LED Traffic Signal Lamp Characterisitics
State Job No. 14748(0)

Final Report

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16. Abstract

LED traffic signal lamps are being used to replace incandescent traffic signal lamps because of the long-term cost saving associated with reduced energy consumption and longer service life. The are reasons to believe that the use of LED traffic signal lamps may compromise of the safety features designed into traffic signal systems that were intended for use with incandescent lamps. The focus of this study is to analyze the electrical characteristics of LED traffic signal lamp assemblies and determine if they are compatible with exisiting typical traffic signal hardware (load switches and conflict monitors). The as-new state and failed state electrical characteristics of the LED lamps assemblies are measured and analyzed. A testing procedure is established and documented for repeating this analysis on newer models of LED traffic signal lamps in the future.

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I. INTRODUCTION AND BACKGROUND

Traffic signals using Light-Emitting Diode (LED) devices as luminous sources are gaining rapid acceptance across the nation, and around the world. LED Traffic Signal Lamp (LED TSL) assemblies are still relatively new on the market, becoming widely available in the mid-1990s. The use of LED TSLs offer several advantages over standard incandescent lamps to the signal maintenance agency. First, we will review traffic signals before the era of LED TSLs.

Each unit (red, yellow, green) of a conventional traffic signal uses a long-life incandescent bulb. The incandescent lamp produces light by passing an electric current through its tungsten filament (inside the evacuated glass envelope) to produce a temperature of around 2200 degrees F. When the filament becomes ‘white-hot’, an incandescent bulb produces ‘white’ light, consisting of a continuous spectrum of light from purple through blue, green, yellow, orange, and red. Much of the generated energy also lies in the invisible infrared (heat) range. A reflector behind the bulb directs the luminous energy from the bulb into a tinted lens, where the undesired color components are absorbed, and the remaining desired color components are focused toward the approaching traffic. While simple in implementation, the incandescent lamp is woefully inefficient. As noted above, only a small fraction of the electrical energy consumed is delivered through the lens as light energy to the motorist. It also suffers a fairly short lifetime. A significant contributor to the limited lifetime of incandescents is thermal shock (expansion and contraction) to the filament, which cycles between 100 degrees and 2200 degrees F. with every on/off event. Long-life incandescent signal lamps are normally replaced on a 12-month or 18-month schedule. This type of relamping schedule, performed when traffic is light, reduces the risk of having to make emergency runs to replace failed lamps under then-prevailing traffic conditions.

Electric traffic signals were commonly in use by the 1920s. With minor improvements, signal lamp technology went largely unchanged for the next fifty years. No practical alternative to the incandescent lamp was available. Coal-fired power plants provided cheap electrical power before smokestack emissions were regulated. However, the inefficiency of incandescent lamps became a significant consideration as urban congestion and the unbounded growth of automobile and truck traffic necessitated ever-increasing signalization of city streets. Traffic signals, unlike residential energy demands, and unlike most industrial and commercial energy demands, require their power every minute of every day.

Among the explosion of new semiconductor devices of the seventies, experimentation with semiconductor junctions created the LED, a two-terminal semiconductor device which produces visible light when a current is passed in its forward direction. The radiated output of this emitter, defined by the band-gap of the placed impurities at the junction, is essentially monochromatic (single-color), and can be generated over the visible spectrum (and also into the invisible infrared and ultra-violet regions) by proper doping. Most of the electrical energy accepted by the LED lamp is converted to visible light at the specified color. A LED device is only moderately warm to the touch after hours of operation. Early work created the red LED, followed soon by yellow, orange, and green.

LEDs found their way into traffic signals in the 1990s. Their economy of operation was a compelling consideration, especially in Western USA, where summer brownouts and total power outages were becoming more common. Since any one LED device consumes only a fraction of a watt, the LED TSL requires an array of LED devices, as few as sixteen, and up to four hundred, in various designs. Contemporary designs lie mostly in the range of one hundred fifty to three hundred LED emitters per signal lamp, with typical power consumption from ten to twenty-five watts. These many LED devices are soldered to a round flat circuit board to provide mechanical support plus associated electrical connections. In front of this planar array of LEDs is mounted the primary lens array, segmented into one lens for each LED emitter. This injection-molded array also serves as the front weather-seal. Its lens array is located about an inch away from the LED device front surfaces, at the plane where the luminous flux of the individual LED emitters comes to a focus. Current mechanical designs universally employ an all-in-one assembly which includes the lens, the LED array board, and the associated electronic power supply, all in one weather-tight package, to facilitate upgrades from incandescent signal lamp installations. Two views of an opened LED lamp are shown on page 3, Figures 1A and 1B.

In its application to traffic signals, the LED's color-specific luminance adds to its basic efficiency compared to incandescents because it generates only the color desired. It is not necessary to absorb unwanted light energy with tinted lenses. Many LED lamps in current use have no tinting in the lens array. However, it has been found that looking at a clear lens (in the off-state) is distracting to some motorists, and some manufacturers now add tinting simply to eliminate this potential confusion. In addition to their efficiency, evidence to date suggests that LED traffic lamps will provide a service lifetime in excess of five years, so that routine relamping costs (parts plus labor) can be substantially reduced. Even if some of the individual LED devices fail, the lamp will continue to operate in an acceptable manner, and replacement can be scheduled at an opportune time, rather than under duress.

II. RESEARCH OBJECTIVES: THE COMPATIBILITY ISSUE

When an incandescent lamp in a traffic signal is working normally, it presents a terminal resistance of around 100 ohms, more or less, depending on the wattage of the lamp. When the lamp fails (burns out), the lamp presents a resistance of millions of ohms, virtually an open circuit. In a modern traffic signal, an electronics package, called the load-switch, switches the power on and off to the signal lamp, and a second package, called the signal monitor, senses the voltage across each of the lamps. When the incandescent lamp is functional, the signal monitor reads full line voltage (typically 120 volts) across the lamp when the associated load switch is in its on-state, and less than 15 volts across the lamp in its off-state. When the incandescent lamp is burned-out, the voltage across the lamp is still full line-voltage in the on-state (even though the lamp is not burning). Since this is also true for a good lamp, it conveys no fault information. But the burned-out lamp voltage in the off-state is still some large fraction of the line voltage, typically 80 volts or more. This is due to a designed-in leakage current through the load-switch, which allows detection of an open circuit (burned out) incandescent lamp by the signal monitor. The signal monitor tests for voltages greater than 70 volts (red) or 25 volts (yellow and green) during the off-state. When this condition is found, the signal monitor then places the signal into a flasher state (flashing yellows on the primary approach and flashing reds on the secondary approach) to alert motorists and pedestrians to proceed with extra caution. This is a proven method of enhancing the safety of signalized intersections that has been in use since the mid 1980s.

When an incandescent lamp is replaced by a LED TSL in a traffic signal, it is necessary for the LED TSL to present a similar set of resistances under 'good' and 'failed' conditions if the fault detection and reporting measures built into the signal control system are to remain viable. Unfortunately, some of the early LED TSLs were designed by people who understood LED assemblies, but who did not understand the complex electrical environment in which traffic lamps operate. Some of the early lamp designs had the potential for compromising the safety of motorists and pedestrians.

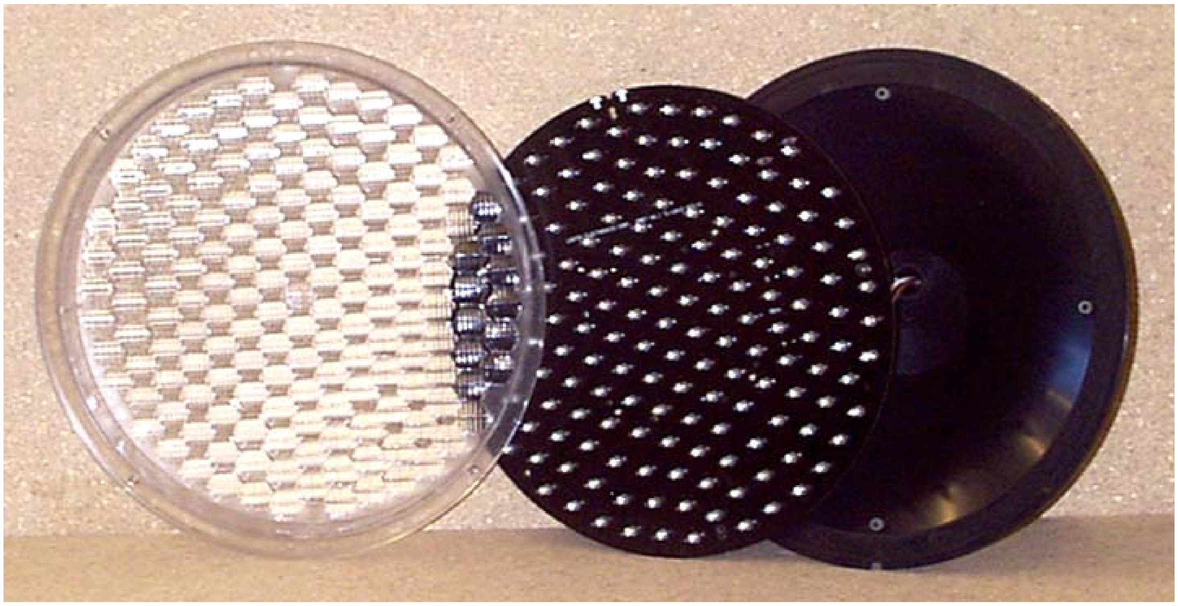

Figure 1A. Showing the (clear) front lens, the front side of the LED mounting panel, and the rear cover. This is a Leotek TSL-12G-MG 12-inch (300mm) green lamp with 163 LED emitters. The lamp is OFF, the white spots are reflections of the flashlamp off the LEDs.

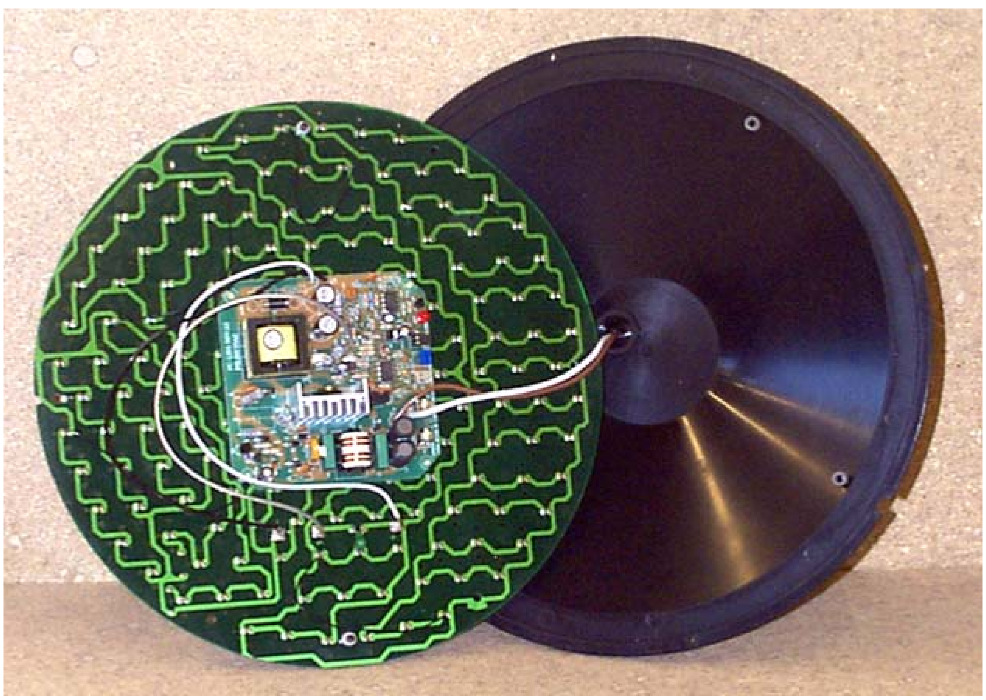

Figure 1B. The power control board is mounted on spacers to the backside of the LED panel in this lamp. In addition to the square sub-panel of the power controller, the green-colored conductive traces which power the LEDs are clearly visible on the LED circuit board. Each close-spaced pair of white dots identifies the soldered-in leads of a LED emitter. The brown and white wires through the rear cover bring in the 120-volt power to operate the lamp.

When manufacturers began introducing products, and the demand for the product was strong, the Institute of Transportation Engineers (ITE) set out to create a code of standards for the LED TSL. A first draft appeared in November of 1997, and an "Interim LED Purchase Specification" was released in July 1998. This standard addressed most of its attention to the visible light as seen by the motorist - intensity, chromaticity, and angular dispersion. These characteristics are very important in a LED TSL, since they address the ability of the motorist to see and interpret the signal without undue confusion. Less attention was given to the lamp's compatibility with the electrical environment in which it operates. The main section of the document affecting electrical characteristics is labeled "Optional".

Several state transportation departments, recognizing the potential for electrical compatibility issues by using the ITE standard to define performance, desired a more definitive document. The new specification would have to clearly define the electrical characteristics of the LED TSL to maintain the high degree of motorist and pedestrian safety achieved with incandescent lamps.

Existing performance and design standards for traffic signal control systems have been developed over the preceding twenty years by the National Electrical Manufacturers' Association (NEMA) and by the Federal Highways Association (FHWA) in association with the California Department of Transportation (CALTRANS). Part of ODOT's effort to develop a knowledge base in the LED TSL field was to initiate this project with Athens Technical Specialists. The overall goal of this project is to verify whether or not current production LED TSLs satisfy the electrical compatibility requirements identified above, and develop procedures to facilitate the procurement of acceptable LED TSL designs.

III. RESEARCH APPROACH: DEFINING TEST PROCEDURES

A repeatable and comprehensive test method was needed to test samples of current production LED TSLs provided by the manufacturers for this project. The test method was developed and documented to allow other parties to conduct similar testing. The test method is designed to show if the LED TSL under test will be electrically compatible with typical, existing traffic system control components in use across North America (US and Canada). In particular, the test results should indicate if the LED TSL will preserve the failed lamp detection scheme that is based on the characteristics of incandescent lamps.

Test Objectives:

1. Determine normal state impedance: A functional LED TSL must present a low terminal resistance in its off-state such that the off-state voltage across the LED TSL will be below 15 VAC RMS.
2. Determine failed state impedance: A failed lamp must present a high terminal resistance in its off-state, such that the off-state voltage across the LED TSL will be above 70 VAC.
3. Obtain design-identifier data for acceptance testing: Measure electrical characteristics of new, functional LED TSLs with power applied and document these values to facilitate comparison to other LED TSL samples in the future. The purpose is to verify that new product deliveries are the same as the samples that were sent for approval prior to the sale.

As noted above, the off-state voltage is developed by an output leakage current from the solid-state relay, called a load switch, that is used to turn on traffic signal lamps in typical installations.

Because of the rigorous sealing of the LED TSL against moisture intrusion, recoverable access to the interior circuitry is possible in only a few cases, and even then, repair is questionable from an economic perspective. In some cases, cutting open the rear cover is the only means of accessing the circuit to force the failed state for this test. Therefore, all normal/functional state tests must be completed before the failed-state tests are started.

The test for terminal resistance for a normal/functional LED TSL in its off-state is simple and non-destructive. This test result will satisfy Test Objective 1.

To satisfy Test Objective 2, the LED TSL must first be placed into a failed state. While there are several ways to force the LED TSL into a failed state, the anticipated path is the result of successive and additive open-circuit failure of the individual LED devices in the emitting array. Other failure causes, such as knock-downs and the use of traffic signals as targets for small-arms fire, lie outside the normal range of predictability and coping, although even in these extreme conditions, the lamp failure mechanisms will probably be operative.

To satisfy Test Objective 3, power consumption characteristics are measured to provide a non-destructive method of comparing a newly-purchased LED TSL against one which has already passed all the acceptance tests. To this end, a non-destructive two-terminal voltage/current table was chosen as the ‘fingerprint’ for the LED TSL. The voltage range chosen is that defined by the above-noted ITE specification, 135V through 80V. Given the highly non-linear voltage/current characteristic of a typical LED TSL power supply, even minor circuit differences between two otherwise similar lamps would be expected to produce a detectable difference in their pattern.

