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Photocontrol data acquisition system for lamp life prediction in high pressure sodium lighting

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PHOTOCONTROL DATA ACQUISITION SYSTEM FOR LAMP LIFE PREDICTION IN HIGH PRESSURE SODIUM LIGHTING

by

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For the College	

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ABSTRACT

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PHOTOCONTROL DATA ACQUISITION SYSTEM FOR LAMP LIFE PREDICTION IN HIGH PRESSURE SODIUM LIGHTING
2003/04
Dr. Peter Mark Jansson
Master of Science in Engineering

This thesis begins with a brief historical account of high intensity discharge (HID) lighting. It begins in the seventeenth century and concludes with the modern high pressure sodium (HPS) lamp, which has become the most widespread HID lighting source due to its high efficacy (Lumens/Watt) and acceptable color rendition. Following a more in-depth discussion on the HPS lamp, a means of estimating the arc tube voltage of an HPS lamp from the confines of a photocontrol is introduced. This technique is implemented as part of a 'smart' photocontrol data acquisition unit that functions as part of a proposed practical asset management system that has the capability to provide the lamp life data stored in the photocontrol to utility companies through wireless communication. The monetary and physical advantages of this system are discussed along with the accomplishments associated with this thesis and recommendations for future work to help bring this concept to fruition.

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NOTICE

This thesis is of proprietary and confidential nature to the author, Rowan University, and Lighting Consortium Members (PHI Lighting – a.k.a Steve Steffel, AEL/DTL, and PSE&G). This document shall not be copied or reproduced in any way.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF EQUATIONS

LIST OF TABLES

CHAPTER 1
HIGH INTENSITY DISCHARGE LAMPS

1.1 History

High Intensity Discharge (HID) lighting has become a widely used technology and provides reasonably efficient lighting for modern society. Today, it is very common for High Pressure Sodium (HPS) lamps to light roads and highways at night. However, over three centuries of research have been involved in bringing electric discharge lighting to the current point. Beginning with the inspiration of a single spark of static electricity, a plethora of scientific advancements and inventions eventually resulted in the development of today's high temperature ceramic material surrounding a vacuum-sealed plasma arc. Present HID lighting technology can achieve efficacies of up to 64% of the theoretical maximum 220 Lumens per Watt [1]. Though this triumphs over the popular 16% efficient incandescent lamp, clearly, there is still room for improvement.

1.1.1 *The Dawn of Electric Discharge Lighting*

The first significant step toward generating light from electricity was made in the middle of the seventeenth century by Otto von Guericke. In 1660 he successfully invented the first electric generator, which used friction to produce static electricity [2]. The device contained a large sulfur sphere mounted on a long shaft inside a glass globe. The ball was manually rotated at high speed with a hand crank and produced a static electric spark when a cloth was rubbed against it, thus Guericke became the first person to witness electroluminescence from a man-made machine [3]. At that point in time, however, he did not realize that this effect was static electricity. His invention was used for entertainment and parlor tricks as during that time no one had ever seen anything like it.

In 1709 Francis Hawksbee invented a device that produced static electricity using a glass sphere, rather than a sulfur sphere as Guericke had done. This machine produced a much larger amount of light. The greatest results were achieved when most of the air was evacuated from the globe. This invention of Hawksbee was the "forerunner of fluorescent lighting and the neon signs of today" [3].

The first person to witness the light produced by the discharge of electricity between two carbon electrodes was Humphry Davy. He observed this in 1800 and recalled the experience twelve years later as follows:

> *"When pieces of charcoal, about an inch long and one-sixth of an inch in diameter, were brought near each other (within the thirtieth or fortieth part of an inch), a bright spark was produced..., and by which drawing the points from each other constant discharge took place through the heated air, in a space at least equal to four inches, producing a most brilliant ascending arch of light."* [4]

The arc lighting that Davy described is not actually caused by the electric arc itself. The light emanates from the white-hot carbon electrodes heated by the electric charge. It was actually more of a form of incandescent lighting [5]. This crude artificial source of light would soon be morphed into practical technologies that continue to provide light along highways and in homes and buildings today.

1.1.2 *The Geissler Tube*

The next major step toward high intensity discharge lighting was made by Heinrich Geissler. Geissler was born in Germany in the village of Igelshieb in Saxe-Meiningen on

May 24, 1814 and educated as an artist and a glassblower. Geissler settled in Bonn, Germany in 1854 and quickly gained a reputation for his skill and ingenuity in the fabrication of chemical and physical instrumentation. Geissler's most well-known accomplishment occurred in 1856 when he invented the Geissler Tube [6]. This was an extremely significant step toward achieving efficient electric discharge lighting. The tube, seen in Figure 1.1, exhibited the phenomena associated with the discharge of electricity through highly rarified vapors and gases. When an electric charge of the appropriate magnitude is applied to a tube filled with a particular gas it ionizes. To provide light, one must ionize a gas that emits radiation in the visible light spectrum.

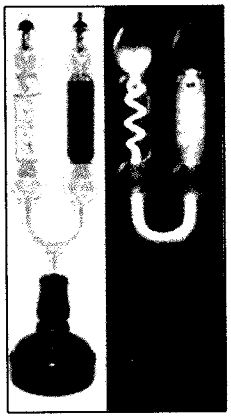
Figure 1.1: *Geissler Tube*

1.1.3 *Sir William Crookes and "Radiant Matter"*

Another important contributor to the development of the electric discharge lamp was Sir William Crookes (see Figure 1.2 [7]). Crookes was born in London on June 17, 1832 as the eldest son of Joseph Crookes and his second wife Mary Scott. His scientific career began at the age of 15 when he enrolled in the Royal College of Chemistry in Hanover Square, London, under August Wilhelm von Haufmann. Throughout his career Crookes had been president of the Chemical Society, Institute of Electrical Engineers, Society of Chemical Industry, British Association, and the Royal Society [8].

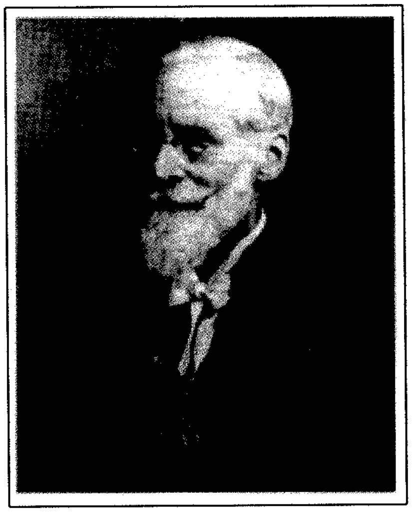
Figure 1.2: *Sir William Crookes (1832-1919)*

One of William Crookes' fundamental research endeavors was the passage of an electric discharge through rarefied gases at low pressures. His breakthrough discovery occurred when he observed that an electric discharge through a rarefied gas causes the dark space around the cathode (negative electrode) to extend, while rays, now known as cathode rays, are emitted from the electrode. His investigation of the properties of these rays deduced that they travel in straight lines, cause phosphorescence in objects upon which they impinge, and their impact produces great heat. He believed that he had discovered a fourth state of matter, which he called radiant matter. This "radiant matter" is a subatomic phenomena identified today as plasma. The results he obtained in 1879 were poor and inconsistent because it had not yet been discovered that there is a certain desirable pressure needed to maximize performance based on the type of gas used [6].

1.1.4 *Conclusion of a Decade of Silence*

Crookes' inconsistent discharge tube results discouraged further work in discharge lamp technology. By 1880, the newly invented incandescent light bulb was superior, more convenient, and cheaper and easier to manufacture and sell. In 1890, enthusiasm for discharge lighting was again increased when Thomas Edison field-tested a Crookes vacuum tube containing calcium tungstate which fluoresced when an electric discharge was passed. During March of 1893 an American electrical journal predicted success for the new technology with the following quote:

> *"these tubes are now receiving the earnest attention of electrical experimenters with the fond and not chimerical hope that in the illumination of these tubes lies the desired secret of practical lighting by glowworm or phosphorescent light – light without heat."* [9]

In 1895 the first official public acknowledgement of X-rays by William Conrad Roentgen aroused even more interest in the various related fields of cathode rays, vacuum tubes, gaseous discharge, and fluorescence. One of the greatest instruments that came from this time period is Edison's Fluoroscope. When used in conjunction with a calcium tungstate screen, the Fluoroscope can be used to capture X-ray images. Amongst all of the progress in electric discharge lighting during this time, there was not a single commercially successful product claimed by 1896.

1.1.5 *The Moore Lamp*

Daniel McFarlan Moore, pictured in Figure 1.3 [10], was a former Edison Electric employee who had become interested in electric discharge tubes in 1891. He thought the incandescent lamp was "too small, too hot, and too red." Moore desired a lamp that would give a cool, efficient, balanced, white light like the sun, rather than the carbon filament lamp, which was too strong in the reds and too weak in the blues. This fundamental problem realized by Moore continues to persist today due to the high temperatures required to achieve adequate light from a tungsten filament [6].

Figure 1.3: *Daniel McFarlan Moore (1880-1940)*

Upon leaving General Electric (GE, formerly Edison Electric) in 1894, he obtained financial backing and founded the Moore Electric Company and the Moore Light Company. He then went on to develop and manufacture the first commercial product to make use of the Geissler Tube. The first demonstrations featured two tubes. The first was 7' long and 2" in diameter and the second tube was 9' long and 2 ½" in diameter. They operated on a 110-volt DC power supply. The color rendition and efficiency of the lamps were fantastic judging by the standards of the day, however, a short lamp life haunted Moore as it did his predecessors. After several years of work Moore overcame this dilemma with a built-in automatic valve. The valve permitted gas flow into the tube when pressure became too low. As the gas pressure inside of the tube dropped below the standard one-one thousandth of an atmosphere, current flow was increased. The augmented current flow strengthened the field of an electromagnet; as a result iron wires mounted in a glass tube floating in mercury were lifted. As the iron rose, the mercury level was lowered, thus exposing a piece of carbon through which the gas could escape until the desired pressure was sustained [6].

