitting diodes (LEDs). LEDs are familiar to most consumers as the tiny indicator light on the electric razor, or the flickering lamps embedded in the heels of some current children's sport shoes.

A number of different semiconductor materials have been tried in this regard, with a premium placed on obtaining sufficient light output to match that available with the existing incandescent technology. The threshold appears to have been crossed several years ago based on advances by Hewlett Packard in developing first AlInGaP, then later TsAlInGap LED technology. Single forms of these devices are so bright that can now be used on key chains to replace small flash lights. Arrays of several hundred appear to be able to serve the purpose of signaling a motorist as to whether to stop or go at an intersection. Such devices use as little as 1/6 that of the incandescent lamp. This energy saving is large enough, that, coupled with an expected life exceeding seven years, even the high initial capital cost can be absorbed with net savings.

Number of cities have experimented with the earliest versions of this technology., The conclusion is that predicted life, and costs estimates are realizable.

The vision problem

If it is accepted that one can readily² replace an incandescent fixture with a solid state one that will last longer and consume only a small fraction of the energy, all that remains is to demonstrate that motorists

¹ Executive Order W-83-94 by Governor Pete Wilson of California prescribed a cumulative state government energy savings goal of \$500 million by the year 2004.

² All alternative technology devices available for purchase are offered in configurations that allow for ready installation in existing fixtures.

who once stopped at an incandescent-powered signal will stop as often and with the same certainty at an LED-based fixture. It was with this question in mind that Caltrans Department of Traffic Operations, a major traffic signal operator in the State of California, approached PATH to arrange for an experimental test to verify the visual suitability of the new technology. The question was not a trivial one because there are significant differences between the spectral composition of the LED fixture and also of the spatial distribution of its intensity. Both of these parameters are well-known to vision scientists to affect visibility. It is true that in the usual circumstance, an instrument known as a photometer can imitate the human eye and provide a quantitative estimate of the equivalence of two fixtures. But in the case of red traffic signals, the red end of the spectrum presses such a device to its limits of accuracy, and spatial inhomogeneity in a target which can affect visibility, cannot be accounted for. Hence, the so-called '44-point test'³ is not necessarily able to supply an indication of the ultimate visual effect of a candidate traffic light. If one is prudent, one requires more direct evidence than a photometer can provide, as regards the visual equivalence of incandescent and LED devices.

The PATH Human Factors Project

Scientists in the Visual Detection Laboratory (VDL) at the School of Optometry worked with Caltrans Traffic Operations and State and Local Project Development (the office with cognizance for department-wide energy savings) personnel to plan a project that would answer the question of visual suitability. The approach taken was conceived by Daniel Greenhouse, a PhD who had worked for a number of years with the LBL Lighting Lab. He proposed the adoption of a variant of a traditional technique for measuring light effects, that of heterochromatic flicker photometry (HFP). In HFP, one arranges for the silent replacement of a test light with a comparison light many times (perhaps 20) per second, while maintaining the spatial integrity of the scene viewed by an observer. Usually in HFP, the lights in question are of small size and this can be accomplished with suitable use of mirrors and prisms on a laboratory bench. But in this case, the lights were 12 inch diameter ponderous, about 4 FT tall, fixtures. Richard Knowles, senior technician at VDL created a special purpose instrument that enabled an observer to view alternately one fixture, then the other, 20 times per second, without moving, and without knowing which fixture was before the eye at any given moment. Taking advantage of a very long hallway, and through the use of mirrors at one end, observers were placed at a distance from the fixtures (300 FT) which corresponds to the stopping distance of interest to Caltrans engineers. Using optical control of the intensity available from each fixture, the observer could arrive at an adjustment that rendered the two fixtures visually equivalent. The level at which this equivalence was achieved told us whether the LED-based fixture could be counted on to do the visual task set for it.

Results for TsAlInGaP LED-based red fixtures.