As this concept developed, a reporting form was created to record the results of all the testing and facilitate comparison of an accepted LED TSL design against a sample from a purchased lot, to verify that the purchased lot is indeed the electrical equivalent of the approved lamp. It was decided to present the current consumption information in a graphical format, as well as a tabular format, in order to facilitate quick visual comparisons. The reporting form developed provides:

(1) Tabular and graphical presentation of the current and volt-ampere values over the 135V to 80V range of operation.
(2) Reporting of the off-state voltage across the LED TSL for operational lamps.

The reporting form is shown as Figure 2.

In the test setup used, the off-state voltage is also confirmed with a conflict monitor. The form also provides space for reporting the failure-mode tests, including verification of the fault detection with the conflict monitor. This last test, of course, will be performed only for certification testing.

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Retest to new format

LED LAMP EVALUATION REPORT

MFR: Prec. Solar SIZE/COLOR: 12" grn PWR CONN push-ons

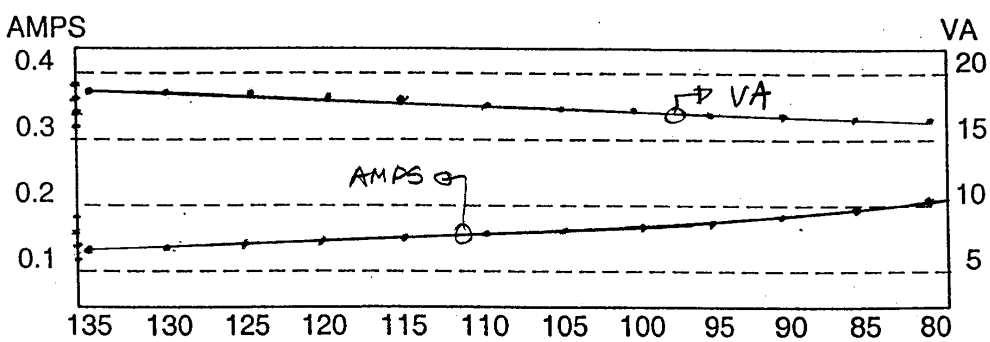
MODEL: 2035 PART NO.: ______ S/N: AB0-944

OTHER MFR INFO: 19 watts, 120VAC, 60Hz, 19.3VA mfr 11/00

TESTED BY: JCG DATE: 02/08/02

TWO-WIRE TERMINAL CHARACTERISTICS

VOLTS	AMPS	VA	VOLTS	AMPS	VA	VOLTS	AMPS	VA
135V	0.1382	18.66	115V	0.1541	17.72	95V	0.1793	17.03
130V	0.1414	18.38	110V	0.1592	17.51	90V	0.1880	16.92
125V	0.1452	18.15	105V	0.1651	17.34	85V	0.1979	16.82
120V	0.1495	17.94	100V	0.1717	17.17	80V	0.2092	16.74



OTHER DATA, VISIBLE INDICATIONS, ALL AT 120V EXCEPT AS NOTED:

INTENS @ 120V 158.1, @135V 158.2 = 0 %, @80V 158.3 = 0 %

OPERATION AT LIMITS: @ 135V OK @ 80V OK

VOLTAGE DROP IN OFF-STATE: 3.43V 3.54 @ 135V 3.12 @ 80V

FAILURE THRESHOLD: ______%, FAILED-STATE IMPEDANCE: ______

TOTAL HARM DIST: 9.9 %, POWER FACTOR: 0.98

Figure 2: LED TSL Data collection form

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IV. IMPLEMENTATION: DATA COLLECTION ON AVAILABLE LED LAMPS

During the early phases of the project, LED TSL manufacturers were invited to send samples of 12 inch (300mm) assemblies for project use. The test samples provided were used for multiple purposes: first to validate the above tests and reporting format, and secondly to obtain the electrical 'fingerprint' against which future LED TSLs might be compared for acceptance. The manufacturers were requested to provide two samples of each LED TSL they wanted to include in this program, so that one could be run through all tests including the failure-mode test, and a second, presumably identical, LED TSL would remain to reconfirm all non-destructive tests as needed. All lamps provided were the larger standard 12-inch (using the jargon of the signal industry, or 300 mm metric) lamp, a universal choice over the older 8-inch (200mm) lamp for new installations. Thirty-seven LED TSLs from five cooperating manufacturers were tested in the "as-new" state for basic two-terminal electrical characteristics and all other non-destructive tests noted above. Ten LED TSLs from four manufacturers were also tested for their failed-state characteristics. In a few cases, access to internal circuitry for failure-mode testing was gained by removing a few screws, but in one series of lamps, it was necessary to cut loose the rear cover with a Dremel tool, and in another series, to break off portions of the lens, to gain necessary access to the interior of the assembly.

The full test procedure and test facilities used to obtain the results are described fully in the appendices of this report. These appendices are organized in a way that facilitates their use as manuals for a test lab to procure the needed hardware, build the test stand, gather the needed measurement instruments, and perform the tests.

Figure 3, on the following page, is a table describing the makes and models of LED TSLs used in this project. Because of the rapid development cycles and extremely competitive nature of this industry, these particular models of LED TSLs may not be available by the time this report is published and distributed.

The manufacturers who responded to ODOT's solicitation for samples were:

COOPERLED, a division of Cooper Lighting, Peachtree City, GA.
Leotek Electronics, Taiwan, distributed by Leotek Electronics, Santa Clara. CA
Dialight Corp, Roxboro, NC
GELcore, a division of General Electric, Quebec, Canada (formerly called Ecolux)
Precision Solar Controls, Garland, TX

Some manufacturers who responded early also sent improved samples late in the course of this project, and some delayed their shipment until the release of an upgraded product. All comments which follow are based on the last-received lamps in all cases.

MANUFACTURER	BALL DESCRIPTION	MODEL #	SERIAL #	WATTAGE	•NOTES•••
Dialight	12"-Red Ball	433-1210-003	20001952	10.5	•Successive lamps off the same assembly line allow validation of the "fingerprint" concept.
			20001951	10.5	
	12" -Green Ball	432-2270-001	010511040	10.7	
			003160304	14.9	
Precision Solar	12" -Red Ball	1877	ABO-723	13	
			ABO-741	13	
	12" -Green Ball	2035	ABO-940	19	
			ABO-944	19	
	12" -Yellow Ball	2015	ABO-717	24•	•These lamps are clearly mislabeled, since the actual wattage was between 15 and 18 watts for line voltages between 135 and 80 volts.
			ABO-720	24•	
Cooperled	12" -Red Ball	CLB12RAS	00000002	15	
	12" -Green Ball	CLB12GAS	00000000	15	
	12" -Yellow Ball	CLB12YAS	00000001	15•	•This lamp is clearly mislabeled, since the actual wattage was between 28 and 30 watts, for line voltages between 135 and 80 volts.
Leotek	12" -Red Ball	TSL-12R-MG	T010599994	11	
			T010599995	11	
	12" -Green Ball	TSL-12G-MG	T010499994	11.7	
			T010499995	11.7	
	12" -Yellow Ball	TSL-12Y-MF	T010499990	21.3	
			T010499991	21.3	
GELcore (formerly: Ecolux)	12" -Red Ball	D12RA4	547226	9	
			547227	9	
	12" -Green Ball	D12GA4	547263	11.8	
			547264	11.8	

Figure 3

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V. RESULTS OF TESTS AND CONCLUSIONS

This ODOT project was initiated in June, 2000. ATSI had done prior work with LED TSLs on a consulting basis, and had knowledge of the status of LED TSL designs at the onset of the project. Some manufacturers, in their rush to get a product to market, had hastily-designed products which produced acceptable levels of illumination, but had some less desirable electrical characteristics, such as:

(1) poor power factor
(2) excessive harmonic distortion
(3) poor response to outages of the individual LED devices

On the positive side, these early designs proved that LED TSLs significantly reduce the electrical power consumed at an intersection, and that LED TSLs have a much longer service lifetime than the incandescent lamps they replace. This latter characteristic is so much longer that a typical service lifetime has yet to be determined. Present lifetime estimates are based on 'accelerated aging' tests.

Over the span of about five years that LED TSLs have been available, the good design features from all manufacturers have migrated across corporate borders, replacing weaker design features as they went**.** There is a considerable degree of similarity, circuit-wise and performance-wise, among the samples tested as a part of this project.

All final samples tested were found compatible with modern load switches and monitors found in existing (incandescent) traffic signal installations.

While testing to the ITE standards was not an identified task in this project, conformance with safety-related standards was also tested on most of the LED TSLs.

None of the final samples departed from any of the ITE safety-related standards to an extent considered hazardous.

The ITE standard most frequently missed was the lamp-failure criterion, where the (optional) standard specifies no-fail operation for a 25% loss of luminance, and must-fail for a 40% loss of luminance. Lacking the instrumentation to measure absolute luminance, the loss-of-luminance criterion was equated with the percentage reduction of emitting LED devices. This alternative criterion is subject to error on the long side, since removal of LEDs in some designs increases the current to the remaining functional LEDs, thus providing a measure of luminance compensation for the non-operative LEDs. The largest departure encountered was a lamp which would not enter a fail-state with 60% of the LEDs dark, until by chance, it was turned on with the lamp-voltage control set to about 85 volts (within the defined operating voltage range), and it promptly entered the fail-state. All prior successively-greater-failure tests on this lamp, as on all lamps tested, had been done at the ITE-specified reference voltage of 120 volts. It is safe to assume that a fail-state at 120 volts would have occurred with removal of a few more LEDs, since the fail-state trigger mechanism was clearly functional.

All tested LED lamps of current design include circuitry which senses the status of the LED emitters, and initiates a failure state when a specified outage condition is exceeded. Unfortunately, the failed state is permanent in most cases.

These LED-lamp samples provided by five major suppliers in this industry are all considered safe for substitution in signals now using incandescent lamps with modern load switches and signal monitors. Extension of this evaluation to other recently-developed products of these manufacturers is probably valid, but should be verified before making commitments. All these lamps are of the all-in-one design, in which the LED array, its lens, and associated electronics, are all included in a single moisture-tight package to facilitate installation in existing signal heads.

The attached appendices expand on some areas which may be of lesser interest to a general readership. Appendix 1 provides detailed technical information on the LED-lamp test station used to obtain the tests reported, to help the reader duplicate such a tester if desired. Appendix 2 presents the test reports, similar to preceding Figure 2, for all the newest lamps tested. These reports provide the quantitative basis for most of the judgements reported above.

APPENDIX 1. LED TSL TESTING FACILTY AND PROCEDURE

All measurements in this report were obtained using a hand-built special test station and commercially available test instruments. This document provides all the information necessary to assemble the testing facility and the procedure to perform the tests. LED TSL designs are constantly changing to reflect new technology and maintain a competitive status in the marketplace, so testing of new products could be a regular event.

The special test station simulates a small portion of a typical traffic signal control system to allow valid testing. Two devices used with the test station come directly from a signal cabinet; the conflict monitor and the load switch. The load switch is a solid-state relay-equivalent device, controlled by 24 VDC, which applies the 110 VAC power to the LED TSLs under test. The conflict monitor is a device that senses the voltage applied to all the signal lamps in the intersection and determines if a dangerous condition exists. Each "channel" of the conflict monitor consists of 3 inputs for the 3 signal lamps (Red, Yellow, Green) on one approach in an intersection. The monitor's decision matrix is based on a manually-programmable permissive card which is adjusted to reflect the signal design for a particular intersection. For testing purposes, the monitor must be set to allow no permissives. Channel 1 of the conflict monitor is wired to monitor the LED TSLs under test, and channel 2 is wired to a set of small incandescent lamps to provide a reference channel to the monitor.

The test station allows testing of one, two, or all three LED TSLs on channel 1. When less than 3 LED TSLs are being tested, small incandescent lamps are used on the non-testing inputs as electrical loads to meet the requirements of the conflict monitor. Three internal/external toggle switches allow the user to select the incandescents or the binding posts (to which the external LED TSLs are connected) for any or all of the channel 1 lamps. All three (RYG) channel 1 lamps are driven by a standard three-circuit load switch, and are monitored on channel 1 of any NEMA or 210/2010 signal monitor. Three more toggle switches replace the controller outputs for channel 1, driving the inputs to the load-switch with 24-volt logic signals, to activate any one, or none, of the channel 1 lamps. Instead of being locked into a programmed controller sequence, any given signal state is maintained until the user flips the toggle switches.

Channel 2 is designed to be as simple as possible, compatible with the constraints imposed by the signal monitor. The electrical loads are small incandescent lamps, driven directly by a second set of toggle switches (replacing channel 2 controller outputs and load switch) to provide any one or none of the channel 2 lamps. A load switch is not needed, since channel 2 outputs are required only to provide a reference set of inputs to the signal monitor. As above, any state is maintained until the switches are changed. Channel 2 will be in a red-on, yellow-off, green-off state for most tests.

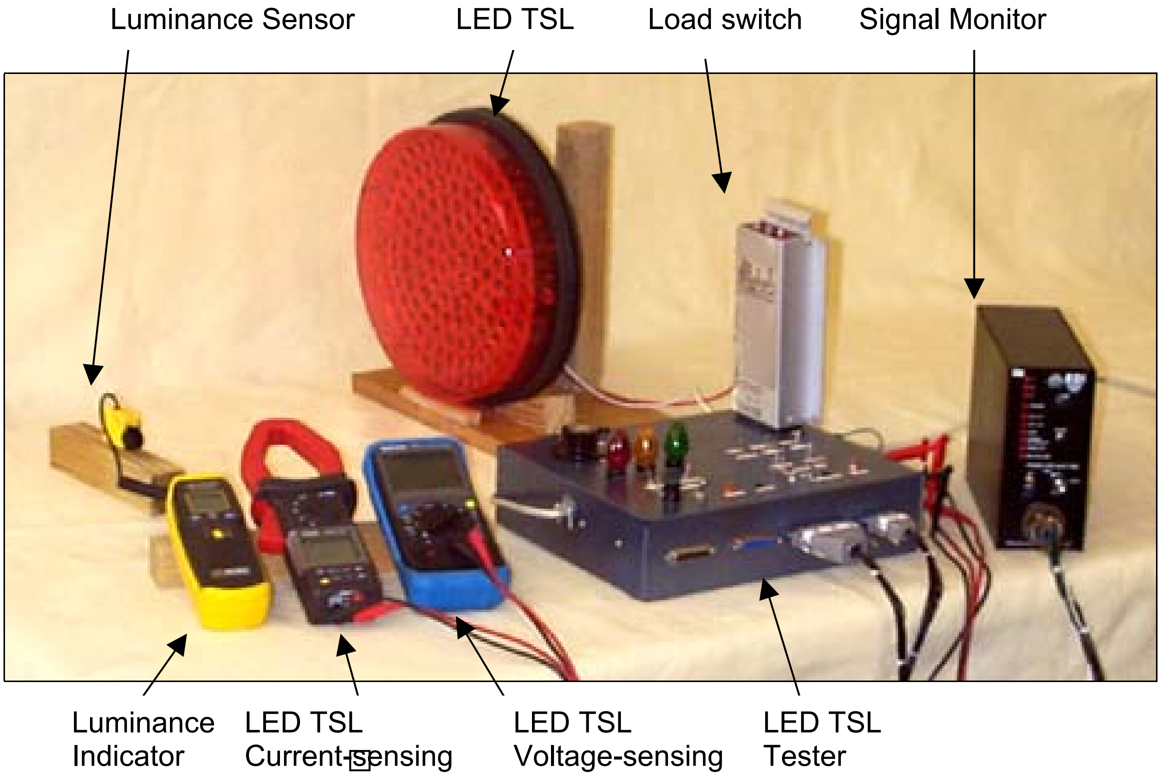


Figure A1-1. Typical test setup for single-lamp testing. This setup was used to gather most of the data discussed earlier in this report, to obtain the voltage/current ‘fingerprint’, the off-state voltage drop, power factor, and harmonic distortion. The LED TSL in this photo is a GELcore D12RA4, a 9-watt red lamp, which utilizes 132 individual LEDs. The load switch is a PDC SSS-86-I/O, a 3-lamp universal load switch with input and output indicators. The conflict monitor is an EDI NSM-3L, a 3-channel basic NEMA monitor, chosen primarily for its small physical size. LED TSL voltage-sensing is provided by a Tektronix TX1 true-rms multimeter. LED TSL current-sensing and harmonic-content measurements are provided by an AEMC 725 Harmonic meter. An AEMC CA813 Lightmeter was used to make some relative (not absolute) luminous intensity measurements in an exploratory manner, not to provide any reported values.