Moore's lamps, using nitrogen gas, had an efficacy of approximately 10 Lumens per Watt. The tube was employed for commercial use, powered by AC, and required a step-up transformer to achieve the 16,000 volts needed to sustain the arc given a 110-volt line potential. Even though it was expensive to install, complicated, and required high operating voltages, the lamp found restricted use in stores, offices, and similar general lighting applications such as photography and advertising. The most efficient incandescent lamp of the day (1904) used a non-ductile tungsten filament and achieved an initial efficacy of just 7.85 Lumens per Watt. Moore's lamp threatened General Electric's heavy investments in the incandescent lamp, and provided additional motivation to improve their product. The breakthrough for GE occurred when William Coolidge succeeded in creating a ductile tungsten filament in 1910. This boosted their efficacy to 10 Lumens per Watt, the same as the Moore lamp. After 1910, Moore's lamps began to fade from the market and his patents, the Moore Electric Company, and the Moore Light Company were absorbed by GE in 1912; Moore rejoined the GE laboratory workforce. Although his tubes could not survive against the fierce research and development power of General Electric, his ideas were improved upon and put to good use even as Moore's companies dissolved [6].

1.1.6 *Improved Moore Lamp*

One of the limitations Moore faced was that only common atmospheric gases were available to him for use in his lamps. It was not until the conclusion of the 19th century that the five inert gases (argon, neon, helium, krypton, and xenon) were isolated. However, the cost of extracting these gases from air was so exorbitant at the time that it could not be done commercially until 1907. After years of work, Georges Claude, a French inventor, and Carl von Linde, a German inventor, succeeded in developing a method for liquefying air and separating it into its various ingredients. Using the now readily available gases, Claude continued where Moore's experiments had left off. He found that filling a nitrogen/carbon-dioxide Moore tube with neon yielded a brightly colored light that found ready use in advertising. Claude also succeeded in enhancing Moore's electrode design. He patented the discovery the electrical load of a given electrode surface should remain below a level of 4.5mA/cm^2 [11]. This reduced the disintegration of the cathode from ion bombardment, or sputtering. The ions would eject metallic particles that trapped gas particles, which lead to reduced gas pressure and thus a shorter lamp life. Claude began marketing his product in France and eventually to the United States.

Figure 1.4: *1923 - First neon sign in the United States*

Figure 1.4 [12] is a photograph of the first neon sign used in the United States. Claude sold two of these signs to a Packard car dealership in 1922 for \$1,250*. Fortunately for GE, the neon lamp was still no competition for the ductile tungsten filament lamp. In fact, the supremacy of the incandescent lamp led to lull in electric discharge lamp progress for about 20 years [6].

1.1.7 *Return of the Discharge Lamp: Cooper-Hewitt, 1930*

In 1901 an American inventor by the name of Peter Cooper-Hewitt introduced a new lamp design. The Cooper-Hewitt Lamp was made of "a tube of glass or quartz containing mercury, mercury vapor and wires sealed into the ends of the tube to conduct electricity to and from the current carrying vapor" [13]. It was inclined at a fifteen-degree angle with both ends slightly enlarged. Mercury was contained at the lower end and acted as a cathode, or negative electrode. The opposite side contained an iron or tungsten electrode which served as the anode, or positive electrode. Figure 1.5 provides a graphical representation of the tube [14]. To start the lamp, the tube was tilted so the

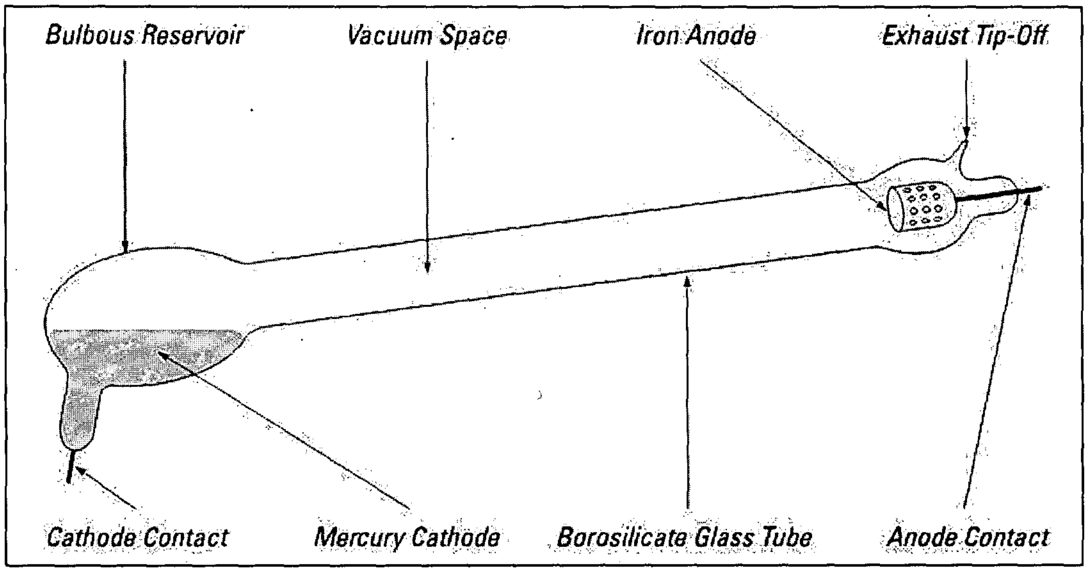

Figure 1.5: *Cooper Hewitt Mercury Vapor Lamp, 1901*

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* The sign stayed fully functional until at least 1974 [12].

mercury bridged the gap between the two electrodes; current flowing through the stream of mercury heated it and eventually some was vaporized. When the stream was broken, the current was powerful enough to leap the small gap and ignite the arc. The ionization of mercury vapor and the flow of electrons and positive ions produced light in very much the same manner as the Geissler-based tube developed by Moore. The disadvantages of this lamp were that it was strong in the green and blue portions of the spectrum however, almost entirely lacking in red, and it required a ballast to maintain constant current flow. For these reasons they were used mainly in photography, drafting and other industrial applications [6, 13].

General Electric bought the Cooper-Hewitt lighting company in 1919 after capturing the market with their improved incandescent lamp. GE developed the high-pressure mercury-vapor technology that Cooper-Hewitt had been experimenting with prior to the buyout. Once commercially introduced, these new lamps received much attention from Philips in Holland, Osram in Germany, and the General Electric Company, Ltd., in England before catching on in the United States. In 1934, the Westinghouse Company introduced the 400-Watt mercury-vapor lamp to the US. Smaller and larger sizes would soon follow as indicated in Table 1.1 [6].

Rated Lamp Watts	Date of Introduction	List Price (1946)	List Price (2004)*	Rated Initial Lumens/Watt	Rated Average Life (Hours)
100	1938	$9.50	$92.03	30	1,000
250	1936	$8.50	$82.34	28	2,000
400	1934	$9.50	$92.03	40	3,000
1,000	1938	$9.00	$87.18	65	75
3,000	1942	$40.00	$387.49	40	2,000

Table 1.1: *Principal mercury-vapor lamps made in the United States, 1934-1946*

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* 1946 price represented in 2004 dollars; calculated using CPI statistics from the US Dept. of Labor

1.2 The Modern High Pressure Sodium Lamp

In the early 20th century General Electric (GE) scientists in Schenectady, N.Y. experimented with sodium vapor. They found that the sodium ionized at a high efficacy; however, it only lasted for a few hours. The hot sodium vapor would blacken any glass then available. Eventually, developments in glass technology allowed low-pressure sodium (LPS) lamp to be developed. LPS lamps were made available primarily for street and highway lighting in 1933 [15].

It was later discovered that a sodium discharge under high pressure yields a higher efficacy and better color rendition than that of the primarily yellow low-pressure sodium lamp. This ignited a search for a material that could withstand the presence of sodium under high temperatures and pressures. The search ended in the early 1960s when General Electric invented a new ceramic material called polycrystalline alumina (Al_2O_3). This material has been given the name "translucent aluminum oxide" or Lucalox. It is capable of transmitting more than 90% of the visible radiation released during the discharge of sodium [16]. Once GE was equipped with Lucalox technology, the High Pressure Sodium (HPS) lamp became a reality.

Similar to a Multi-Vapor lamp, the Lucalox lamp has an excess amalgam reservoir. This amalgam composition and temperature is vital in controlling the spectrum of the sodium discharge. A higher color temperature is realized with an increased amalgam temperature. A better color appearance can be obtained by assuring that the amalgam composition contains a sodium mole fraction of about 80 percent, with the other 20 percent consisting of xenon and mercury [1].

Niobium (Nb) is the material used to make the end caps of the Lucalox arc tube. Nb is highly resistive to attacks by sodium vapor at high temperatures and pressures making it an ideal choice for the HPS lamp. The end cap contains three components: the shaft, a coiled tungsten coated electrode, and a back-arcing shield. These components are connected together using an electron beam after the caps are sealed to the tube as a unit in a sintering process. The arc tube, with the sodium amalgam reservoir end open, is then processed by pumping and cleaning prior to injecting the amalgam and xenon. After this has been completed the amalgam-end is sealed and the tube is mounted onto its support structure. This completed structure is shown in Figure 1.6 [1] and is designed to withstand the constant expansion and contraction of the arc tube during operation.