We express the results of our tests in terms of a *usability factor*, which can be thought of as a correction factor to be used with the measurement that would be obtained using photometry. Here's how the LEDs fared. Viewed straight on with the highly acute central area of the eye, the LED fixture was measured to have an average a usability of 99%. This means that it was within 1% of the incandescent, that 1% more intensity would leave it equivalent. Seen in the peripheral visual field, the usability increases by 3% to over 100%. This improvement isn't surprising (though the amount of improvement is) because the peripheral visual system has little acuity and would be insensitive to the spatial variation that can be seen in the central field and which leads, we think, to a small advantage in visibility for the incandescent fixture. But more important perhaps, is that statistically speaking, these usability numbers differ little if at all from 100%. Accordingly, we were able to conclude that fixtures that would perform adequately if they pass the standard 44-point photometric test.

A simple field test was used to verify this result. We placed two fixtures, the incandescent and the LED side by side (Fig. X). We adjusted their intensities according to the usability factor so that they should appear equally bright. We then arranged for observers to drive toward the twin lights and to note the distance at which they became visible and whether any visibility difference was noted. The LED

³ The 44-point test is described in "Vehicle Traffic Control Signal Heads", ITE Journal, May 1984, pp. 13-19. It requires among other things, photometric quantification of light output in 44 different directions spanning a range of 17.5 DEG down and 27.5 DEG side-to-side.

proved to be equally visible as the incandescent and both, despite severe attenuation of intensity (about 7-10 times), were visible at distances over three times the stopping distance, when seen against a very bright background.

Other Issues: What about color blind or aged eyes?

Recent proposals⁴ to adjust the allowable spectral content of traffic signals so that persons who might tend to confuse reds and greens do not confuse red and green traffic lights, make clear the very special needs of the color blind segment of the driving population. At the same time, mean driver age is rising as the elderly segment of the population expands, and with mean age comes a variety of age-related visual deficiencies, many of which are not grounds for exclusion from licensure. What can we expect of the LED devices in the eyes of these beholders?

We have obtained some preliminary indications that the picture is fairly rosy. Take the case of the protanomalous (and also the protanopic) eye, which is deficient for red lights. One can calculate that such an eye would actually exhibit an improved usability for TsAlInGaP LEDs (though not so for the longer wavelength TsAlGaS LED which has also been introduced) because they have a slightly lower peak wavelength than the incandescent lamp. Measurements on one such individual showed a usability factor did meaningfully different from unity. We expect no difference at all for deuteranomalous observer (or for deuteranopes) because their insensitivity is toward middle wavelengths.

In the case of the aging eye, the main meaningful difference that might be expected to affect traffic signal visibility is lower acuity, and this would favor the LED device (resulting in a predicted usability of unity) as described above. Measurements on one such individual bore out this prediction.

Other features of the technology

Traffic engineers have a number of issues to consider as they evaluate the suitability of a new technology for traffic signals. For a number of these the LED fixture supplies some surprising and significant advantages. One problem that engineers have noted, and one which is mentioned in the ITE standard, is that of the 'sun phantom' the appearance of illumination of a fixture when it is off but directly faces the rising or setting sun. Our measurements show that the LED fixture reflects 50% less light than does the incandescent fixture (due mainly to a reflector built in to the latter). We would thus expect highly favorable performance under conditions that can lead to sun phantom.

A final note relates this new technology, which will be otherwise viewed as pedestrian by planners engaged in ITS studies, to the potential for inclusion as a component in advanced ITS features in the future. Unlike the incandescent lamps that these replace, the LED fixtures can be modulated at frequencies far in excess of the flicker fusion limit of the human eye. This modulation would thus not be detectable by the driver, but could be used as part of the ITS infrastructure to convey locally important information (e.g. the identity of the cross street or the existence of minimally visible pedestrians in the intersection) to an oncoming vehicle thru light sensors installed on the vehicle.

Conclusion

Last March, and based in part on the foregoing results, Caltrans issued a performance specification for the purchase of LED-based traffic signals⁵. Changes in these fixtures are now underway throughout the state and the nation and the result will be a considerable savings in energy and maintenance cost with no apparent degradation in the purpose that these devices are intended to serve.

⁴ CIE Technical Report, "Review of the official recommendations of the CIE for the colours of signal lights," publication # CIE 107-1994.

⁵ <http://www.dot.ca.gov/hq/traffops/electsys/led/index.htm>