The test station supplies the conflict monitor with other signals to prevent the conflict monitor from transferring to the fault state for reasons not pertaining to the lamp voltage sensing functions. The Red-enable input of the conflict monitor is wired to the AC line, to allow red-fail detection on tested channels 1 and 2. Because of this, any inactive higher channels present in the monitor (3 through 18), are internally wired with a RED signal at line voltage to avoid fault detections from the monitor. All non-lamp inputs to the monitor (24VDC, CVM, DC inhibit, watchdog, etc.) are provided with no-fault signals to avoid non-lamp-related fault indications from the conflict monitor. The state of the monitor’s fault relay is returned to the tester, where it controls a LED fault indicator. A push-button on the tester panel allows the user to reset the monitor.

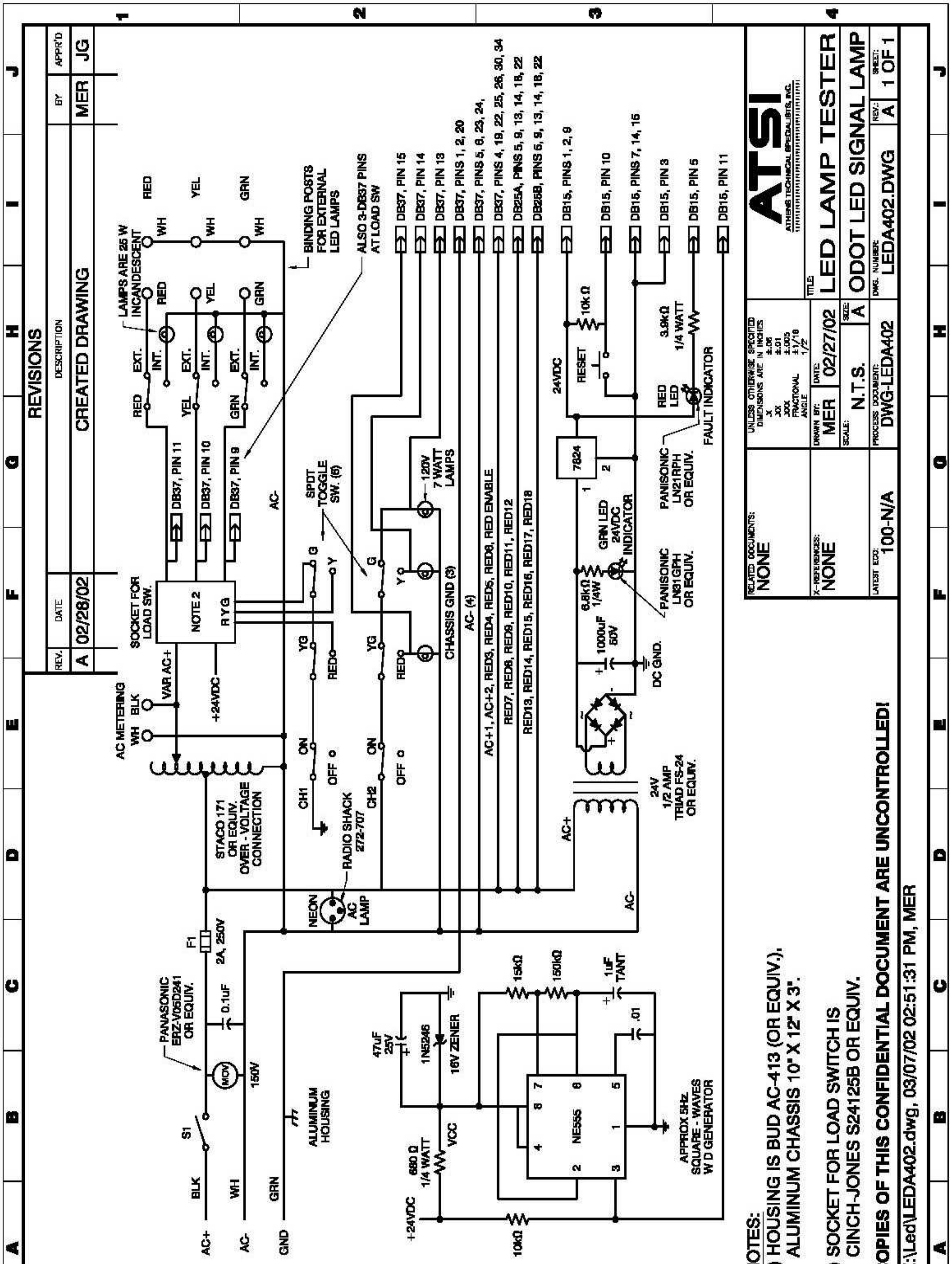
The DB-connectors along the front vertical panel provide connections to any conflict monitor designed to NEMA or FHWA/CalTrans standards. The appropriate cabling is determined by the available signal monitor, and can be made up by the user, or it can be purchased from ATSI.

Figure A1-2. Layout of the LED-lamp tester.

Power enters on the left side, the four DB-connectors to the conflict monitor are located across the front side, and the binding posts for connecting the external LED TSLs are on the right side. It is worth noting that if a NEMA 3-channel or
6-channel monitor is available, only the DB15 and DB37 connectors are needed, the two DB25 connectors can be omitted.

The enclosed space inside the chassis holds the body of the variable AC transformer, the three 25-watt internal lamps for phase 1, the 24V DC power components, watchdog generator, etc. In the figure above, the 25-watt lamps are located under the rear center area, where no components are top-mounted. The red and black test jacks (left rear) were to meter the variable AC, but are not needed, since metering is now performed at the LED TSL connections.

A complete detailed schematic diagram of the tester unit is shown in Figure A1-3 following this page. The tester shown is built into an aluminum chassis with all controls on the top surface. These include the main power switch, fuse, AC power indicator, and variable voltage adjustment knob. The toggle switches to activate lamps for phases 1 and 2, along with those to select internal/external lamps for phase 1, are all located on the top surface. The small LEDs which serve as 24VDC power indicator and conflict monitor fault (transfer) indicator, along with a conflict monitor reset button, are located on top. The three 7-watt lamps for phase 2 are located on top, adjacent to their toggle switches. The socket for the load switch is also located on top.


REVISIONS
REV. DATE DESCRIPTION BY APPR'D
A 02/28/02 CREATED DRAWING MER JG
NOTES:
1) HOUSING IS BUD AC-413 (OR EQUIV.), ALUMINUM CHASSIS 10" X 12" X 3".
2) SOCKET FOR LOAD SWITCH IS CINCH-JONES S24125B OR EQUIV.
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E:\Led\LEDA402.dwg, 03/07/02 02:51:31 PM, MER
ATSI
ATHENS TECHNICAL SPECIALISTS, INC.
TITLE: LED LAMP TESTER
ODOT LED SIGNAL LAMP
DRAWN BY: MER
DATE: 02/27/02
SCALE: N.T.S.
SIZE: A
PROCESS DOCUMENT: DWG-LEDA402
DWG. NUMBER: LEDA402.DWG
REV: A
SHEET: 1 OF 1
RELATED DOCUMENTS: NONE
X-REFERENCES: NONE
LATEST ECO: 100-N/A
NE555
APPROX 5Hz SQUARE - WAVES W D GENERATOR
SOCKET FOR LOAD SW.
SPDT TOGGLE SW. (6)
LAMPS ARE 25 W INCANDESCENT
BINDING POSTS FOR EXTERNAL LED LAMPS
STACO 171 OR EQUIV. OVER - VOLTAGE CONNECTION
RADIO SHACK 272-707
NEON AC LAMP
24V 1/2 AMP TRIAD FS-24 OR EQUIV.
FAULT INDICATOR
GRN LED 24VDC INDICATOR
CHASSIS GND (3)
AC- (4)
ALUMINUM HOUSING

DATA COLLECTION USING THE LED-LAMP TESTER

Data collection with the LED TSL tester follows the format defined by the LED TSL test report form, shown in the main body of this report. The header portion of this report form identifies the LED TSL to be tested, the person doing the testing, and the date of the testing. A blank test report form is included in this appendix for the use of the reader to record their own test data and to follow along with these instructions.

It is suggested to proceed with the testing in the order that it appears on the test report form. These instructions follow that order.

1.0 The technician should fill in the information at the top of the form identifying the unit to be tested, and the test operator and date.

2.0 The two-wire terminal characteristics follow, in which the current drawn by the LED lamp is measured and recorded at 5-volt intervals from 135V down to 80V. The person testing can do the calculations and plotting of the two curves on completion of this group of measurements, or the calculation and plotting can be delayed until all measurements are completed. The equipment setup for performing these tests will be similar to that shown in Figure A1-1.

3.0 Next, using the luminous flux detector, the 'INTENS..' tests can be executed. With the 120V reference line voltage applied to the lamp, set up the detector in relation to the LED lamp's beam such that at least two digits over 80, but preferably three digits, are indicated by the detector. The location of the detector can be anywhere close to the lamp, but ONCE CHOSEN, THE LAMP-DETECTOR PHYSICAL RELATION MAY NOT BE ALTERED until this particular test is completed. The data shown in Appendix 2 were taken with the detector at 20 to 30 inches separation from the face of the LED TSL. For all these data, allow ample settling time for the LED TSL and detector. Both are adjusting to each change of conditions. Up to a full minute may be required before the indication becomes stable. After recording the reference flux at 120V, raise the voltage slowly to 135V, watching the detector as the voltage rises. It may rise slightly, or fall slightly, as the voltage is raised, but for the data reported in Appendix 2, no change of direction was noted in any of the lamps tested. When 135V is reached, again allow a settling time until the detector indication is stable, and record the flux reported. Next, run the voltage slowly down, and pause at 120V to reconfirm the flux at the reference voltage, then continue on down to 80V. This is the long interval, 40V, as compared to the earlier interval of only 15V. After settling, record the flux reported at this voltage. Again, the calculations may be made now, or delayed until all test data have been collected. The percent change is simply the change of flux (e. g., 135V value – 120V value) divided by the 120V value, and multiplied by 100 to express the result as a percentage.

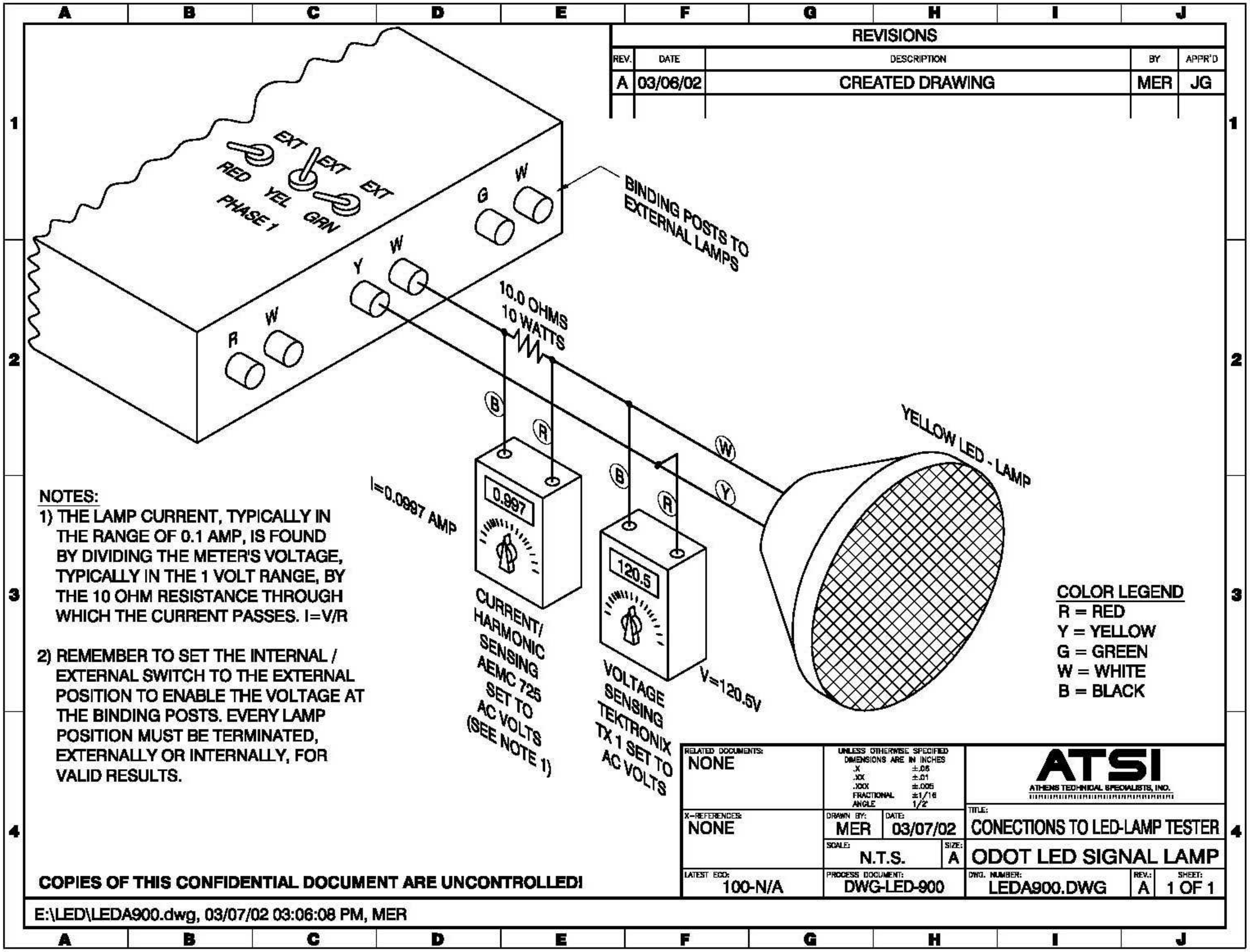
4.0 The next test, 'OPERATION ..', verifies that the lamp will behave normally at both extremes of the ITE-specified line-voltage range. The importance of this test was forcefully brought to the writer's attention long before this study was begun, when a early-design LED lamp was accidentally left ON at about 130V, and it proceeded to self-destruct within a few minutes. For this test, the lamp voltage is set to 135V, and then the tester switch is set to turn off the tested lamp, and go to another lamp of the same phase, e.g., green to yellow. Allow a few seconds, then reverse the last change (your monitor may indicate a sequence error, but ignore it, it has no effect on the lamps). This is to verify that the tested lamp responds properly to its inputs at the elevated voltage. Now let the tested lamp remain in a constant ON-state for 15 or 20 minutes, then repeat the functionality test. If all went well, indicate this with 'OK' on the 135V block of the report form. Now drop the LED lamp's line voltage to 80V, and repeat the above tests at the low end of the operating range.

5.0 The next test, 'VOLTAGE DROP ..', checks that the lamp satisfies the off-state compatibility requirement for a functional LED lamp. The voltage is that which appears at the lamp's terminals when the tested lamp is in its off-state, i. e., when either of the other lamps is the active lamp. This is the voltage which must be below 15V (green or yellow) or below 50V (red) to assure that no false fault condition will be presented to the monitor. If the monitor happens to be in a transfer state before this test is started, it should be reset so it can confirm the voltmeter's reading. This test should be performed at 135V, 120V, and 80V. For the samples tested in this study, all functional lamps reported an off-state voltage below 7 volts. The ITE spec suggests a similar test, substituting a resistor for the input impedance of the monitor, requiring an off-state voltage <10V, and adding a 100mS timing condition to the off-state lamp voltage.

6.0 **NOTE: Perform test number 7.0 BEFORE altering the LED TSL.** The next test, 'FAILURE ..', applies to the test in which LED emitters are successively disabled until the lamp's fault-detection system declares a failure state and forces the lamp's terminal impedance to a high value, approximating an open circuit. As noted in the main body of this report, an absolute luminous flux measuring system is necessary to perform this test accurately. As a poor alternative, some tests were made by cutting out LED emitters from the active array, until a fail condition was forced on the fault-detection subsystem, and the lamp is forced to a high-impedance state. While the definition of the fault condition is not very accurate, the one very important value that is properly reported is the failed-state input impedance. This is best measured with the lamp totally disconnected from the tester, to avoid erroneous readings due to shunting impedances of the test setup. Since most multimeters use an internal DC voltage source for resistance measurements, the impedance of the failed lamp should be taken with the meter leads in one pairing with the lamp's terminals, then reversed, to cover any possible polarity-sensitive cases.