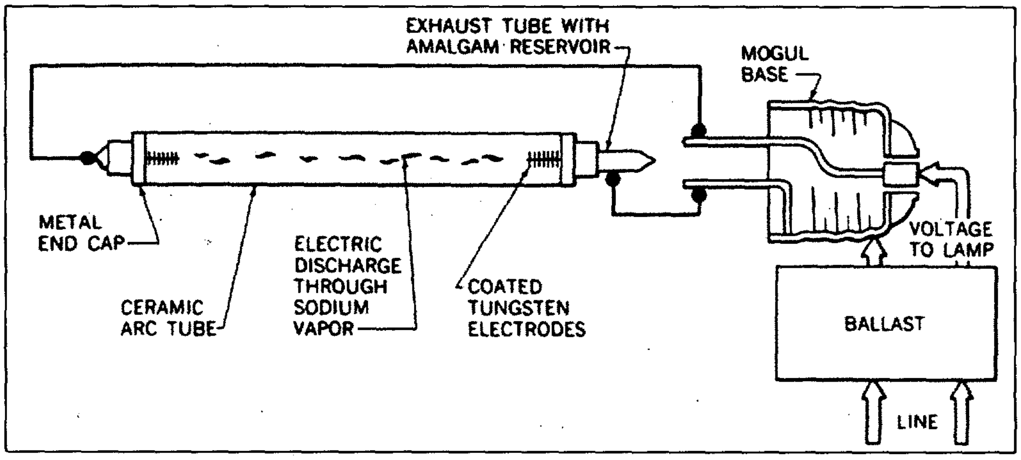


Figure 1.6: *Completed arc tube structure*

CHAPTER 2
BACKGROUND: HIGH PRESSURE SODIUM TECHNOLOGY

2.1 Plasma – Electric Discharge Ionization

An understanding of plasma must begin with a basic understanding of how light is created. The net energy change of an atom is expressed by the movement of electrons. In a given state, electrons travel around the nucleus of an atom in an orbital. The further the orbital is from the nucleus, the higher the energy level of the electron. If energy is added to an atom its electrons may be temporarily boosted to a higher orbital. When the electrons return to their steady-state orbital, the gained energy is released in the form of a light particle, or photon. The wavelength of the photon emitted is determined by the amount of energy released by the electron. The de Broglie wavelength equation can be used to calculate the wavelength of a photon given the kinetic energy and mass of the target electron [17]:

$$\lambda \,?\, \frac{h}{mv} \,?\, \frac{h}{\sqrt{2mKE}} \qquad \textit{de Broglie wavelength} \quad (2.1)$$

Where:

λ = de Broglie wavelength of a photon
h = Planck's constant = 6.63×10^{-34} J•s
m = Mass of target electron
v = Speed of target electron
KE = (Energy of electron in atom in eV)(1.6×10^{-19} J/eV)

When using plasma to create visible light, it is imperative to choose an element that has electrons at the proper energy level to produce photons at the desired wavelength.

Plasma results from adding energy to a gas to break the internal bonds of some of its individual atoms, ionizing those atoms and freeing negatively charged electrons. When this happens to a significant number of atoms, the resulting electrically charged collection of particles escalates into a plasma, the fourth state of matter [18].

2.2 Lamp Ignition and Stabilization

All discharge lamps require an ignition process to convert the gas in the arc tube from a non-conductive to a conductive state. High pressure sodium lamps have external starters that provide a voltage of sufficient amplitude and appropriate duration and rise time to cause "breakdown" of the starting gas (xenon) to occur. Typically, a starting pulse with a peak voltage of 2500 volts is employed for 1 microsecond. Once breakdown occurs, a self-sustaining discharge takes over and the starter is no longer needed as each electron released at the cathode gives rise to at least one successor, or secondary electron [19]. A more detailed explanation of this process is outside the scope of this thesis; more details are provided in [19].

The stabilization phase of an HPS lamp involves limiting the current that is drawn by the arc tube. Since it has a negative resistance characteristic, the current being drawn by the lamp would increase indefinitely eventually leading to its destruction [20]. The solution to this problem is to place a current limiting device between the lamp and the power supply. Electromagnetic and electronic ballasts have been designed for this purpose. In addition to limiting current, ballasts are designed to operate lamps within a particular range of efficiency. After this range has been exceeded the ballast no longer provides the lamp with the power that it needs to operate continuously. This leads to the lamp switching on and off continually as it attempts unsuccessfully to reach stabilization; a condition commonly known as cycling.

2.3 Importance of Lamp Operating Voltage

One of the fundamental characteristics of a modern high pressure sodium lamp is that the lamp operating voltage, or arc tube voltage, increases as the lamp ages. There are several factors that contribute to the rise in arc tube voltage, namely, electrode fall, arc length, and electric field strength [19]. Electrode fall is defined as the voltage drop along the thin current transfer zone between plasma and electrode [21]. The arc length is simply the length of the plasma arc between electrodes. Finally, the electric field strength, measured in V/m, is the strength of the electric field created by an operational HPS lamp. A change in any of these three parameters causes a change in lamp voltage.

Over the lifetime of an operational HPS lamp, the tungsten electrodes lose their activator material. The coating is lost due to both the high voltage pulses provided by the starter and evaporation during steady-state operation. Once the activator material is depleted, the length of the plasma arc has increased by a few millimeters. In addition, the lack of activator material causes a greater electrode fall. When both increased arc length and greater electrode fall are present, they will never cause a lamp voltage rise of more than 10 Volts. It is because of this that a majority of the increase in lamp voltage is associated with changes in electric field strength [19].

The electric field strength of an HPS lamp is determined primarily by the partial vapor pressures of the sodium and mercury gas in the arc tube and the temperature and composition of the liquid amalgam. There have been several different models created to calculate the electric field strength and relate it to rise in lamp voltage. Appendix 1 summarizes one method presented in Jacobs [22] that was used to determine the interactions of the said parameters in influencing rise in lamp voltage.

2.4 High Pressure Sodium Ballasts

As mentioned in Section 2.2, electromagnetic and electronic ballasts have been designed to promote stability in HPS lighting systems by limiting the current that can be drawn by the lamp. Combining the current provided by the ballast with the operating voltage of a lamp yields the power consumed by the lamp. As the arc tube voltage increases throughout the life of the lamp, the current (and therefore power) must be

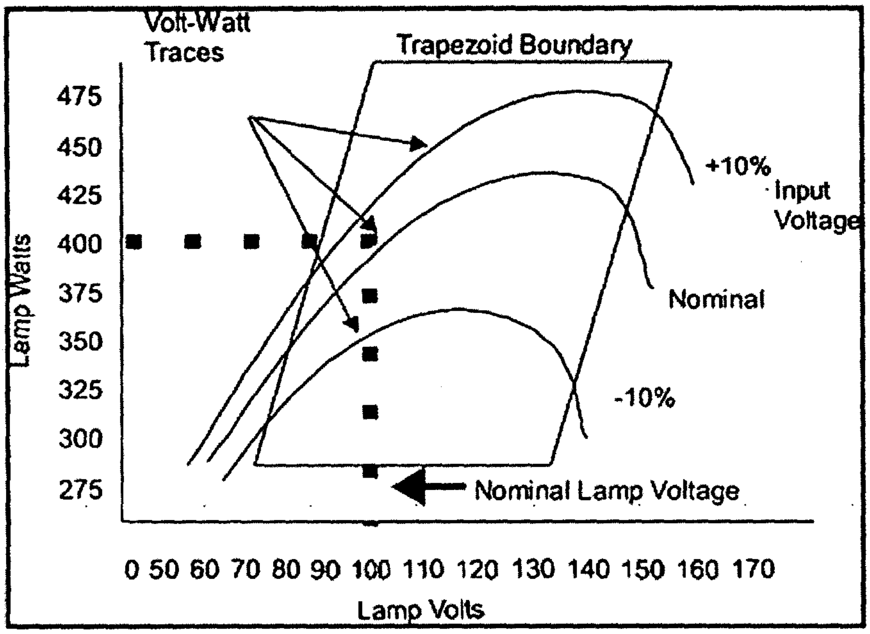


Figure 2.1: *HPS ballast trapezoid diagram for a 400W lamp*

regulated to meet efficiency standards set by the American National Standards Institute (ANSI). These standards have been designed to ensure HPS lamps give exceptional performance in life, luminous output, and stability and are represented graphically by the trapezoid diagram in Figure 2.1 [21, 1]. This diagram provides the range of voltage and wattage in which the upper and lower boundaries of the trapezoid represent maximum and minimum power, respectively, the lamp is permitted to consume. The leftmost and rightmost boundaries represent minimum and maximum operating voltages that the lamp is allowed to operate. The three lines represent the power regulation, in Watts, throughout the life of the lamp. A ballast design based on ANSI standards does not allow the lamp to operate outside these parameters. Once the lamp voltage exceeds the rightmost boundary of the trapezoid, cycling begins because the lamp is no longer provided with the power it needs to operate.