7.0 The total harmonic distortion and power factor measurements are both performed with commercial meters specific to the task, as recommended by the ITE spec. As shown in the test setup earlier in this appendix, harmonic content is derived from the current input to the lamp. The current is sensed as the voltage across a 10-ohm, 1% tolerance series resistor, so that the voltage inputs of the AEMC 725 Harmonic Meter can be used. The current input to the meter was too insensitive to read accurately the tiny currents of the LED TSLs.

Other power meter may offer the necessary sensitivity for power factor measurements on these low-power loads. Both of these tests are performed only at the 120V reference condition.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W
BINDING POSTS TO EXTERNAL LAMPS
10.0 OHMS
10 WATTS
B
R
B
R
W
Y
I=0.0997 AMP
0.997
120.5
CURRENT/ HARMONIC SENSING AEMC 725 SET TO AC VOLTS (SEE NOTE 1)
VOLTAGE SENSING TEKTRONIX TX 1 SET TO AC VOLTS
V=120.5V
YELLOW LED - LAMP
NOTES:
1) THE LAMP CURRENT, TYPICALLY IN THE RANGE OF 0.1 AMP, IS FOUND BY DIVIDING THE METER'S VOLTAGE, TYPICALLY IN THE 1 VOLT RANGE, BY THE 10 OHM RESISTANCE THROUGH WHICH THE CURRENT PASSES. I=V/R
2) REMEMBER TO SET THE INTERNAL / EXTERNAL SWITCH TO THE EXTERNAL POSITION TO ENABLE THE VOLTAGE AT THE BINDING POSTS. EVERY LAMP POSITION MUST BE TERMINATED, EXTERNALLY OR INTERNALLY, FOR VALID RESULTS.
COLOR LEGEND
R = RED
Y = YELLOW
G = GREEN
W = WHITE
B = BLACK
RELATED DOCUMENTS: NONE
X-REFERENCES: NONE
LATEST ECO: 100-N/A
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
.X ±.05
.XX ±.01
.XXX ±.005
FRACTIONAL ±1/16
ANGLE 1/2°
DRAWN BY: MER
DATE: 03/07/02
SCALE: N.T.S.
SIZE: A
PROCESS DOCUMENT: DWG-LED-900
ATSI
ATHENS TECHNICAL SPECIALISTS, INC.
TITLE: CONECTIONS TO LED-LAMP TESTER
ODOT LED SIGNAL LAMP
DWG. NUMBER: LEDA900.DWG
REV.: A
SHEET: 1 OF 1
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Website: www.atsi-tester.com

LED LAMP EVALUATION REPORT

MFR:_______________SIZE/COLOR:_____________PWR CONN____________

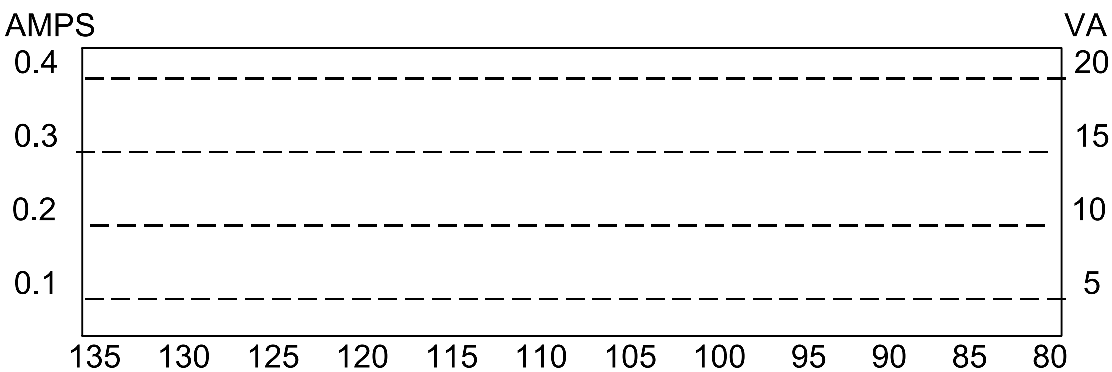
MODEL:______________ PART NO.:________________S/N:________________

OTHER MFR INFO:____

TESTED BY:_____________________________________DATE:______________

TWO-WIRE TERMINAL CHARACTERISTICS

VOLTS	AMPS	VA	VOLTS	AMPS	VA	VOLTS	AMPS	VA
135V	_____	_____	115V	______	_____	95V	______	_____
130V	_____	_____	110V	______	_____	90V	______	_____
125V	_____	_____	105V	______	_____	85V	______	_____
120V	_____	_____	100V	______	_____	80V	______	_____



<u>OTHER DATA, VISIBLE INDICATIONS, ALL AT 120V EXCEPT AS NOTED:</u>

INTENS @ 120V _____ , @135V_______ =______%, @80V______ =______%

OPERATION AT LIMITS: @ 135V ______________ @ 80V _______________

VOLTAGE DROP IN OFF-STATE: ______________

FAILURE THRESHOLD:________%, FAILED-STATE IMPEDANCE:_______

TOTAL HARM DIST: __________%, POWER FACTOR: _______________

APPENDIX 2. REPORTS ON LED TSL TESTS

This appendix contains a series of test reports from testing done on LED TSLs as a part of this project. Due to the dynamic nature of this industry, it may be that the models described herein are out of production at the date of publication. The value to these reports are to give the reader a sense of typical performance and repeatability that could be expected from the test procedure.

The following commentary/explanatory text is meant to be read in conjunction with the report forms which follow, starting on page A2-5. In this section, "LED lamps" refers to "LED Traffic Signal Lamp assemblies", abbreviated as "LED TSL" in other parts of this document.

Pages A2-5 thru A2-6
The first two report forms came from consecutively numbered red LED lamps manufactured by DIALIGHT. They are Model 433-1210-003 lamps, made in The Netherlands, with serial numbers 20001951 and 20001952. Such a pair would be expected to provide essentially identical 'fingerprints', the two-terminal voltage/current characteristic. The excellent agreement of the data obtained from these two lamps confirms two critical assumptions: First, that two presumed identical twins do indeed produce the same data, and second, that the testing system used to obtain these data is sufficiently sensitive and accurate to confirm that agreement.

Looking at the reported data below the fingerprint box, the line starting with 'INTENS @ ..' reports on the variation of luminous flux as the line voltage is varied over the range of 135V to 80V. The ITE spec requires that the flux over the range of 135V and at 80V lie within +/- 10% of the flux at the 120V reference voltage. While the flux measuring meter is not set up to measure absolute flux, it is easy to measure departures from a given reference value, such as the flux at a line voltage of 120V. In this case, as in all others, the endpoints define the maximum departure from the reference, tiny as it is. It is seen that the variation of the above lamps over the 135V to 80V input range lies within a fraction of 1% of the reference flux value at 120V.

The line starting with 'OPERATION AT ..' reports the results of functionality testing at the endpoints of the defined operating region, 135V and 80V. Functionality testing involves proper turn-on and turn-off response to ON and OFF conditions, along with an extended ON-state of 15-20 minutes at each endpoint without impairment of any functions. The 'OK' here confirms the lamp had no quirks in its response to these conditions.

The line starting with 'VOLTAGE DROP ..' reports the voltage of a good lamp in its OFF-state, one of the critical compatibility tests mentioned in the main report. This voltage must be below 50V for RED lamps, and below 15V for YELLOW and GREEN lamps, to assure correct recognition of a good LED lamp by the signal monitor. While only the OFF-state voltage at the 120V reference is mentioned in the ITE spec, the LED lamp was checked at the endpoint voltages as well.

The line starting with ‘FAILURE ..’ is intended to report the percent outage of LEDs when the lamp’s internal monitor declares a fail-state and irreversibly presents a high-impedance at its input terminals. Since the LEDs-out criterion is only a poor approximation of the loss-of-flux condition, and since the ITE defined this as an ‘optional’ criterion, this test was not performed on all lamps. Some earlier lamps with less-sophisticated compensation schemes passed within the 25% and 40% outage condition, but some newer lamps required an outage of the order of 50% to 60%. This line is left on the reporting form in anticipation of a more sophisticated measurement capability which will accurately sense the luminous flux.

The line starting with ‘TOTAL ..’ reports the total harmonic distortion and the power factor of the LED lamp tested. The ITE spec requires that total harmonic distortion be below 40% for LED lamps with power consumption of less than 15 watts, and below 20% for lamps consuming 15 watts or more. The spec also requires that the power factor be 90% or more for all LED lamps. These specs are easily satisfied by all LED lamps tested.

Pages A2-7thru A2-8
The next two Dialight lamps are dissimilar. DG1 (Model 430-2270-001, serial number 003160304), is rated at 14.9 watts or 15.4 vars, while DG2 (Model 432-2270-001, serial number 010511040), is rated at 10.7 watts or 11.5 vars. This difference is readily confirmed on comparing the two fingerprints, also as expected. It is reassuring to observe the good agreement between the labeled volt-ampere rating and that actually measured in both cases.

The Dialight lamps were clearly not designed to facilitate user access to the internal circuitry. To gain access to the LED panel, it was necessary to use a Dremel tool with a small router bit to cut the full circumference around the back cover, after which all the necessary access became available. The green LED lamp was cut open to permit access to the LEDs for determining the failure condition. Although no circuit information was provided, the LED connection matrix was easily readable from the wiring traces on the LED panel. When it had not yet failed at 54% outage, the test was terminated. From the exposed LED wiring traces, it could be seen that a measure of luminous compensation was provided by the circuitry, so the percent outage of LED emitters would not be an accurate measure of luminous flux loss. (Recall that the ITE spec calls for an optional fault condition below 40%, but greater than 25%, loss of luminous flux.)

Pages A2-9 thru A2-14
PRECISION SOLAR supplied two each of red, green, and yellow lamps, nearly contiguous in serial numbers. These were manufactured in November, 2000 and were tested in early December, 2000. Both sets of lamps were subjected to the

non-destructive tests, and one set was further tested to the failure condition. The format of the reporting form for earlier tests differed from that in current use, testing over a wider voltage range, and not keyed so closely to the ITE spec. The first three Precision Solar report sheets show data taken on the lamps which were also tested for failure conditions. Failure on all three lamps was found at the same condition – failure on four of the 18 strings present, or a 22% lamp outage at failure. The second three reports were re-taken in early February of 2002 on those lamps not subjected to the failure conditions. These results are reported on the newer report forms. It is interesting to note the extreme stability of luminous output over the wide range of operating voltage, less than 1% variation over a range of 55 volts. Some of these lamps differ significantly between the rated and measured values of volt-amps, which is not a cause for concern. The Precision Solar lamps were accompanied by excellent documentation, which was very helpful in understanding various results, and in selecting traces for cutting in the failure mode tests.

Pages A2-15 thru A2-20

COOPERLED supplied one each of their red, green, and yellow LED lamps early in this program, and another set in January of 2001. While two of the three lamps of the early set had a minor problem which would surface only under extremely improbable conditions (off-state voltage in the 50V range when the supply voltage is 135V), this situation was not present in the later set. It was noted that the labeled 15 watts power consumption is at considerable variance with measured volt-amps in the range of 28-30 vars for the yellow lamp. This set of lamps, like the Dialight lamps above, was packaged in a manner intended to discourage the curious user. In this case, it would have been necessary to break off the lens array in order to gain access to the LED panel inside. The testing to failure was omitted for this set of lamps.

Pages A2-21 thru A2-26

LEOTEK contributed two each of red, green, and yellow lamps. These lamps were all paired by adjacent serial numbers, so they supported the fingerprint verification for all lamp samples. These comparisons were good in the form of the curves, but seemed to suffer a bit in scale, perhaps as a result of a final manual adjustment of a trimpot or similar calibration device. All data obtained were totally acceptable in terms of standards. The enclosure allowed easy access to the interior workings, as previously seen in Figures 1A and 1B of the main body of this report. An early setup accident with one lamp caused the control panel's fuse to pop, but it was replaced with an equivalent fuse and operation was restored immediately. Leotek provided complete documentation, so that the failure tests could be performed with ease. Red and yellow lamps both required an outage of about 40%, while green required an outage of about 32%, to produce the fault-fail state. All were restored to like-new condition by simply replacing the small fuse. This family was so well-suited to this purpose that some of these lamps were wired with dip-switches to facilitate user-selection of blocks of inactive LEDs, to demonstrate the fault-to-fail phenomenon.

Pages A2-27 thru A2-30

GELCORE provided two red and two green lamps for this work, along with complete documentation. Each pair was consecutively numbered. Good-to-excellent agreement of the fingerprints was found in the pairs. All numbers found were well inside the acceptable range, except for the fall-off of luminous flux at 80V, which for all lamps was in the range of –20% from the value at 120V. This result might well be anticipated, since the power consumption starts to fall off noticeably below 95V line voltage. These lamps allowed easy access to their innards, and one of each color was tested for the failure state. The red lamp s/n 547226 was the first to be opened. It had no visible conductive traces, so the removal of LEDs was totally random. This lamp entered the fail-state between 20 and 24% outage of randomly-selected LEDs, giving an off-state impedance of greater than one megohm. By contrast, the green lamp s/n 547263 had a clearly defined set of traces on the backside, and the organization of the LEDs was quickly determined. (It was later noted that both boards carry the same before-stuffing part number.) Out of curiosity, the green LEDs were cut in such a manner that <u>outages at each step were distributed as uniformly as possible among the strings of LEDs.</u> When a 50% outage was realized without failure, the testing was terminated. It is evident that you can fool the detection system, but such a pattern of outages is extremely improbable.