2.4.1 *Power Basics for HPS Ballasts*

A full comprehension of how a ballast is designed to limit current and provide the voltage and current needed by a lamp throughout its lifetime requires knowledge of how AC circuits are affected by inductive and capacitative loads. One important concept is power factor, defined as the fraction of apparent power that is actually supplying real power to a load. Figure 2.2 [23] depicts an AC voltage and current waveform in a

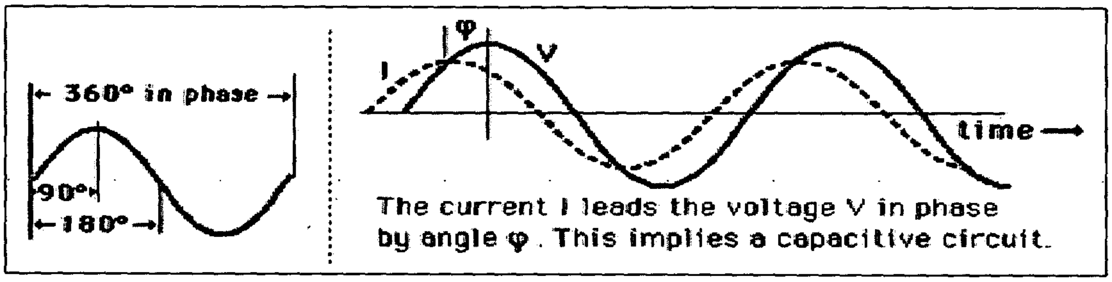


Figure 2.2: *Illustration of a waveform from a capacitative circuit*

capacitative circuit. The phase angle and power factor can be calculated using the power triangle in Figure 2.3 and the following equations [24]:

$$\varphi \; ? \; \arctan ?\frac{X_L \; ? \; X_C}{P}? \; ? \; \arccos ?\frac{P}{S}? \; ? \; \arcsin ?\frac{Q}{S}? \qquad \textit{Phase Angle} \; (2.2)$$

$$PF \; ? \; \cos(\varphi) \qquad \textit{Power Factor} \; (2.3)$$

Where:
φ = Phase angle (degrees)
X_L = Inductive reactance ($2\pi f L$)
X_C = Capacitative reactance $?\frac{1}{2\pi f C}?$
P = Real power (Watts)
Q = Reactive power (Volt-Amps Reactive, VARs)
S = Apparent power (Volt-Amps, VAs)
PF = Power factor

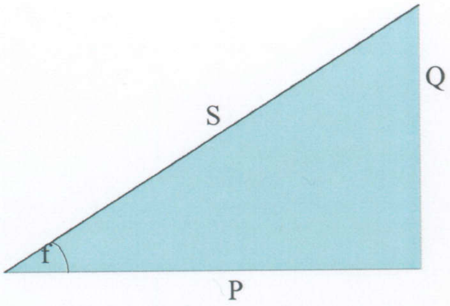


Figure 2.3: *Power triangle*

The overall power consumed by the circuit is represented by apparent power (S), the hypotenuse of the power triangle. This quantity is composed of two separate forms of power, real and reactive. Real power is the power delivered to or consumed by the load connected to a circuit. When working with direct current (DC) one can simply multiply voltage and current to obtain the real power in Watts. In AC circuits, however, the voltage and current may be out of phase as explained above. In this case the real power is obtained by multiplying the product of voltage and current by the cosine of the phase angle that represents the time difference between the voltage and current waveforms:

$$P \; ? \; VI[\cos(\varphi)] \qquad \textit{Real Power} \; (2.4)$$

Reactive power is defined as the energy that is first stored and then released in the magnetic field of an inductor or the electric field of a capacitor [24]. Similarly to calculating real power, reactive power is found by multiplying the product of voltage and current by the sin of the phase angle:

$$S \; ? \; VI[\sin(\varphi)] \qquad \textit{Reactive Power}\ (2.5)$$

There are five primary electromagnetic ballast designs utilized in modern utility distribution systems. Each has differentiating characteristics that make it desirable for a typical situation. For example, ballasts with a high power factor (90% or greater) permit the use of large quantities of luminaires and high wattage lamps on each distribution circuit [25]. Using high power factor ballasts in this situation allows the designer to keep initial costs down by utilizing a smaller wire size because of reduced current consumption. Thus, a basic knowledge of each ballast family is necessary for any lighting system designer. In the following sections, each type of ballast will be explained along with the typical applications for each.

2.4.2 *Reactor Ballast*

The reactor ballast is commonly used in roadway lighting applications. The design consists of a series connected choke coil wound on an iron core to limit the current to the lamp. It is primarily used in areas where the line voltage is kept within +/- 5% of the nominal voltage (120V) because its ability to regulate is limited and dependent upon the air gap in the core of the inductor. The ballast is relatively small and light in comparison with other designs. The main advantages in using this ballast are its efficiency and low cost; it is the least costly of the electromagnetic ballasts to operate and maintain. The reactor ballast is most economical for 50 – 150 Watt HPS lamps. A drawback of the design is its inherently low power factor, usually ranging from 40-60%. This can be corrected by placing a shunt capacitor in the circuit, as seen in Figure 2.3 [26]. However, doing this couples a high starting current with the already excessive operating current, thus increasing operating costs [27, 28]. The power factor correction is ideal for utilities because it reduces the amount of reactive power consumed. The consumer whose power consumption is monitored by a meter that does not account for reactive power consumption, however, would benefit from the lower power factor configuration.

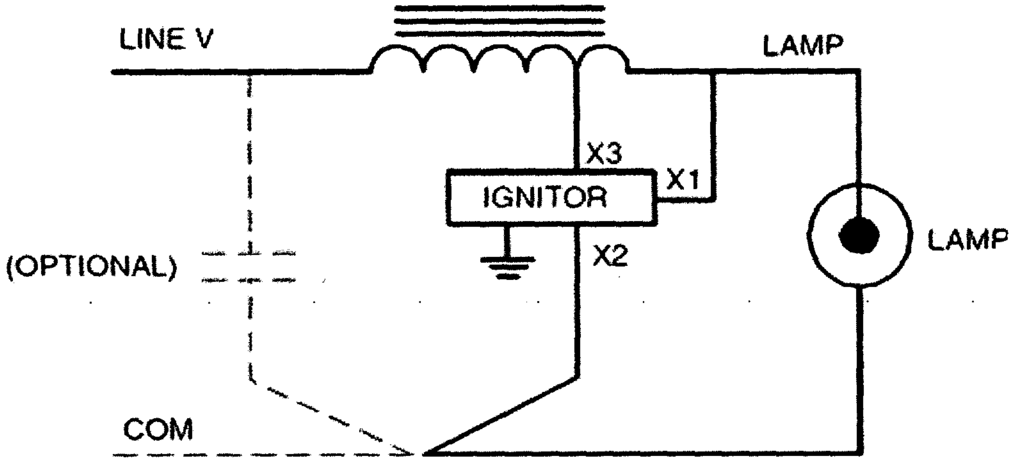


Figure 2.4: *Reactor Ballast*

2.4.3 *Constant Wattage Autotransformer (CWA) Ballast*

The CWA ballast is a popular design in which the primary and secondary coils are electrically connected. The circuit decreases current as arc tube voltage rises to keep the lamp operating wattage within the limits of the trapezoid (Figure 2.1) [27]. The capacitor in series with the secondary coil improves the power factor of the circuit to higher than 90%, making it more efficient than the reactor ballast. The cost of the CWA ballast is higher than the reactor ballast; however, the tradeoff is the commendable increase in efficiency. The ballast can tolerate reductions in line voltage of more than 10% before it can no longer sustain the lamp load. This decreases the risk of accidental lamp outages, making CWA ballasts best for locations where the light provided by the fixture is critical. Figure 2.4 is a schematic for the CWA ballast [26].

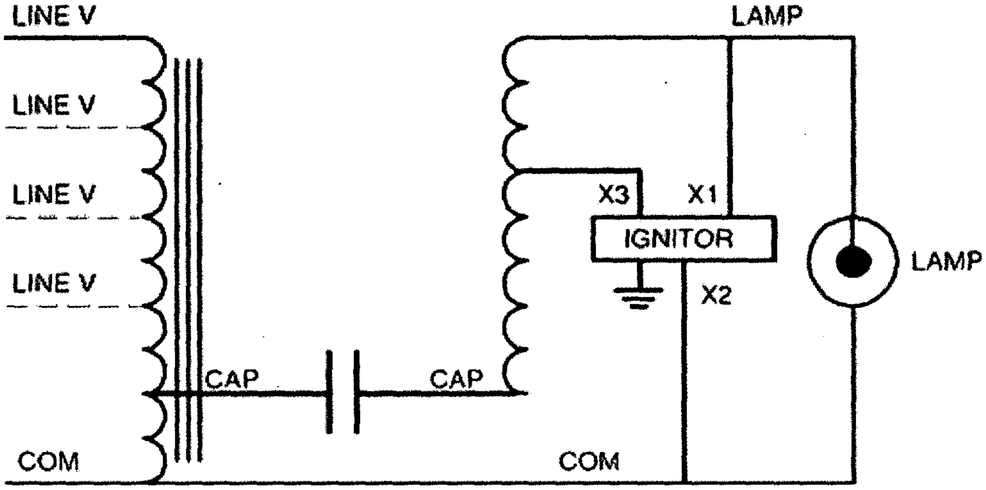


Figure 2.5: *Constant Wattage Autotransformer (CWA) Ballast*

2.4.4 *Constant Wattage Isolation Transformer (CWI) Ballast*

The CWI ballast is very similar to the CWA ballast in performance and design. The major difference between the two is that the CWI electrically isolates the lamp socket, ignitor, and capacitor from the line. An advantage of the CWI ballast is that it is a good regulator, thus it performs superbly where there are minor fluctuations of up to +/-10% from the nominal line voltage. The CWI is more costly than the CWA; as a result they are used only when line conditions warrant them. Figure 2.6 is a schematic of the CWI circuit [26].