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LED LAMP EVALUATION REPORT

MFR: ~~LUMILEDS~~ DIALIGHT SIZE/COLOR: 12" Red PWR CONN Push-On

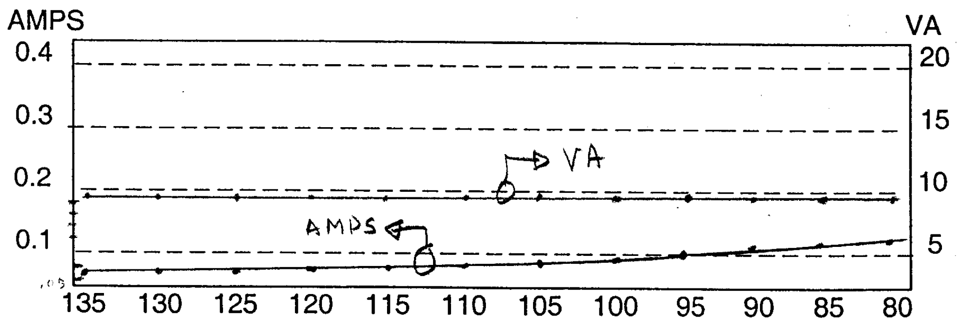
MODEL: DIALIGHT 433-1210-003 PART NO.: 75-0210 S/N: 20001951 made in The Netherlands

OTHER MFR INFO: 120V, 10.5W, 10.8VA, 60Hz, meets or exceeds ITE etc
MAX ORDER. 300588

TESTED BY: JCG DATE: 11 Feb '02

TWO-WIRE TERMINAL CHARACTERISTICS

VOLTS	AMPS	VA	VOLTS	AMPS	VA	VOLTS	AMPS	VA
135V	0.072	9.72	115V	0.083	9.545	95V	0.100	9.50
130V	0.074	9.62	110V	0.087	9.57	90V	0.106	9.54
125V	0.077	9.625	105V	0.091	9.555	85V	0.113	9.605
120V	0.080	9.60	100V	0.095	9.50	80V	0.120	9.600



OTHER DATA, VISIBLE INDICATIONS, ALL AT 120V EXCEPT AS NOTED:

INTENS @ 120V 122.5, @135V 122.3 = -0.16%, @80V 122.0 = -0.41%

OPERATION AT LIMITS: @ 135V OK @ 80V OK

VOLTAGE DROP IN OFF-STATE: 6.22V 6.48V @ 135V 5.60V @ 80V

FAILURE THRESHOLD: ________%, FAILED-STATE IMPEDANCE: ________ not taken

TOTAL HARM DIST: 12.2 %, POWER FACTOR: 0.98

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www.atsi-tester.com
email: sales@atsi-tester.com

LED LAMP EVALUATION REPORT

MFR: DIALIGHT SIZE/COLOR: 12" Red LUMILEDS PWR CONN Push-On

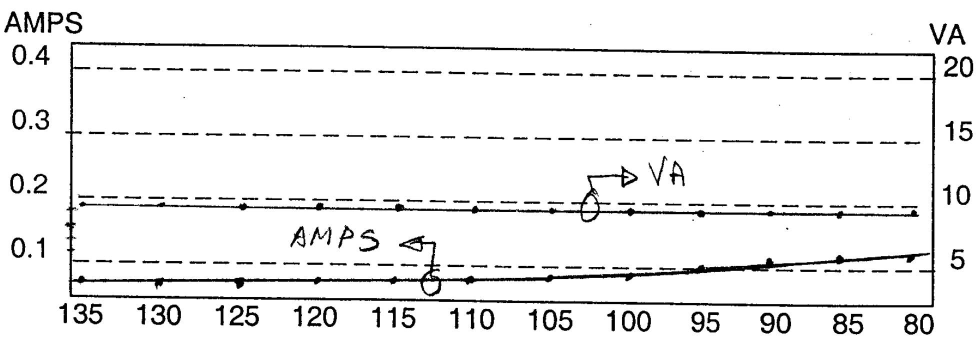
MODEL: 433-1210-003 PART NO.: 75-0210 S/N: 20001952

OTHER MFR INFO: 120V, 10.5W, 10.8VA, 60Hz, meets or exceeds ITE etc. ~~made in The Netherlands~~

TESTED BY: JCG DATE: 11 Feb 02

TWO-WIRE TERMINAL CHARACTERISTICS

VOLTS	AMPS	VA	VOLTS	AMPS	VA	VOLTS	AMPS	VA
135V	0.071	9.585	115V	0.083	9.545	95V	0.100	9.50
130V	0.073	9.49	110V	0.086	9.46	90V	0.106	9.54
125V	0.076	9.50	105V	0.090	9.45	85V	0.112	9.52
120V	0.080	9.60	100V	0.095	9.50	80V	0.120	9.60



OTHER DATA, VISIBLE INDICATIONS, ALL AT 120V EXCEPT AS NOTED:

INTENS @ 120V 120.7, @135V 119.9 = -0.16 %, @80V 120.2 = -0.4 %

OPERATION AT LIMITS: @ 135V OK @ 80V OK

VOLTAGE DROP IN OFF-STATE: 6.05V 6.31V @ 130V 5.45V @ 80V

FAILURE THRESHOLD: ____ %, FAILED-STATE IMPEDANCE: not taken

TOTAL HARM DIST: 12.7 %, POWER FACTOR: 0.95

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LED LAMP EVALUATION REPORT

MFR: Dialight SIZE/COLOR: 12" Green PWR CONN Push-on

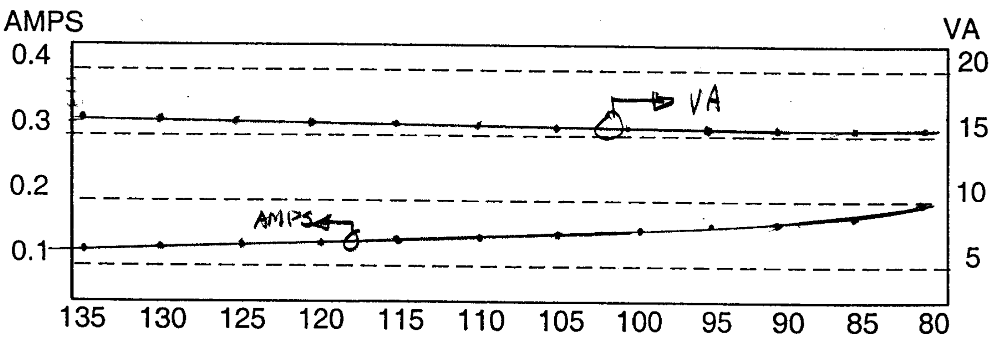
MODEL: ________ PART NO.: 430-2270-001 S/N: 003160304

OTHER MFR INFO: 120V, 14.9 watts, 15.4 VA

TESTED BY: JCG DATE: 11 Feb '02

TWO-WIRE TERMINAL CHARACTERISTICS

VOLTS	AMPS	VA	VOLTS	AMPS	VA	VOLTS	AMPS	VA
135V	0.119	16.055	115V	0.138	15.870	95V	0.164	15.580
130V	0.123	15.990	110V	0.143	15.730	90V	0.173	15.570
125V	0.127	15.875	105V	0.149	15.645	85V	0.183	15.555
120V	0.133	15.960	100V	0.156	15.600	80V	0.145	15.600



OTHER DATA, VISIBLE INDICATIONS, ALL AT 120V EXCEPT AS NOTED:

INTENS @ 120V 249, @135V 249 = ______%, @80V 248 = ______%

OPERATION AT LIMITS: @ 135V OK @ 80V OK

VOLTAGE DROP IN OFF-STATE: 5.35V 5.75V @ 135V 4.02V @ 80V

FAILURE THRESHOLD: ______%, FAILED-STATE IMPEDANCE: ______

TOTAL HARM DIST: 9.3 %, POWER FACTOR: 0.99

The Test Equipment Experts

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email: sales@atsi-tester.com

LED LAMP EVALUATION REPORT

MFR: Dialight SIZE/COLOR: 12" Green PWR CONN Push-on

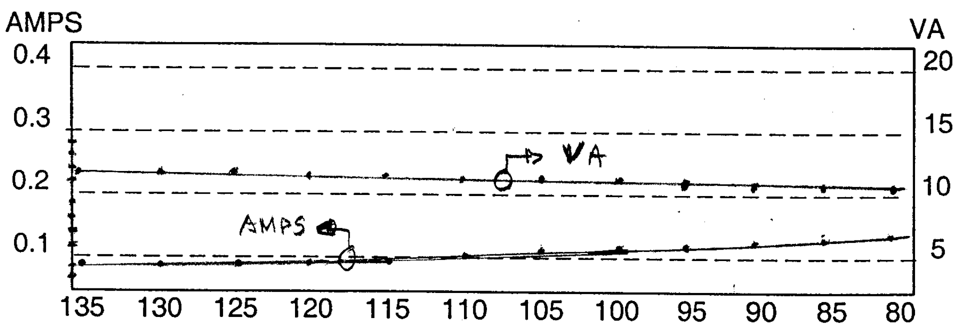
MODEL:________ PART NO.: 432-2270-001 S/N: 0105 11040

OTHER MFR INFO: 120V, 10.7 watts, 11.5VA, meets or exceeds ITE VTCSH part 2 specs

TESTED BY: JCG DATE: 11 Feb 02

TWO-WIRE TERMINAL CHARACTERISTICS

VOLTS	AMPS	VA	VOLTS	AMPS	VA	VOLTS	AMPS	VA
135V	0.087	11.745	115V	0.097	11.155	95V	0.113	10.735
130V	0.090	11.700	110V	0.101	11.110	90V	0.117	10.530
125V	0.093	11.625	105V	0.104	10.920	85V	0.123	10.455
120V	0.095	11.400	100V	0.109	10.900	80V	0.130	10.400



OTHER DATA, VISIBLE INDICATIONS, ALL AT 120V EXCEPT AS NOTED:

INTENS @ 120V 153.6, @135V 153.6 = +0 %, @80V 152.6 = -0.6 %

OPERATION AT LIMITS: @ 135V OK @ 80V OK

VOLTAGE DROP IN OFF-STATE: 5.04V 5.37V @ 135V in, 3.71V @ 80V in

FAILURE THRESHOLD:________%, FAILED-STATE IMPEDANCE:________

TOTAL HARM DIST: 9.8 %, POWER FACTOR: 0.997

Excellent agreement between stated and found VA rating

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Old test -
Lamp burned out

ATSI LED LAMP EVALUATION REPORT

MFR: Precision Solar SIZE/COLOR: 12" Red PWR CONN Spade Lugs

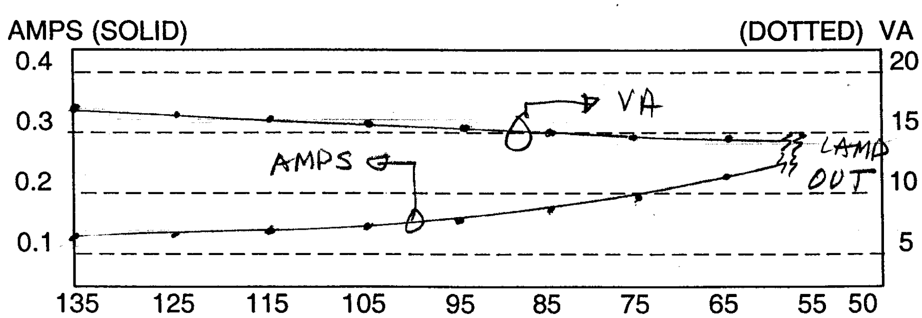
MODEL: 1877 PART NO.: 2398 S/N: ABO-723 Mfg: 11/00

OTHER MFR INFO: 13W, 120VAC, 13.3VA, 60Hz

TESTED BY: JCG DATE: 12/8/00

TWO-WIRE TERMINAL CHARACTERISTICS

VOLTS	AMPS	VA	VOLTS	AMPS	VA	VOLTS	AMPS	VA
135V	0.1268	17.12	105V	0.1489	15.63	75V	0.1972	14.79
130V	0.1293	16.81	100V	0.1543	15.43	70V	0.2105	14.74
125V	0.1324	16.55	95V	0.1606	15.26	65V	0.2256	14.66
120V	0.1357	16.28	90V	0.1679	15.11	60V	0.2394	14.36
115V	0.1396	16.05	85V	0.1767	15.02	55V	~~LAMP OUT~~	
110V	0.1439	15.83	80V	0.1860	14.88	50V		



OTHER DATA, VISIBLE INDICATIONS:

LAMP VOLTAGE AT FIRST APPARENT DROP IN INTENSITY: 60.7V

LAMP DROP AT EXTINCTION: 62.4 V IN OFF-STATE: 3.2V

OTHER OBSERVATIONS: Raising voltage from zero, find blinking at 62.1, steady ON at 60.2V. Lamp-fail @ 22% outage.

HARM DIST @120V: THD= 8.3 %, 3RD HARM= 7.0 %, 5TH HARM= 2.4 % 7th 2.3%

Rated and calculated VA differ significantly
Lacks usual neoprene cushioning/sealing ring

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ATSI LED LAMP EVALUATION REPORT

MFR: Prec Solar SIZE/COLOR: 12" Grn PWR CONN Push-Ons

MODEL: 2035 PART NO.: 2400 S/N: AB0-940

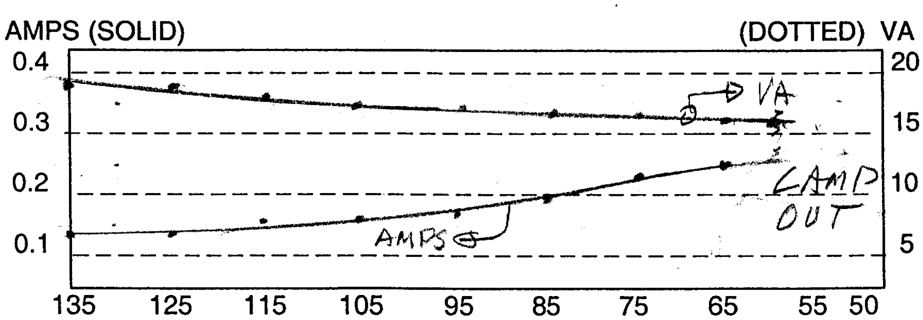
OTHER MFR INFO: 14W, 120VAC, 19.3VA, 60Hz

TESTED BY: JCG DATE: 12/11/00

TWO-WIRE TERMINAL CHARACTERISTICS

VOLTS	AMPS	VA	VOLTS	AMPS	VA	VOLTS	AMPS	VA
135V	0.1392	18.73	105V	0.1661	17.44	75V	0.2232	16.74
130V	0.1425	18.85	100V	0.1727	17.27	70V	0.2380	16.66
125V	0.1463	18.29	95V	0.1803	17.13	65V	0.2450	15.93
120V	0.1503	18.04	90V	0.1888	16.99	60V		
115V	0.1550	17.83	85V	0.1989	16.91	55V	0.018	10.05
110V	0.1602	17.62	80V	0.2100	16.80	50V	0.017	8.13

15.42 ON
61.2/0.2519
64.8/0.020 OFF
} Lamp off



→| ← FLICKER REGION

OTHER DATA, VISIBLE INDICATIONS:

LAMP VOLTAGE AT FIRST APPARENT DROP IN INTENSITY: 66.9V

flicker starts @ 62.5 going down

LAMP DROP AT EXTINCTION: ______ IN OFF-STATE: 3.3V @120V

OTHER OBSERVATIONS: Coming up from zero volts, first flicker @ 65V, full-on @ 62.5V. Lamp fail @ 22% outage

HARM DIST @120V: THD= 7.2%, 3RD HARM= 6.1%, 5TH HARM= 2.2% 7th 2.0

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Old test report on second yellow

ATSI LED LAMP EVALUATION REPORT

MFR: Prec. Solar SIZE/COLOR: 12" yel PWR CONN spade lugs

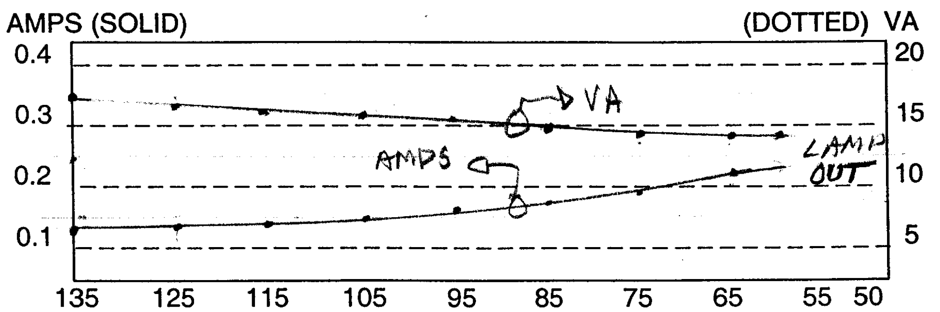
MODEL: 2015 PART NO.: 2015 S/N: ABO-717 mfg: 11/00

OTHER MFR INFO: 24W, 120VAC, 60Hz, 24.2 VA

TESTED BY: JCG DATE: 12/11/00

TWO-WIRE TERMINAL CHARACTERISTICS

VOLTS	AMPS	VA	VOLTS	AMPS	VA	VOLTS	AMPS	VA
135V	0,1289	17,40	105V	0,1493	15,68	75V	0,1954	14,66
130V	0,1312	17,06	100V	0,1543	15,43	70V	0,2079	14,55
125V	0,1339	16,74	95V	0,1604	15,24	65V	0,2229	14,49 ON/OFF
120V	0,1370	16,44	90V	0,1673	15,06	60V	0,2374	14,2 0,020
115V	0,1406	16,17	85V	0,1753	14,90	55V	0,019	OFF
110V	0,1445	15,90	80V	0,1846	14,77	50V	0,018	OFF



OTHER DATA, VISIBLE INDICATIONS:

LAMP VOLTAGE AT FIRST APPARENT DROP IN INTENSITY: 59.5V

LAMP DROP AT EXTINCTION: 61.4V falling IN OFF-STATE: 3.1V

OTHER OBSERVATIONS: First turn-on at 65.5V rising

Abrupt turn-on/turn off ~ 60V, Lamp-fail @ 22% outage.