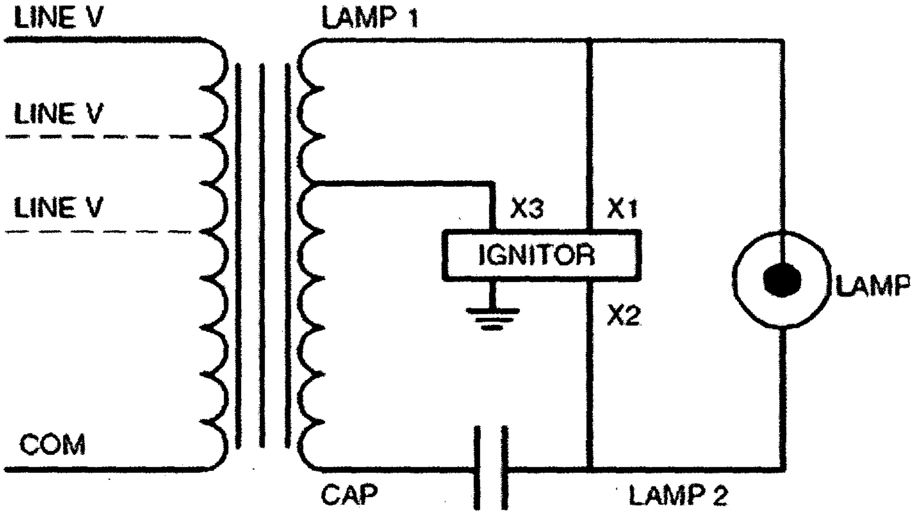


Figure 2.6: *CWI Ballast*

2.4.5 *High Reactance-High Power Factor (HX-HPF) Ballast*

Generally this type of ballast is called high reactance; however, a capacitor gives it the "high power factor" status. The HX-HPF ballast, shown in Figure 2.7 [26], is of the autotransformer type, accomplished through combining primary and secondary coils to form one piece of a single high leakage reactance transformer. A distribution line with approximately +/- 5% voltage variation is ideal for this design. The open circuit current, or starting current, is always higher than the operating current. It may be applied to input voltage circuits ranging from 120 – 480 volts. It is most commonly used for lamps that are 150 Watts or less.

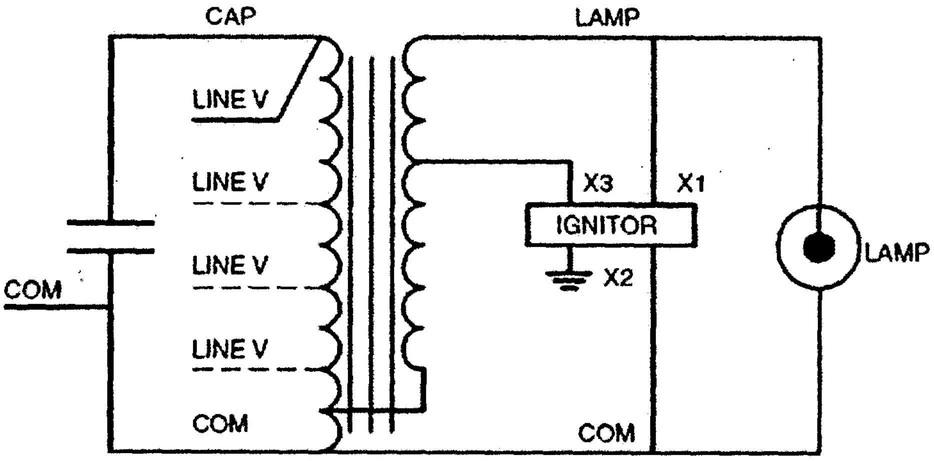


Figure 2.7: *HX-HPF Ballast*

2.4.6 *Regulated Lag Ballast*

The Regulated Lag ballast contains three inductive coils, seen in Figure 2.7 [26]. The primary and secondary transforms the voltage from the mains and feeds it through the tertiary winding to the lamp. The capacitor is in the circuit to control wattage as the lamp voltage increases and draws more power over its lifetime. The major advantage of the regulated lag ballast is that it can withstand voltage variations of +/- 10%. This ballast is ideal for areas where the line voltage fluctuates often. Another advantage is that it is a high power factor device (over 90%), so several of these ballasts on a varying voltage line will not be detrimental to the power factor of the area. The disadvantages of this device are that they have the highest ballast losses, operating losses, and manufacturing losses of all of the electromagnetic ballasts. Thus, it is very uncommon for this ballast to be used when the line voltage is nominal [27].

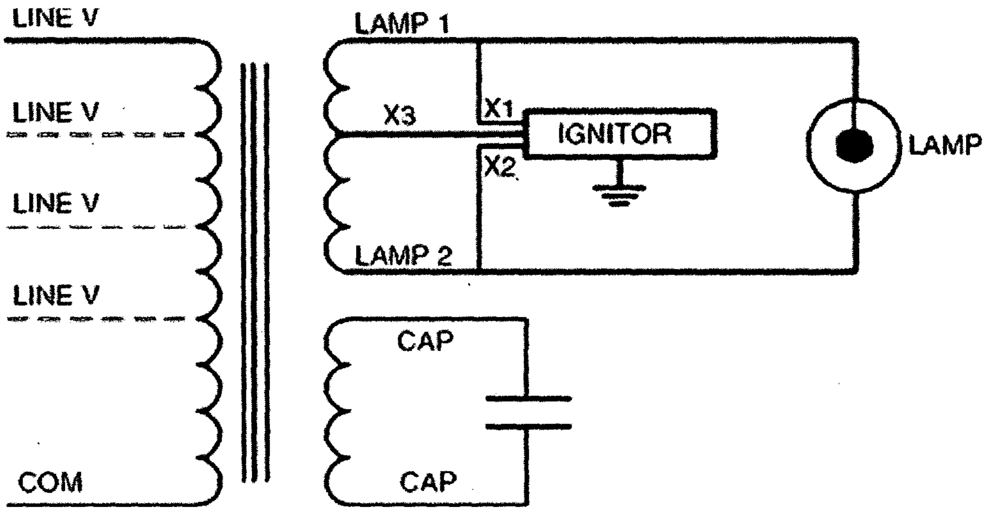


Figure 2.8: *Regulated Lag Ballast*

2.5 Lamp – Ballast System

The lamp and ballast system that comprises a luminare is complex due to the reactive components in the ballast as well as the complexity of the high pressure sodium lamp itself. While details about how the lamp actually works physically and chemically have been revealed and mathematical models are available, it has not yet been possible for utility companies to determine a method to accurately forecast street lamp replacement. Instead, lamps are automatically replaced in four to five year cycles whether or not they have remaining life left.

2.5.1 *Electrical Characteristics*

The primary electrical parameter of an HPS lamp and ballast system that changes over time is lamp voltage. Also known as arc tube voltage, the lamp voltage is the potential between the anode and cathode of the arc tube. Since the gases in the arc tube are being exhausted through both regular use and leakage through imperfect arc tube seals, the potential needed to sustain an arc discharge increases as a lamp ages. This phenomenon produces a net effect on the V-I characteristic throughout the circuit. The ballast has to compensate for the increasing lamp voltage by adjusting the power provided to the lamp while effectively limiting the amount of current that the HPS lamp is permitted to draw [1].

Another characteristic that influences the system is input voltage. The different ballasts are described as having limited or superior "regulation." Regulation is how well the ballast can compensate for changes in input voltage. For example, recall that the reactor ballast is best for systems that change no more than +/- 5% whereas the regulated lag and CWA ballasts can tolerate variations of +/- 10% or greater.

2.5.2 *Research Challenges*

The principle question that faced this research endeavor was: How can one detect lamp voltage rise without directly measuring lamp voltage? This is an important obstacle to overcome because it is not cost effective to redesign electromagnetic ballasts to allow access to the lamp voltage itself. In addition, electromagnetic ballasts are slowly being replaced by electronic ballasts; therefore, it would be fruitless to change a technology that will be eventually phased out.

One could postulate that the power (real and/or reactive) being consumed by the lamp and ballast would be correlated with lamp voltage. Since power changes as the ballast compensates for the changes in lamp voltage, it seems reasonable that change in power is linearly related to change in lamp voltage. However, this is not necessarily the case since power line conditions often vary greatly in distribution systems. This has a great influence on the way a ballast provides voltage and current to a lamp, therefore, skewing the results accordingly. Additionally, as discussed in the previous sections, different types of ballasts behave differently and have various characteristics that influence the power detected on the line side of a system. The solution must not be influenced by the distribution line conditions and electrical characteristics of different ballasts.

A second question that this work addresses is: How does lamp voltage rise differ across manufacturers and wattages? Empirical testing has been done in this regard and will be elaborated on in the next chapter. However, the basic property of lamp voltage rise is inherent in all HPS lamps and only varies based on the quality of the manufacturing process and the conditions under which the lamp is operated. The only difference is that the magnitude of the voltage across the arc tube is greater in higher

Wattage lamps because a greater potential is needed to ignite and sustain the arc discharge.

CHAPTER 3
ESTIMATION OF HPS LAMP AGE

3.1 Project Background

Utility companies today struggle with the task of replacing streetlamps in a timely and effective manner. Driving through many towns and cities one can undoubtedly spot a cycling or failed lamp that needs to be addressed. Presently, the responsibility of reporting lamp failures is primarily taken on by the customer rather than the utility company itself. This type of system may work well in residential areas; however, many times the average person is not likely to report a failed streetlight that does not directly affect them. Adding to the complications is the cost of servicing a streetlight. The majority of the high cost of individual lamp servicing comes from sending a crew out in a bucket truck to replace a single lamp, not from the cost of the parts that are being replaced. For this reason, utilities have implemented a system to maintain the lighting system known as group re-lamping. The group re-lamping process begins by a utility dividing its service region into zones. Rather than sending a crew out to replace a single lamp, all of the lamps in a given zone are replaced on a periodic basis (i.e. every 4 or 5 years). It is assumed that if lamps are replaced well before the end of life (typically 8 years on average), all of the lamps in that area will likely stay operational during the period until the next re-lamping. This is a reasonable assumption since the average life of an HPS lamp can vary from 4 to 12 years.

During the summer of 2002 PHI Lighting (i.e. Steve and Milan Steffel) approached Dr. Peter Mark Jansson, Associate Professor of Electrical and Computer Engineering at Rowan University, with a possible engineering clinic project. The project scope involved developing a photocontrol that would be capable of monitoring lamp life and sending this data to a passing utility vehicle upon request. This technology is aimed at addressing the flaws with the current group re-lamping method of maintaining streetlamps.

PHI Lighting has been established for over four years and specializes in testing high pressure sodium lamps discarded by public utility companies. They test for the arc tube voltage of the salvaged lamps and resell the ones that still have significant life left [28]. The proposed project stemmed from research performed by PHI Lighting that led to a technique for estimating lamp life without directly measuring the arc tube voltage. This technique is based on "insertion resistance" and is the foundation of the evolved product that has been two years in development. PHI Lighting had already paid to have an engineering firm develop a circuit to implement a first-generation insertion resistance system that would insert various resistances and output the data via RS232 to Microsoft Excel. The task for Rowan University was to transform their technology into something commercially viable that could conceivably be implemented within the packaging constraints of a street lighting photocontrol.

3.1.1 *Insertion Resistance*

PHI had implemented a series of tests to establish their "insertion resistance" theory and provided Rowan University with the results they had compiled. Rowan replicated the tests, using the same instrumentation that PHI had used, to see if the data could be reproduced.

The testing process for the initial insertion resistance validation included several pieces of equipment designed by PHI, as shown in Figure 3.1. Preparation for the testing process began with connecting 120VAC to the resistance box which contains a circuit whose functionality is described in the "Resistance Box/Pedal" block. After igniting the HPS lamp and waiting fifteen minutes for the arc discharge to stabilize, the steady state lamp voltage is recorded. A pedal is used to open SW2 and close SW1 simultaneously, thus forcing current to flow through the potentiometer resulting in a voltage drop. This drop is transferred to the multi-ballast box which contains five different types of 100-watt HPS ballast circuits. If the voltage drop caused the lamp arc to extinguish the resistance is recorded along with the steady state lamp voltage. Next, the lamp is allowed fifteen minutes to return to steady state and a lower resistance is inserted. The objective of this part of the procedure is to find the lowest resistance that will cause a voltage sag sufficient to extinguish the lamp arc. However, if the resistance does not cause the lamp to extinguish it is recorded and the lamp is again allowed fifteen minutes to return to

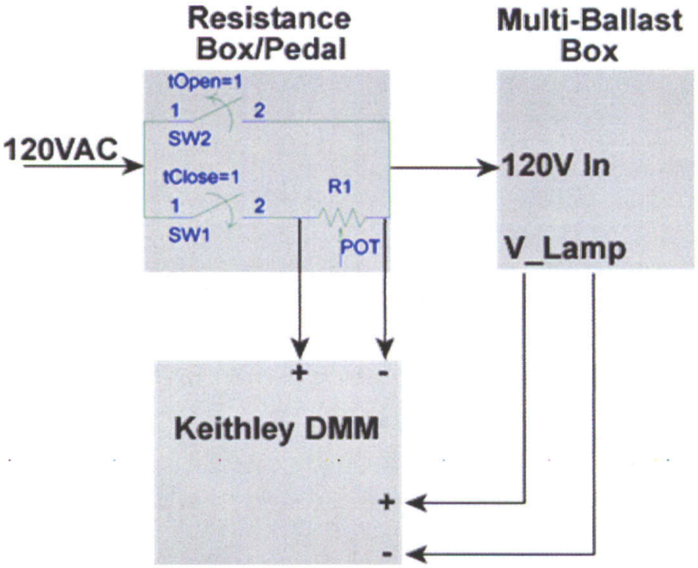


Figure 3.1: *Insertion Resistance Test Setup*

steady state and a higher resistance is used. This procedure is continued until the goal stated above is achieved. The following flow chart in Figure 3.3 describes the insertion resistance test procedure graphically.

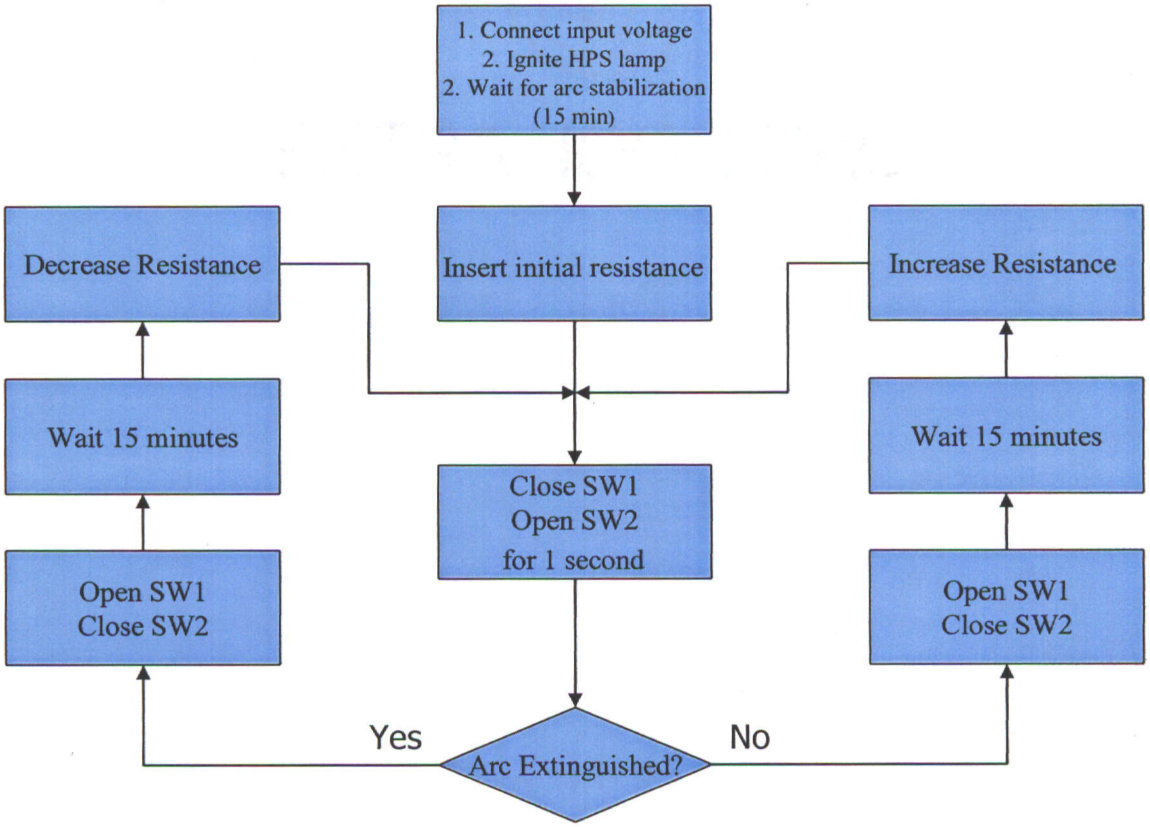


Figure 3.2: *Insertion resistance test flow chart*

After several months of testing, results were suitable for comparison to the data presented by PHI Lighting. Figure 3.3 compares data collected by Rowan with the data recorded by PHI in January of 2002. The linearity of the data sets is judged by the R^2 value of the X and Y points. R^2 is the square of the Pearson product moment correlation coefficient and is calculated using the following equation:

$$R\,?\,\frac{?\;?x\,?\,\mu_x\,??y\,?\,\mu_y\,?}{\sqrt{?\;?x\,?\,\mu_x\,?^{?}\,?\;?y\,?\,\mu_y\,?^{?}}}\qquad \textit{Pearson product moment correlation coeff.}\ (3.1)$$

Where:

x = x data point
y = y data point
μ_x = Mean of the x-data
μ_y = Mean of the y-data
R = Pearson product moment correlation coefficient