HARM DIST @120V: THD= 12.0 %, 3RD HARM= 10.7 %, 5TH HARM= 3.7 % 7th 2.8

Rated and Calculated VA differ significantly

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Retest to new format

LED LAMP EVALUATION REPORT

MFR: Prec Solar SIZE/COLOR: 12" Red PWR CONN Spade Lugs

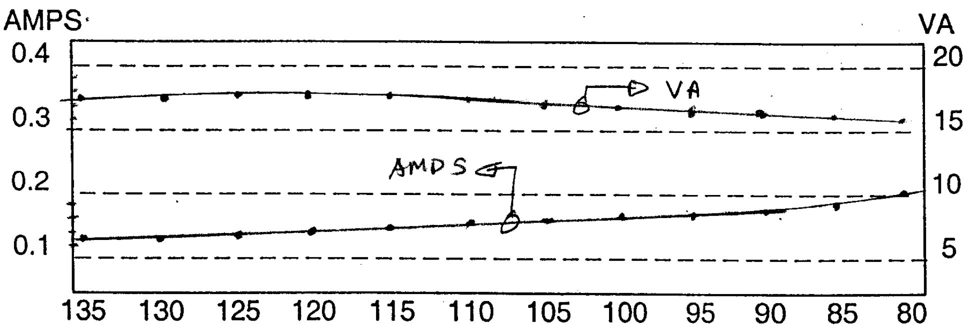
MODEL: 1877 PART NO.: ______ S/N: AB0 -741

OTHER MFR INFO: 13W, 120VAC, 60Hz, 13.3VA, mfr 11/00

TESTED BY: JCG DATE: 02/08/02

TWO-WIRE TERMINAL CHARACTERISTICS

VOLTS	AMPS	VA	VOLTS	AMPS	VA	VOLTS	AMPS	VA
135V	0.1292	17.44	115V	0.1528	17.57	95V	0.1775	16.86
130V	0.1351	17.56	110V	0.1584	17.42	90V	0.1851	16.66
125V	0.1416	17.70	105V	0.1641	17.23	85V	0.1936	16.46
120V	0.1473	17.68	100V	0.1705	17.05	80V	0.2020	16.16



OTHER DATA, VISIBLE INDICATIONS, ALL AT 120V EXCEPT AS NOTED:

INTENS @ 120V 110.5, @135V 110.5 = 0 %, @80V 110.6 = +0.09%

OPERATION AT LIMITS: @ 135V OK @ 80V OK

VOLTAGE DROP IN OFF-STATE: 3.23V 3.33@ 135V 2.93@ 80V

FAILURE THRESHOLD: ______%, FAILED-STATE IMPEDANCE: ______

TOTAL HARM DIST: 11.5 %, POWER FACTOR: 0.96

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Retest to new format

LED LAMP EVALUATION REPORT

MFR: Prec. Solar SIZE/COLOR: 12" grn PWR CONN push-ons

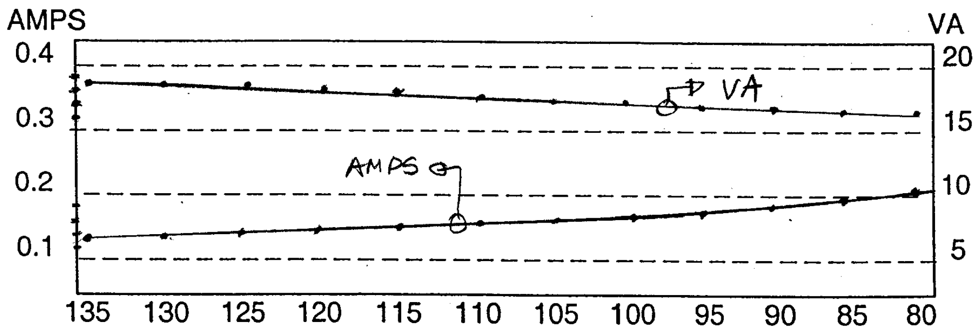
MODEL: 2035 PART NO.:________ S/N: AB0-944

OTHER MFR INFO: 19 watts, 120VAC, 60Hz, 19.3VA mfr 11/00

TESTED BY: JCG DATE: 02/08/02

TWO-WIRE TERMINAL CHARACTERISTICS

VOLTS	AMPS	VA	VOLTS	AMPS	VA	VOLTS	AMPS	VA
135V	0.1382	18.66	115V	0.1541	17.72	95V	0.1793	17.03
130V	0.1414	18.38	110V	0.1592	17.51	90V	0.1880	16.92
125V	0.1452	18.15	105V	0.1651	17.34	85V	0.1979	16.82
120V	0.1495	17.94	100V	0.1717	17.17	80V	0.2092	16.74



OTHER DATA, VISIBLE INDICATIONS, ALL AT 120V EXCEPT AS NOTED:

INTENS @ 120V 158.1, @135V 158.2 = 0 %, @80V 158.3 = 0 %

OPERATION AT LIMITS: @ 135V OK @ 80V OK

VOLTAGE DROP IN OFF-STATE: 3.43V 3.54 @ 135V 3.12 @ 80V

FAILURE THRESHOLD:________%, FAILED-STATE IMPEDANCE:________

TOTAL HARM DIST: 9.9 %, POWER FACTOR: 0.98

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Retest to new format

LED LAMP EVALUATION REPORT

MFR: Prec. Solar SIZE/COLOR: 12" yellow PWR CONN Spade Lugs

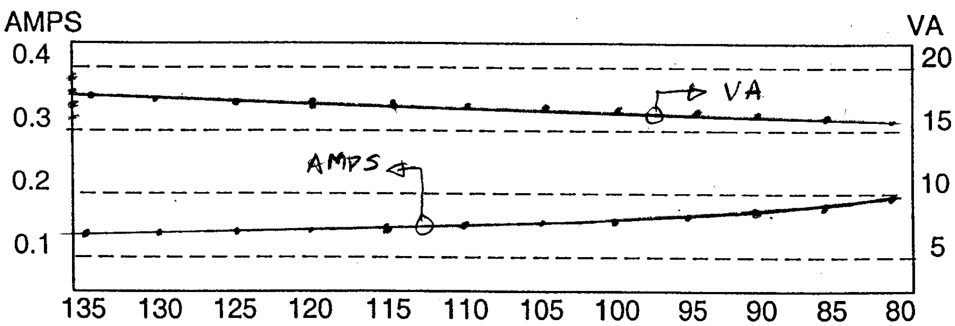
MODEL: 2015 PART NO.:______ S/N: ABO-720

OTHER MFR INFO: 24W, 120VAC, 24.2VA, 60Hz mfr 11/00

TESTED BY: JCG DATE: 02/08/02

TWO-WIRE TERMINAL CHARACTERISTICS

VOLTS	AMPS	VA	VOLTS	AMPS	VA	VOLTS	AMPS	VA
135V	0.132	17.86	115V	0.147	16.88	95V	0.171	16.21
130V	0.135	17.54	110V	0.152	16.74	90V	0.177	15.94
125V	0.138	17.23	105V	0.158	16.60	85V	0.185	15.73
120V	0.142	17.02	100V	0.164	16.39	80V	0.195	15.56



OTHER DATA, VISIBLE INDICATIONS, ALL AT 120V EXCEPT AS NOTED:

INTENS @ 120V 64.5, @135V 64.5 ⇒ 0 %, @80V 64.5 ⇒ 0 %

OPERATION AT LIMITS: @ 135V OK @ 80V OK

VOLTAGE DROP IN OFF-STATE: 3.23V 2.93@80V 3.35@135V

FAILURE THRESHOLD:______%, FAILED-STATE IMPEDANCE:______ not taken

TOTAL HARM DIST: 13.4 %, POWER FACTOR: 0.96 0.7ms

RATED (24.2VA) and OBSERVED (17.02VA) volt-amps differ significantly.

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RETEST OLD LAMPS

LED LAMP EVALUATION REPORT

MFR: Cooper SIZE/COLOR: 12" Red PWR CONN Bared Wires

MODEL: R 1200 PART NO.: ______ S/N: 05200015

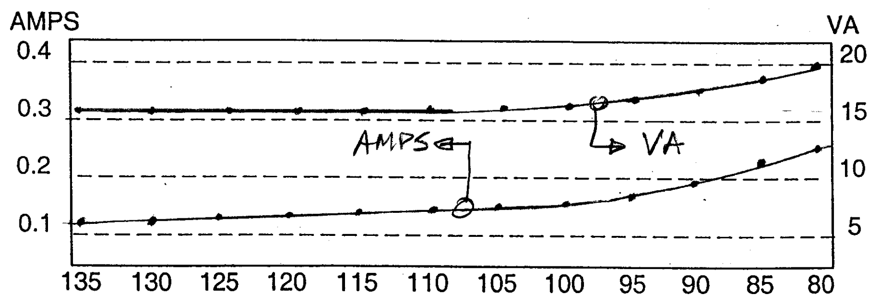
OTHER MFR INFO: 120VAC, 60Hz, 15watts, 18 VA — OLDER LAMPS REC'D DEC 2000

TESTED BY: JCG DATE: 02/07/02

RETESTED TO NEW REPORT FORMAT

TWO-WIRE TERMINAL CHARACTERISTICS

VOLTS	AMPS	VA	VOLTS	AMPS	VA	VOLTS	AMPS	VA
135V	0.115	15.47	115V	0.135	15.53	95V	0.177	16.85
130V	0.119	15.43	110V	0.143	15.70	90V	0.197	17.75
125V	0.123	15.43	105V	0.151	15.89	85V	0.228	19.35
120V	0.129	15.44	100V	0.163	16.30	80V	0.249	19.95



OTHER DATA, VISIBLE INDICATIONS, ALL AT 120V EXCEPT AS NOTED:

INTENS @ 120V 103.2, @135V 103.4 ⇒ +0.2 %, @80V 102.8 ⇒ -0.4 %

OPERATION AT LIMITS: @ 135V OK @ 80V OK

VOLTAGE DROP IN OFF-STATE: 6.11V @120V ✓ sudden drop < 51.3V ? @ 135V ← 6.6V @ 132V 4.46 @ 80V — Corrected in new lamps

FAILURE THRESHOLD: ______ %, FAILED-STATE IMPEDANCE: ______

TOTAL HARM DIST: 11.0 %, POWER FACTOR: 0.97

Recheck for new design → Odd Behavior; Turn-off @ 135V, get 51V off-state; Turn-off @ 132V, get 6.6V off-state (still OK for Reds)

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RETEST OLD COOPER LAMPS

LED LAMP EVALUATION REPORT

MFR: COOPER SIZE/COLOR: 12" GRN PWR CONN BARED Ends

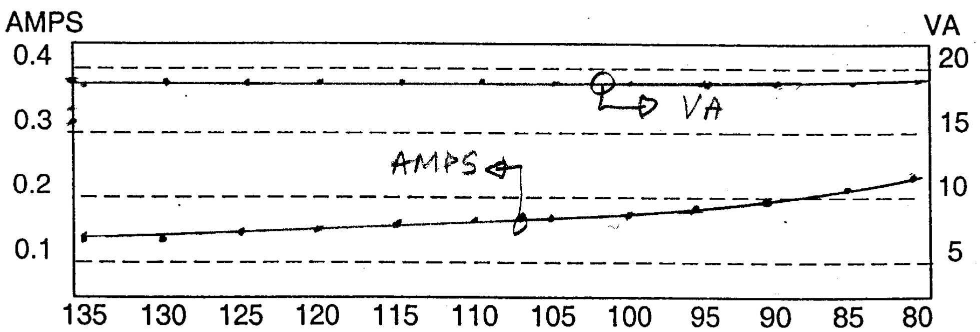
MODEL: G1300 PART NO.: S/N: 0520004

OTHER MFR INFO: 120VAC, 60Hz, 20 watts

TESTED BY: JCG DATE: 02/07/02

TWO-WIRE TERMINAL CHARACTERISTICS

VOLTS	AMPS	VA	VOLTS	AMPS	VA	VOLTS	AMPS	VA
135V	0.139	18.71	115V	0.158	18.19	95V	0.187	17.73
130V	0.143	18.63	110V	0.164	18.07	90V	0.198	17.85
125V	0.148	18.51	105V	0.171	17.91	85V	0.212	17.99
120V	0.153	18.36	100V	0.178	17.78	80V	0.228	18.21



OTHER DATA, VISIBLE INDICATIONS, ALL AT 120V EXCEPT AS NOTED:

INTENS @ 120V 249, @135V 250 → +0.4 %, @80V 250 → +0.4 %

OPERATION AT LIMITS: @ 135V OK @ 80V OK

VOLTAGE DROP IN OFF-STATE: 6.13V < 57.9 @135V, 6.51 @130V, 4.58 @80V ← corrected in new lamps

FAILURE THRESHOLD: ____%, FAILED-STATE IMPEDANCE: ____ not taken

TOTAL HARM DIST: 12.7 %, POWER FACTOR: 0.95

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old lamps
Retest – new format

LED LAMP EVALUATION REPORT

MFR: COOPER SIZE/COLOR: 12" yel PWR CONN Bared Ends

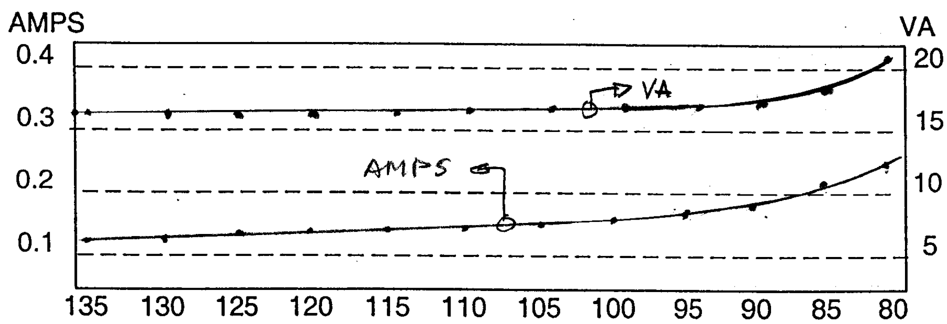
MODEL: Y 1100 PART NO.:______ S/N: 052 00007

OTHER MFR INFO: 120VAC, 60Hz, 13 watts

TESTED BY: JCG DATE: 02/07/02

TWO-WIRE TERMINAL CHARACTERISTICS

VOLTS	AMPS	VA	VOLTS	AMPS	VA	VOLTS	AMPS	VA
135V	0.1196	16.15	115V	0.1404	16.15	95V	0.1754	16.66
130V	0.1243	16.16	110V	0.1477	16.25	90V	0.1878	16.90
125V	0.1290	16.13	105V	0.1533	16.31	85V	0.2127	18.08
120V	0.1345	16.14	100V	0.1646	16.46	80V	0.2543	20.34



OTHER DATA, VISIBLE INDICATIONS, ALL AT 120V EXCEPT AS NOTED:

INTENS @ 120V 126.6, @135V 128.5 = +1.5 %, @80V 109.0 = -13.9 %

OPERATION AT LIMITS: @ 135V OK @ 80V OK

VOLTAGE DROP IN OFF-STATE: 6.30 7.36 @ 135V 4.40 @ 80V

FAILURE THRESHOLD:______%, FAILED-STATE IMPEDANCE:______ not tested

TOTAL HARM DIST: 8.8 %, POWER FACTOR: 0.965

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new lamps 01/28/02

LED LAMP EVALUATION REPORT

MFR: COOPER SIZE/COLOR: 12" Red PWR CONN SPADE LUGS

MODEL: — CATALOG # PART NO.: CLB12RAS S/N: 00000002

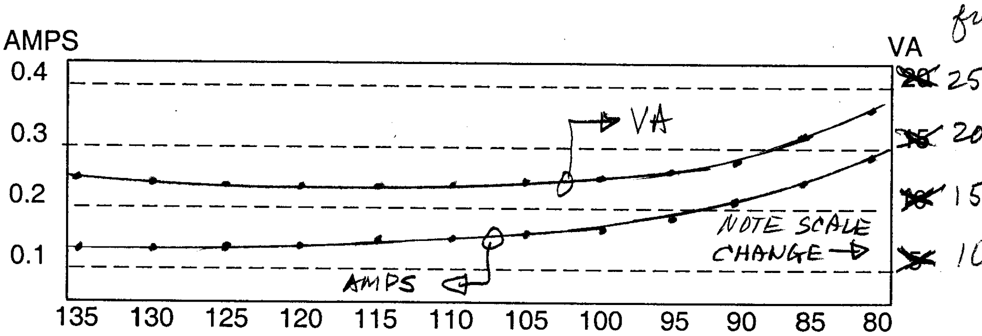
OTHER MFR INFO: 120V, 60Hz, 15watts LENS TINTED RED MFR DATE: 01/23/02