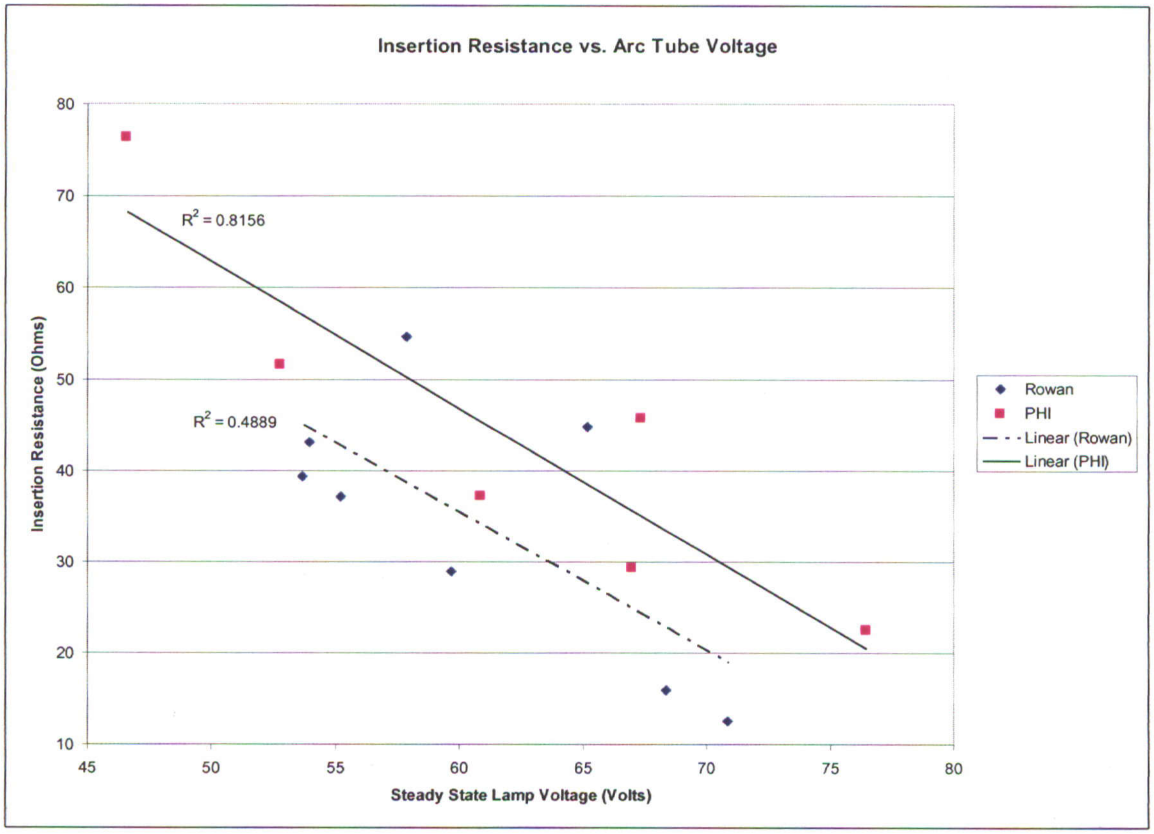


Figure 3.3: *PHI data trend replicated by Rowan*

The data captured by Rowan is mostly linear with the exception of the two stray points located at the lamp voltages of (58,55) and (65,45), which brings the R^2 value of the data down to 0.4889 from 0.9819. Several variables may have led to inaccurate data. The most probable cause of error during this testing process is related to using the pedal to switch the selected resistance into the circuit. The team from Rowan had been advised not to depress the pedal for more than about 5 seconds because the potentiometer would not be able to dissipate the heat for much longer than that. However, depending on the individual performing the tests, the amount of time the pedal is held down varied. This is a cause for concern because holding the pedal down at a particular resistance value for 2 seconds may not be long enough to lower the voltage of the circuit and extinguish the lamp, whereas 3 or 4 seconds would. This phenomenon is undoubtedly caused by the ballast's ability to compensate for temporary input voltage sags. It is important to note that these tests were performed on a reactor ballast. Therefore, influences from ballast regulation are minimal. After the reactor ballast tests were completed research into a more robust method of determining lamp life was initiated. The remaining four ballasts were not tested using the original PHI insertion resistance method.

It was concluded that unless the pedal is held down for the same amount of time during all tests the results were in error. This became a primary motivation for adopting a more sophisticated testing method that would gather results in a repeatable manner. The research team began investigating alternatives to the equipment that had been given to them by PHI.

3.1.2 The Positive Temperature Coefficient Thermistor

The resistance value at the extinguish point is not as important as is the effect resistance has that causes the arc tube to extinguish. Focus shifted to determining how much of a voltage sag a fixture can sustain without allowing the arc to extinguish. A positive temperature coefficient (PTC) thermistor is a straightforward and inexpensive device that supports this method of testing for lamp life.

The PTC thermistor is a solid-state device that increases in resistance as the temperature of the material increases through I^2R heating. They are commonly used as over-current protection devices because they will change from a low-resistance to a high-resistance state in response to an over-current that causes the PTC to become heated. This is known as "tripping" the device. Normally, the resistance of a PTC is much lower than the resistance of the rest of the circuit; therefore, it has little to no effect on its performance. However, if there is a surge in current the thermistor will heat up rapidly and its resistance will increase, or trip, thus reducing the current in the circuit to a value that can be carried safely by any of the circuit elements. After the over-current is eliminated the PTC cools thereby automatically returning to its original low-resistance state [29].

There are two types of PTC thermistors, ceramic and polymer. A polymer PTC (PPTC) is made up of a crystalline organic polymer containing dispersed conductive particles, typically carbon black. When the device is cool low resistance networks are formed in the polymer. Once the polymer is heated above its specified switching temperature the crystalline structure melts and becomes amorphous. The rise in volume during the amorphous phase results in the disruption of the network of conductive paths within the device causing an exponential increase in resistance [30].

The ceramic PTC (CPTC) is made of doped polycrystalline ceramic on the basis of barium titanate. The barium titanite ions of the crystal lattice are replaced with ions of higher valences, giving the CPTC more free electrons and making it conductive. The primary three differences between the CPTC and PPTC are that the CPTC has a higher nominal resistance, slower reaction time to fault currents, and is larger in size. If a PPTC and CPTC with the same hold current are tested, the PPTC would trip much faster than the CPTC because the PPTC is smaller and has a lower resistance due to its chemical composition. The operation of both ceramic and polymer devices is determined by an overall energy balance governed by the following equation [30]:

$$mC_P ?\frac{?\,?\,T}{?\,?\,t}? ? I^2R ? U?T ? T_A ? \qquad \textit{PTC Energy Balance Equation } (3.2)$$

Where:
I = Current flowing through the device (Amperes)
R = Resistance of the device (Ohms)
Δt = Change in time (seconds)
m = Mass of the device (kg)
C_P = Heat capacity of the device (Joules/K)
ΔT = Change in device temperature (K)
T = Temperature of the device (K)
T_A = Ambient temperature (K)
U = Overall heat-transfer coefficient (Watt/m^{2}K)

The polymeric PTC (PPTC) was tried initially in the lamp life tests to observe whether it would cause a voltage sag of an appropriate time frame and magnitude. After performing several tests it was determined that the PPTC tripped too quickly. Therefore, the CPTC was obtained due to its slower trip time. Figure 3.4 and shows the data captured during the testing of both types of PTC devices on a reactor ballast. The CPTC causes the voltage sag to occur over a period of about two seconds whereas the PPTC voltage sag occurs in just about one tenth of a second. The slower response time of the CPTC is necessary because the desired effect of the device is to cause a "sag" and not simply remove power from the ballast. Appendix 2 has additional data for each ballast type.

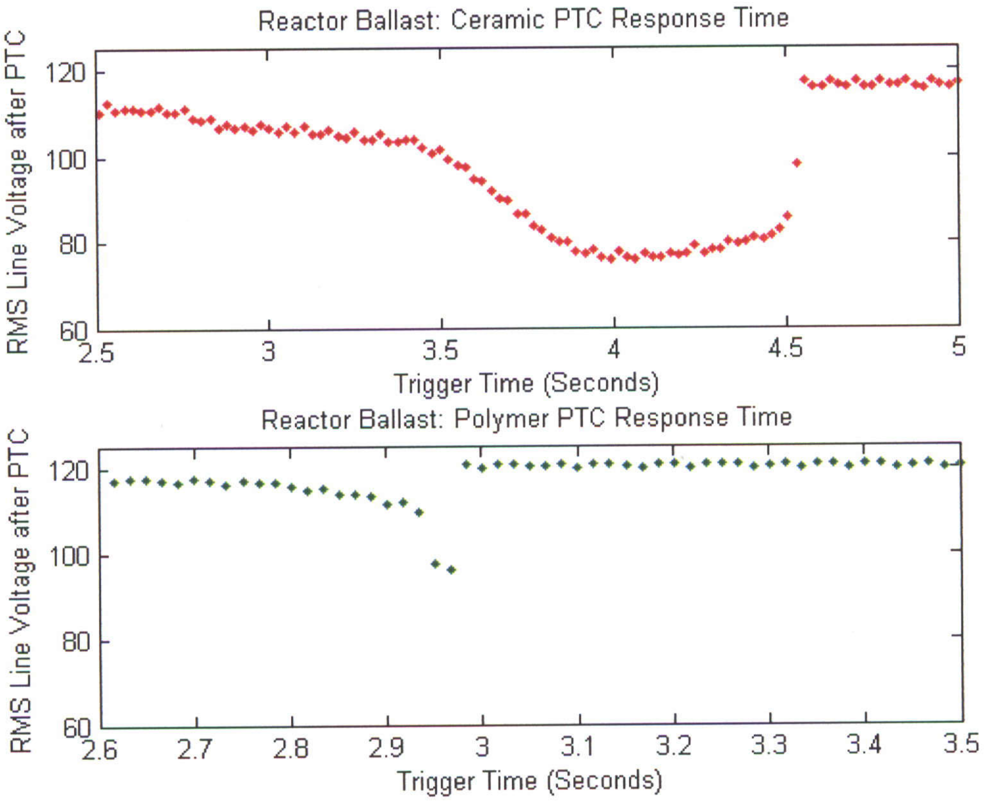


Figure 3.4: *CPTC and PPTC response time comparison*

PHI Lighting obtained a CPTC recommended from Stetron International [31]. It had a trip current of 920mA and a Curie temperature of 120°C. The current drawn by the five ballasts and lamps ranged from 1 to 3 Amperes making a trip current of 920mA adequate for creating a voltage sag that would extinguish the arc. Due to the proprietary nature of the CPTC design, Stetron would not reveal several key material properties (e.g. heat transfer coefficient and heat capacity) needed to accurately calculate the response time of the CPTC. Therefore, the device was tested for response time and it was observed empirically that it reacted in under 8 seconds, which is an appropriate time frame for the voltage sag to occur. The test results section discusses the implications of different ballast types and lamp wattages on choosing the appropriate PTC.