TESTED BY: JCG DATE: 1/30/02

TWO-WIRE TERMINAL CHARACTERISTICS

VOLTS	AMPS	VA	VOLTS	AMPS	VA	VOLTS	AMPS	VA
135V	0.129	17.42	115V	0.147	16.91	95V	0.189	17.96
130V	0.132	17.16	110V	0.154	16.94	90V	0.209	18.81
125V	0.136	17.00	105V	0.163	17.12	85V	0.241	20.49
120V	0.141	16.92	100V	0.174	17.40	80V	0.288	23.04

← Buzzing Noise from Power Converter



OTHER DATA, VISIBLE INDICATIONS, ALL AT 120V EXCEPT AS NOTED:

INTENS @ 120V 112.6, @135V 112.8 ⇒ 0+ %, @80V 108.0 ⇒ -4 % ✓

OPERATION AT LIMITS: @ 135V OK @ 80V OK ✓

VOLTAGE DROP IN OFF-STATE: 5.78V 6.37@135V 4.53v@80v ✓

FAILURE THRESHOLD: ____%, FAILED-STATE IMPEDANCE: ____ not performed

TOTAL HARM DIST: 10.0 %, POWER FACTOR: 0.99 ✓

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New Lamps 01/28/02

LED LAMP EVALUATION REPORT

MFR: COOPER SIZE/COLOR: 12" Green PWR CONN SPADE LUGS

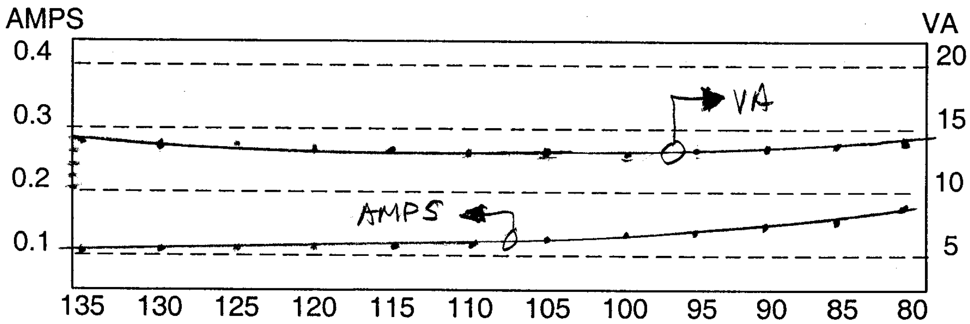
MODEL: —— CATALOG # PART NO.: CLB 12GAS S/N: 00000000

OTHER MFR INFO: 120V, 60Hz, 15 watts, TINTED LENS (GRN) MFR DATE: 01/23/02

TESTED BY: JCG DATE: 01/30/02

TWO-WIRE TERMINAL CHARACTERISTICS

VOLTS	AMPS	VA	VOLTS	AMPS	VA	VOLTS	AMPS	VA
135V	0.103	13.91	115V	0.114	13.11	95V	0.136	12.92
130V	0.105	13.65	110V	0.117	12.87	90V	0.146	13.14
125V	0.108	13.50	105V	0.123	12.92	85V	0.158	13.43
120V	0.110	13.20	100V	0.129	12.90	80V	0.175	14.00



OTHER DATA, VISIBLE INDICATIONS, ALL AT 120V EXCEPT AS NOTED:

INTENS @ 120V 138.3, @135V 138.4 = 0+ %, @80V 138.3 = 0 % ✓

OPERATION AT LIMITS: @ 135V OK @ 80V OK ✓

VOLTAGE DROP IN OFF-STATE: 4.43V 6.5 @ 135V 4.6 @ 80V ✓

FAILURE THRESHOLD: ____%, FAILED-STATE IMPEDANCE: ____ not performed

TOTAL HARM DIST: 11.2 %, POWER FACTOR: 1.00 ✓

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new lamps
01/28/02

LED LAMP EVALUATION REPORT

MFR: COOPER SIZE/COLOR: 12" yel PWR CONN Spade Lugs

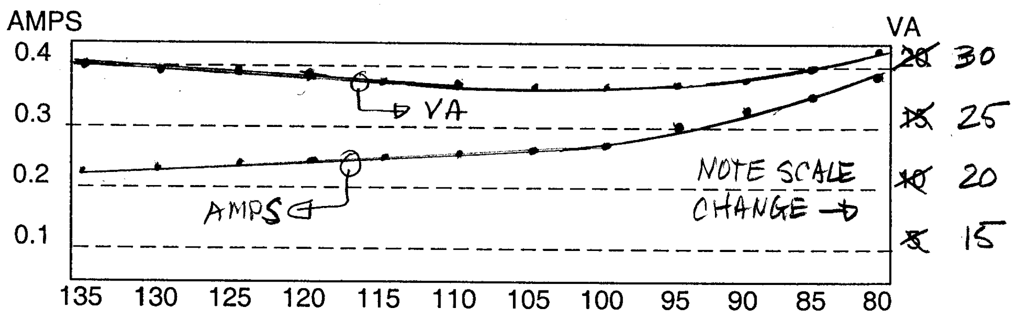
MODEL: — PART NO.: CATALOG # CLB12YAS S/N: 0000 0001

OTHER MFR INFO: 120V, 60Hz, 15watts TINTED LENS (AMBER) MFG DATE 01/23/02

TESTED BY: JCG DATE: 01/30/02

TWO-WIRE TERMINAL CHARACTERISTICS

VOLTS	AMPS	VA	VOLTS	AMPS	VA	VOLTS	AMPS	VA
135V	0.222	29.97	115V	0.253	29.10	95V	0.301	28.60
130V	0.230	29.90	110V	0.261	28.71	90V	0.323	29.07
125V	0.237	29.63	105V	0.271	28.46	85V	0.354	30.09
120V	0.246	29.52	100V	0.283	28.30	80V	0.391	31.28



OTHER DATA, VISIBLE INDICATIONS, ALL AT 120V EXCEPT AS NOTED:

INTENS @ 120V 88.5, @135V 88.5 ⇒ 0 %, @80V 88.4 ⇒ 0⁻ % ✓

OPERATION AT LIMITS: @ 135V OK @ 80V OK ✓

VOLTAGE DROP IN OFF-STATE: 5.40V 6.0V @135V 4.4V @80V ✓

FAILURE THRESHOLD: ____ %, FAILED-STATE IMPEDANCE: ____ not performed

TOTAL HARM DIST: 13.0 %, POWER FACTOR: 0.98+ ✓

measured VA is not compatible with labeled 15watts (mis-labeled)

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newer group

LED LAMP EVALUATION REPORT Re-Test

MFR: LEOTEK SIZE/COLOR: 12" Red PWR CONN SPADE LUGS

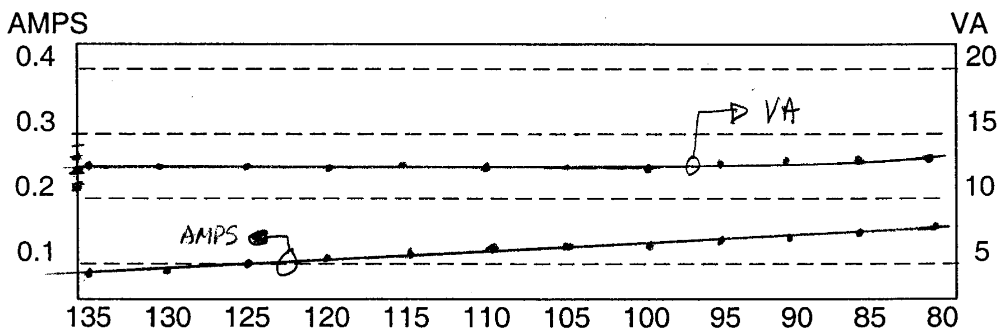
MODEL: — PART NO.: TSL-12R-MG S/N: TO10599994

OTHER MFR INFO: 80-135VAC, 50/60Hz, 11watts, 11.6VA

TESTED BY: JCG DATE: 01/31/02

TWO-WIRE TERMINAL CHARACTERISTICS

VOLTS	AMPS	VA	VOLTS	AMPS	VA	VOLTS	AMPS	VA
135V	0.093	12.56	115V	0.109	12.54	95V	0.132	12.54
130V	0.096	12.48	110V	0.114	12.54	90V	0.140	12.60
125V	0.100	12.50	105V	0.119	12.50	85V	0.149	12.67
120V	0.104	12.48	100V	0.125	12.50	80V	0.161	12.88



OTHER DATA, VISIBLE INDICATIONS, ALL AT 120V EXCEPT AS NOTED:

INTENS @ 120V 47.9, @135V 48.0 = +0.2 %, @80V 47.6 = -0.6 %

OPERATION AT LIMITS: @ 135V OK @ 80V OK

VOLTAGE DROP IN OFF-STATE: 5.8V 6.3-@135V 4.3 @80V

FAILURE THRESHOLD:_______%, FAILED-STATE IMPEDANCE:_______

TOTAL HARM DIST: 11.0 %, POWER FACTOR: 0.999

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LED LAMP EVALUATION REPORT

MFR: Leotek SIZE/COLOR: 12" Grn PWR CONN Spade Lugs

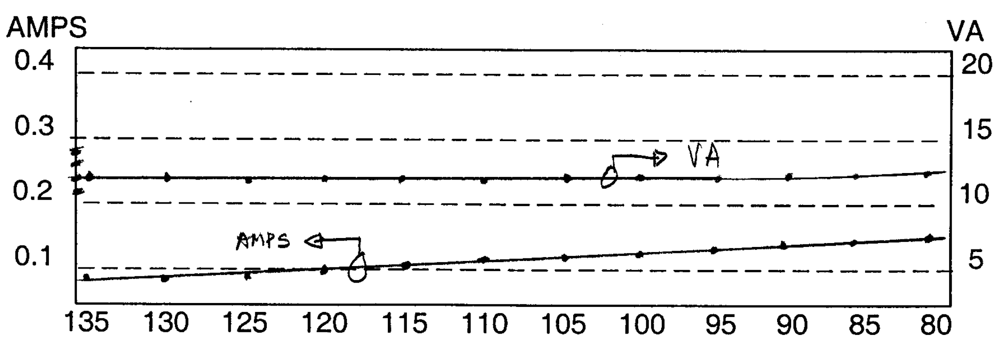
MODEL: — PART NO.: TSL-12G-MG S/N: T0104 99994

OTHER MFR INFO: 80-135VAC, 50/60Hz, 11.7watts, 11.9 VA

TESTED BY: JCG DATE: 01/31/02

TWO-WIRE TERMINAL CHARACTERISTICS

VOLTS	AMPS	VA	VOLTS	AMPS	VA	VOLTS	AMPS	VA
135V	0.090	12.15	115V	0.103	11.85	95V	0.125	11.88
130V	0.092	11.96	110V	0.108	11.88	90V	0.133	11.97
125V	0.094	11.75	105V	0.113	11.87	85V	0.142	12.07
120V	0.099	11.88	100V	0.119	11.90	80V	0.153	12.24



OTHER DATA, VISIBLE INDICATIONS, ALL AT 120V EXCEPT AS NOTED:

INTENS @ 120V 64.5, @135V 64.6 ⇒ +0.1 %, @80V 64.3 ⇒ -0.3 %

OPERATION AT LIMITS: @ 135V OK @ 80V OK

VOLTAGE DROP IN OFF-STATE: 5.80 V 6.40 @ 135V 4.25 @ 80V

FAILURE THRESHOLD:______%, FAILED-STATE IMPEDANCE:______

TOTAL HARM DIST: 11.6 %, POWER FACTOR: 0.997

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LED LAMP EVALUATION REPORT Re-test

MFR: Leotek SIZE/COLOR: 12" Yell PWR CONN Spade Lugs

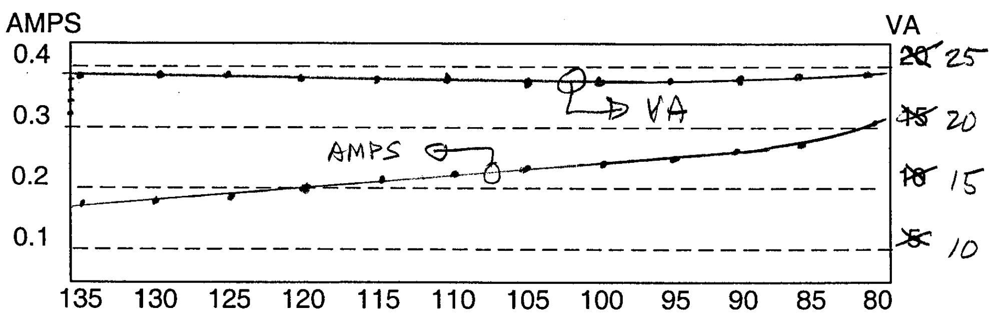
MODEL: — PART NO.: TSL-12Y-MF S/N: T0104999O

OTHER MFR INFO: 80-135 VAC, 50/60 Hz, 21.3 watts, 22.4 VA

TESTED BY: JCG DATE: 01/31/02

TWO-WIRE TERMINAL CHARACTERISTICS

VOLTS	AMPS	VA	VOLTS	AMPS	VA	VOLTS	AMPS	VA
135V	0.180	24.30	115V	0.209	24.04	95V	0.253	24.04
130V	0.187	24.31	110V	0.218	23.98	90V	0.267	24.03
125V	0.194	24.25	105V	0.228	23.94	85V	0.283	24.31
120V	0.201	24.12	100V	0.240	24.00	80V	0.304	24.32



OTHER DATA, VISIBLE INDICATIONS, ALL AT 120V EXCEPT AS NOTED:

INTENS @ 120V ~~100.0~~ 94.5, @135V ~~100.4~~ 94.7 = +0.2 %, @80V ~~99.4~~ 94.3 = -0.2 % long slow drift in intensity

OPERATION AT LIMITS: @ 135V OK @ 80V OK

VOLTAGE DROP IN OFF-STATE: 7.10 V 8.0 @ 135V 5.5 @ 80V

FAILURE THRESHOLD: ________%, FAILED-STATE IMPEDANCE: ________

TOTAL HARM DIST: 17.5 %, POWER FACTOR: 1.0

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LED LAMP EVALUATION REPORT

MFR: Leotek SIZE/COLOR: 12" Red PWR CONN Screw/Spade

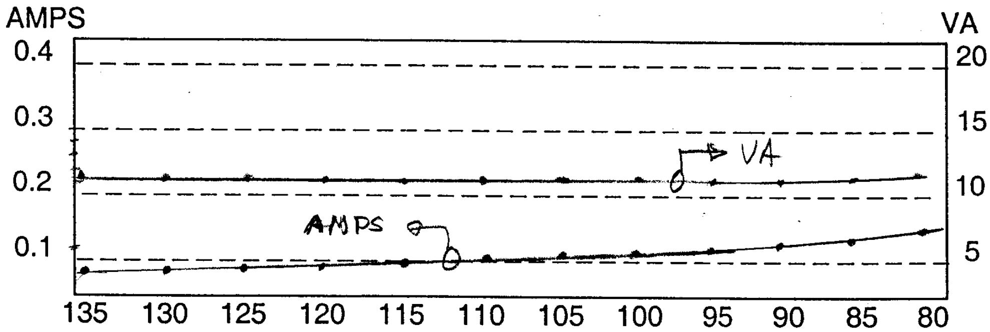
MODEL: ______ PART NO.: TSL-12R-MG S/N: T010599995

OTHER MFR INFO: 80-135VAC/50/60Hz / 11 watts, 11.6VA

TESTED BY: JCG RETEST - NEW REPORT FORM DATE: 02/04/02

TWO-WIRE TERMINAL CHARACTERISTICS

VOLTS	AMPS	VA	VOLTS	AMPS	VA	VOLTS	AMPS	VA
135V	0.085	11.48	115V	0.099	11.39	95V	0.119	11.31
130V	0.088	11.44	110V	0.103	11.33	90V	0.126	11.34
125V	0.092	11.50	105V	0.107	11.24	85V	0.135	11.48
120V	0.094	11.28	100V	0.113	11.30	80V	0.146	11.68



OTHER DATA, VISIBLE INDICATIONS, ALL AT 120V EXCEPT AS NOTED:

INTENS @ 120V 143.6, @135V 143.7 = +0.07 %, @80V 143.5 = -0.07 %

OPERATION AT LIMITS: @ 135V OK @ 80V OK

VOLTAGE DROP IN OFF-STATE: 5.86 V 6.37V @ 135V 4.39V @ 80V

FAILURE THRESHOLD: ______ %, FAILED-STATE IMPEDANCE: ______

TOTAL HARM DIST: 11.7 %, POWER FACTOR: >0.95

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LED LAMP EVALUATION REPORT

MFR: Leotek SIZE/COLOR: 12" Grn PWR CONN Screw/Lugs

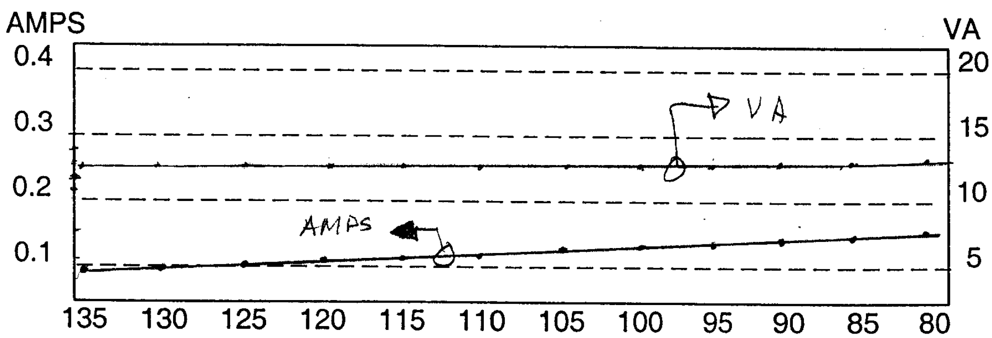
MODEL: ______ PART NO.: TSL-12G-MG S/N: T010499995

OTHER MFR INFO: 80-135VAC/50/60Hz/ 11.7watts, 11.9VA

TESTED BY: JCG RETEST- NEW REPORT FORM DATE: 02/04/02

TWO-WIRE TERMINAL CHARACTERISTICS

VOLTS	AMPS	VA	VOLTS	AMPS	VA	VOLTS	AMPS	VA
135V	0.096	12.96	115V	0.111	12.77	95V	0.135	12.83
130V	0.099	12.87	110V	0.116	12.76	90V	0.144	12.96
125V	0.102	12.75	105V	0.122	12.81	85V	0.153	13.01
120V	0.107	12.84	100V	0.127	12.70	80V	0.165	13.20



OTHER DATA, VISIBLE INDICATIONS, ALL AT 120V EXCEPT AS NOTED:

INTENS @ 120V 112.6, @135V 112.6 ⇒ 0 %, @80V 112.6 ⇒ 0 %

OPERATION AT LIMITS: @ 135V OK @ 80V OK

VOLTAGE DROP IN OFF-STATE: 5.87 6.45@135V 4.37@80V

FAILURE THRESHOLD: ______%, FAILED-STATE IMPEDANCE: ______

TOTAL HARM DIST: 7.8 %, POWER FACTOR: 0.97

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LED LAMP EVALUATION REPORT

MFR: Leotek SIZE/COLOR: 12" Yel PWR CONN Screw/ Spade

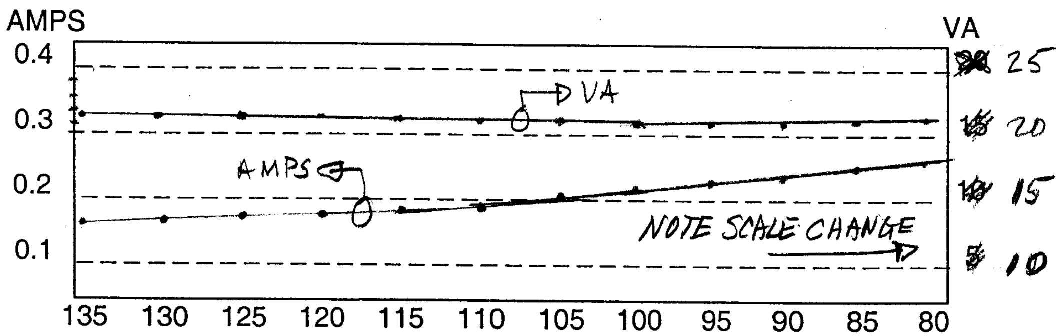
MODEL: — PART NO.: TSL-12Y-MF S/N: TØ1Ø499991

OTHER MFR INFO: 80-135VAC/50-60Hz/ 21.3 Watts/ 22.4 VA

TESTED BY: JCG RETEST - NEW REPORT FORM DATE: 02/04/02

TWO-WIRE TERMINAL CHARACTERISTICS

VOLTS	AMPS	VA	VOLTS	AMPS	VA	VOLTS	AMPS	VA
135V	0.161	21.74	115V	0.186	21.39	95V	0.225	21.34
130V	0.166	21.58	110V	0.195	21.45	90V	0.238	21.42
125V	0.173	21.63	105V	0.204	21.42	85V	0.254	21.59
120V	0.179	21.48	100V	0.214	21.40	80V	0.273	21.84



OTHER DATA, VISIBLE INDICATIONS, ALL AT 120V EXCEPT AS NOTED:

INTENS @ 120V 111.4, @135V 111.9 = +0.4 %, @80V 110.4 = -0.9 %

OPERATION AT LIMITS: @ 135V OK @ 80V OK

VOLTAGE DROP IN OFF-STATE: 5.89V 6.46 @135V 4.35 @80V

FAILURE THRESHOLD: ____ %, FAILED-STATE IMPEDANCE: ____

TOTAL HARM DIST: 17.8 %, POWER FACTOR: > 0.95

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LED LAMP EVALUATION REPORT

MFR: GELCORE SIZE/COLOR: 12" Red PWR CONN Push-On

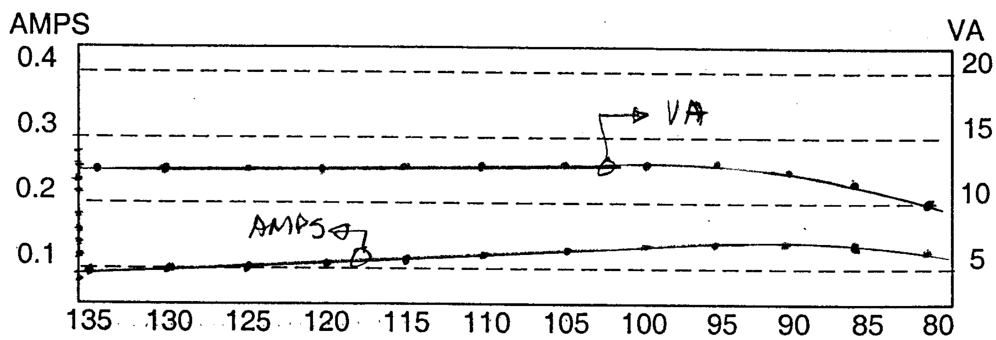
MODEL: DI2RA4 PART NO.: ______ S/N: 547227

OTHER MFR INFO: 9.2VA, 120V, 60Hz, 9 watts, 0.077 A nom MS:VA D/C:0035

TESTED BY: JCG DATE: 14 Feb 02

TWO-WIRE TERMINAL CHARACTERISTICS

VOLTS	AMPS	VA	VOLTS	AMPS	VA	VOLTS	AMPS	VA
135V	0.096	12.96	115V	0.113	13.00	95V	0.138	13.11
130V	0.099	12.87	110V	0.118	12.99	90V	0.138	12.42
125V	0.103	12.88	105V	0.124	13.02	85V	0.132	11.22
120V	0.107	12.84	100V	0.130	13.00	80V	0.125	10.00



OTHER DATA, VISIBLE INDICATIONS, ALL AT 120V EXCEPT AS NOTED:

INTENS @ 120V 144, @135V 144 = 0 %, @80V 114.0 = -20 %

OPERATION AT LIMITS: @ 135V OK @ 80V OK

VOLTAGE DROP IN OFF-STATE: 5.64V 0.15 @ 135V 4.31 @ 80V

FAILURE THRESHOLD: ______ %, FAILED-STATE IMPEDANCE: ______

TOTAL HARM DIST: 14.3 %, POWER FACTOR: 0.997

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LED LAMP EVALUATION REPORT

MFR: GELCORE SIZE/COLOR: 12" Grn PWR CONN push-on

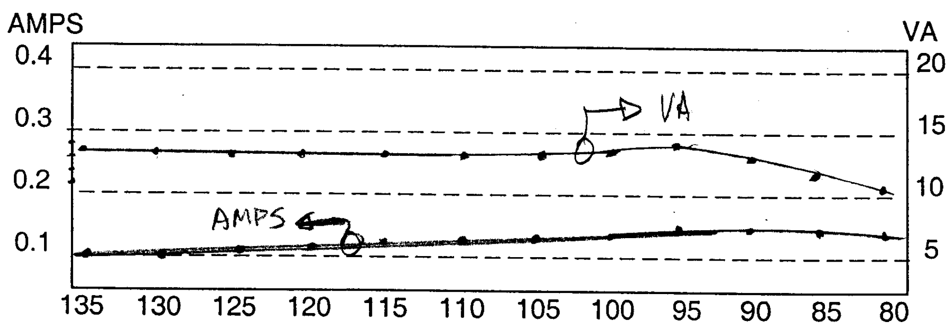
MODEL: D12GA4 PART NO.:______ S/N: 547264

OTHER MFR INFO: 11.9VA, 120V, 60Hz, 11.8W, 0.098A nom MS/VA D/E:0035

TESTED BY: JCG DATE: 14 Feb 02

TWO-WIRE TERMINAL CHARACTERISTICS

VOLTS	AMPS	VA	VOLTS	AMPS	VA	VOLTS	AMPS	VA
135V	0.101	13.635	115V	0.118	13.57	95V	0.149	14.16
130V	0.104	13.52	110V	0.123	13.53	90V	0.143	12.87
125V	0.107	13.38	105V	0.129	13.55	85V	0.138	11.73
120V	0.113	13.56	100V	0.136	13.60	80V	0.131	10.48



OTHER DATA, VISIBLE INDICATIONS, ALL AT 120V EXCEPT AS NOTED: starts down @ 93V

INTENS @ 120V 178.1, @135V 178.0 = -0.05 %, @80V 144.8 = -18.7 % @90V 170 @85V 158

OPERATION AT LIMITS: @ 135V OK @ 80V OK

VOLTAGE DROP IN OFF-STATE: 5.46 6.00@135V 4.16@80V

FAILURE THRESHOLD:______%, FAILED-STATE IMPEDANCE:______

TOTAL HARM DIST: 7.4 %, POWER FACTOR: 0.999

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LED LAMP EVALUATION REPORT

MFR: GELCORE SIZE/COLOR: 12" Red PWR CONN Push-Ons

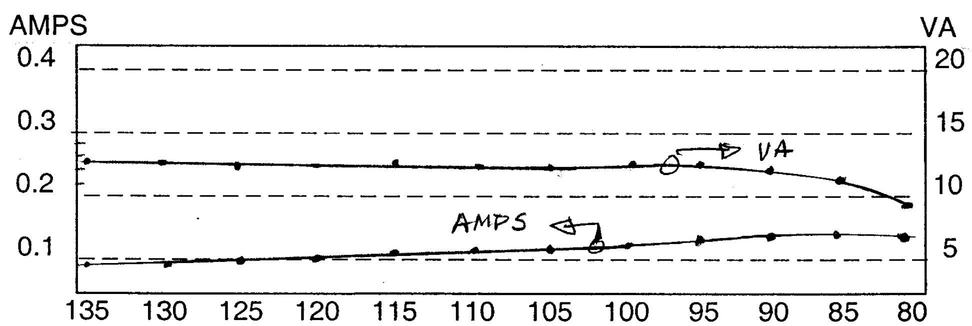
MODEL: D12RA4 PART NO.:________ S/N: 547226

OTHER MFR INFO: 9.2VA, 120V, 60Hz, 9watts, 0.077A nom MSIVA D/C: D035

TESTED BY: JCG DATE: 15 Feb '02

TWO-WIRE TERMINAL CHARACTERISTICS

VOLTS	AMPS	VA	VOLTS	AMPS	VA	VOLTS	AMPS	VA
135V	0.094	12.69	115V	0.108	12.42	95V	0.132	12.54
130V	0.095	12.35	110V	0.113	12.43	90V	0.134	12.05
125V	0.098	12.25	105V	0.118	12.39	85V	0.130	11.05
120V	0.102	12.24	100V	0.125	12.50	80V	0.124	9.92



OTHER DATA, VISIBLE INDICATIONS, ALL AT 120V EXCEPT AS NOTED:

INTENS @ 120V 125.3, @135V 125.6 = +0.2%, @80V 103.2 = -17.6 %

OPERATION AT LIMITS: @ 135V OK @ 80V OK

VOLTAGE DROP IN OFF-STATE: 5.57V 6.02 @ 135V 4.25 @ 80V

FAILURE THRESHOLD: between 20 & 24 %, FAILED-STATE IMPEDANCE: > 1 megohm

TOTAL HARM DIST: 13.7 %, POWER FACTOR: 0.99

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LED LAMP EVALUATION REPORT

MFR: GEL CORE SIZE/COLOR: 12" grn PWR CONN push-on

MODEL: D12GA4 PART NO.: ______ S/N: 547263

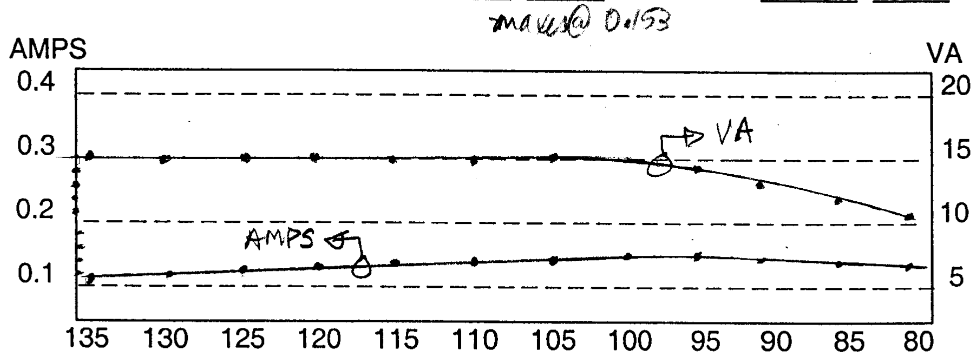
OTHER MFR INFO: 11.9VA, 120V, 60Hz, 11.8W, 0.098A nom MS/VA D/C: 0035

TESTED BY: JCG DATE: 14 Feb 02

TWO-WIRE TERMINAL CHARACTERISTICS

VOLTS	AMPS	VA	VOLTS	AMPS	VA	VOLTS	AMPS	VA
135V	0.111	14.99	115V	0.130	14.95	95V	0.150	14.25
130V	0.115	14.95	110V	0.136	14.96	90V	0.145	13.05
125V	0.120	15.00	105V	0.143	15.02	85V	0.138	11.73
120V	0.125	15.00	100V	0.150	15.00	80V	0.132	10.56

max @ 0.153



OTHER DATA, VISIBLE INDICATIONS, ALL AT 120V EXCEPT AS NOTED:

INTENS @ 120V 160.7, @135V 160.5 = -0.1 %, @80V 126 = -21.6%

OPERATION AT LIMITS: @ 135V OK @ 80V OK

VOLTAGE DROP IN OFF-STATE: 5.57V 6.09 @ 135V 4.31 @ 80V

FAILURE THRESHOLD: >50 %, FAILED-STATE IMPEDANCE: not available

TOTAL HARM DIST: 7.4 %, POWER FACTOR: 0.999