3.1.3 *Testing Methodology*

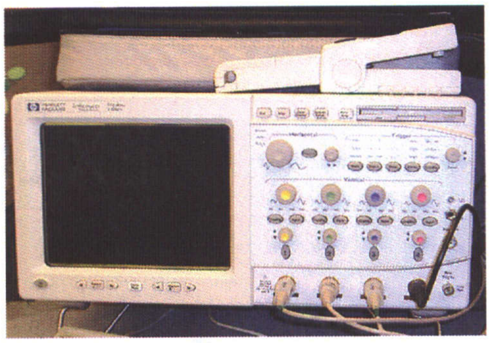


Figure 3.5: *HP Infinium oscilloscope used in testing. Current probe is on top of the scope.*

A multi-ballast box was altered to facilitate lamp life testing with the aid of PTC devices. An HP Infinium 54825A oscilloscope [32] is the primary piece of lab equipment used in the test process and is shown in Figure 3.5. The four parameters that are recorded are arc-tube voltage, line voltage, line current, and the voltage output of a photovoltaic (PV) cell. The arc-tube voltage is acquired by connecting a probe on the positive and negative terminals of the mogul base connections of the HPS lamp. The PTC is placed in series with the ballast. The line voltage is measured on the terminal of the PTC that is connected to the ballast in order to view the voltage drop as the resistance

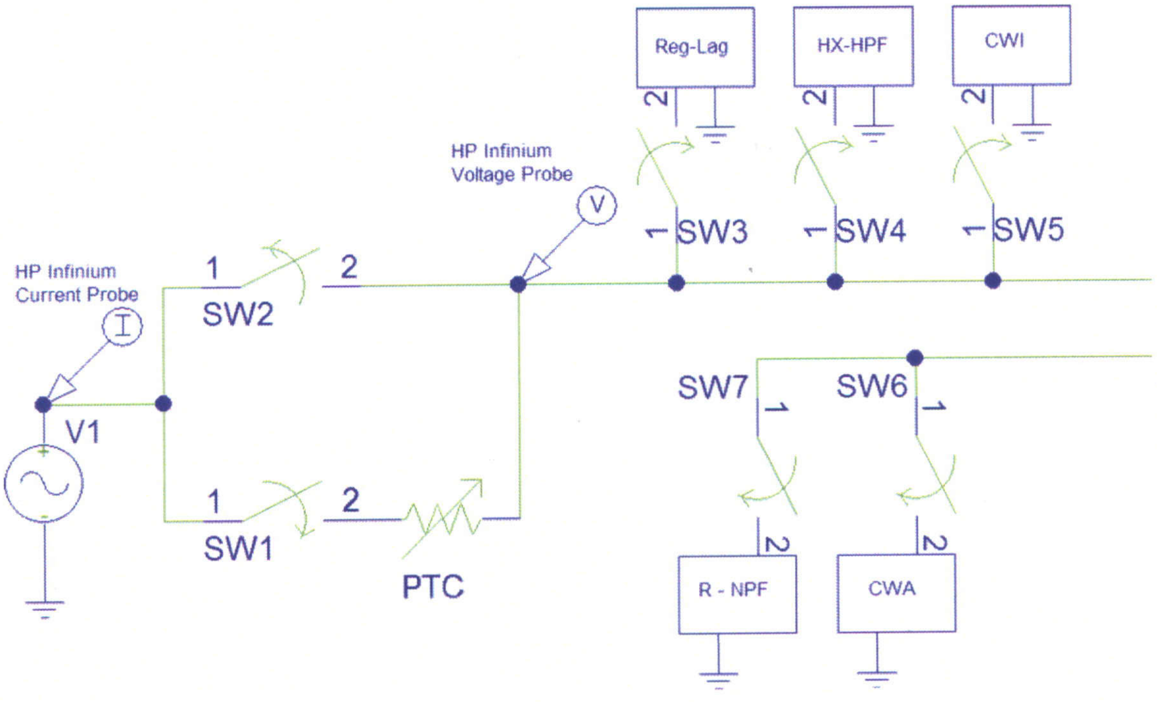


Figure 3.6: *Schematic of multi-ballast box used for 100W lamp testing*

of the thermistor increases. Figure 3.6 shows precisely where in the ballast circuit the probes are placed. An HP 1146A current probe uses Hall Effect technology to capture current information from the line. Finally, a photovoltaic cell is placed in the vicinity of the HPS lamp. This data taken from the PV cell allows one to pinpoint the precise instant that the arc extinguishes by relaying luminous output in the form of a DC voltage.

A custom wooden box fitted with five ballasts (seen in Figure 3.7) had been provided by PHI Lighting to aid in the testing process. This same box is referred to in the block diagram in Figure 3.1. The voltage source is connected to the box and two switches are wired in parallel to ensure that when SW2 is on and the ballast is operating normally, the PTC is not affecting the overall performance of the circuit in any way. Once the lamp arc

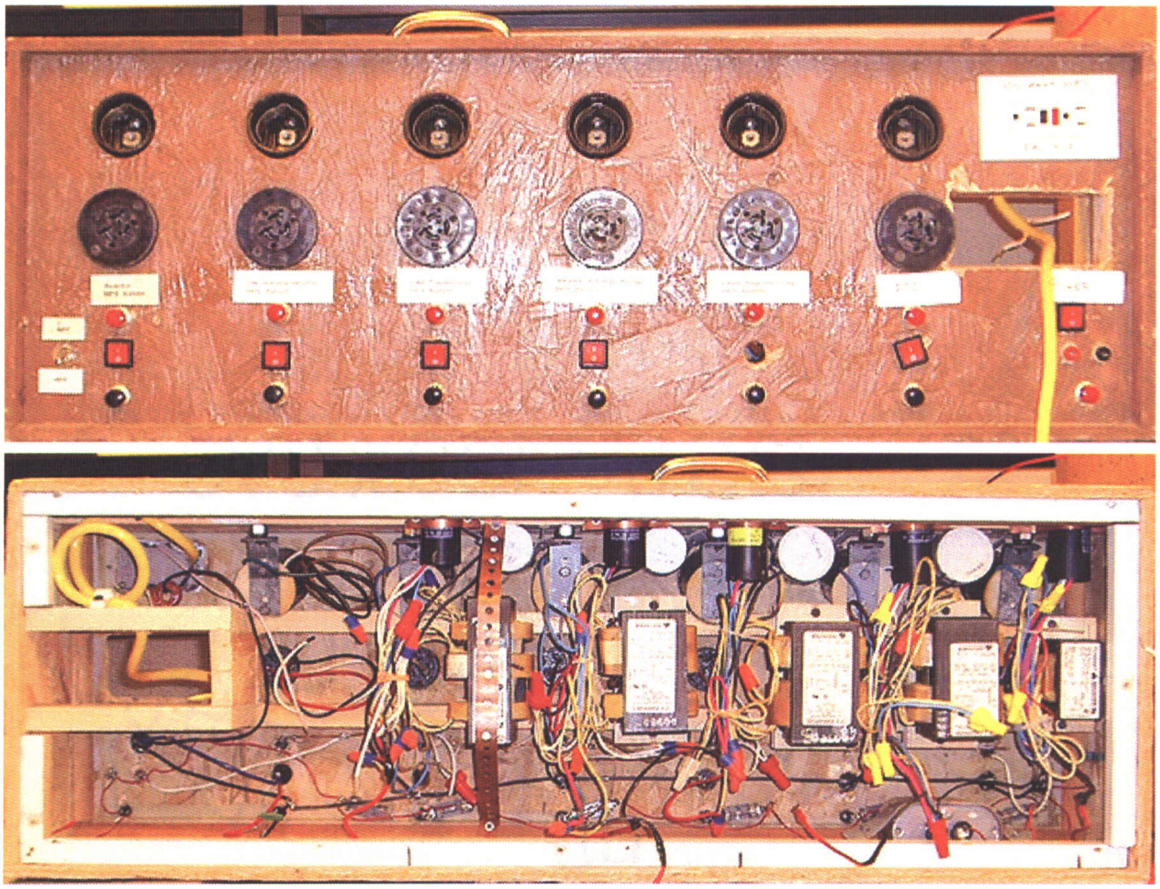


Figure 3.7: *100W multiple ballast box provided by PHI Lighting*

has been given enough time to stabilize (about 15 minutes), SW1 is closed and SW2 is opened, therefore forcing current through the PTC. As this occurs the PTC will begin to warm-up and increase in resistance, producing a decrease in voltage to the ballast. Eventually, depending on the magnitude of current flowing through the PTC, the type of PTC used, and how well the ballast is designed to withstand voltage sags, the voltage will dip below what the lamp-ballast system requires and the arc will extinguish. The average of the last several cycles of the line voltage at which the lamp failed is recorded.

3.1.4 *Summary of Testing Protocol*

Full documentation of the testing protocol is provided in Appendix 2. This section is a summary of the process that will familiarize the reader with how the data presented in following sections was obtained. The first step taken in preparing the laboratory equipment is oscilloscope probe calibration. This ensures that no false readings will be taken due to damaged or un-calibrated probes. After calibration is complete the person(s) performing the testing will proceed to make the connections specified above and depicted in Figure 3.6, except for the lamp voltage probe. The high voltage spikes from the HPS lamp starter can have adverse effects on oscilloscope probes; therefore, it is important to only monitor lamp voltage after the lamp arc is established.

The preparation of the oscilloscope is performed through merely loading a setup file that had been prepared at the start of the testing process. This file assures that multiple students performing testing will gather data in the same format and accuracy. The details of the parameters established through the setup file are provided in Appendix 3.

Once the testing equipment is ready, the lamp is ignited and allowed to warm-up for 15 minutes so that the arc tube voltage can stabilize. Next the steady state values for

RMS line voltage, lamp voltage, and current are recorded. Then, the switch in series with the PTC (SW1 in Figure 3.6) is turned on to place the thermistor in parallel with SW2. This has a negligible impact on the circuit since current will still flow through SW2, the lowest resistance path to the ballast. Next, SW2 is closed and current is forced through the PTC to the load. Immediately there is a slight reduction in voltage and the current then increases the temperature of the thermistor further increasing resistance rapidly. The line voltage begins to drop and when the lamp arc extinguishes, data collection is halted. Finally, the detailed information gathered by the oscilloscope during the test is transferred to a Microsoft Excel spreadsheet.

All of the data described above are instantaneous values and post-processing is required to extract root-mean-square (RMS) values. A MATLAB program is used to convert the instantaneous voltage and current values from the scope to root mean square based on the flow chart in Figure 3.8. The program searches through the data and assigns a "1" in a separate array for every zero crossing found. All other data points are denoted as "0." Next, the routine begins cycling through the 1's and 0's that are correlated with the actual data. When a "0" is encountered the program will copy the data associated with the "0" into a separate array. Then, when a "1" is found all of the data from the previous "0's" are squared, averaged together, and the square root is taken. Thus, the root of the mean squared of the cycle has been derived. The "1" and "0" array is based on the line voltage data and is used as a reference for the lamp voltage and line current data as well. Doing this assures that the three resulting RMS arrays will be of identical size and can be plotted on the same plot for comparison at the end of the primary data parsing program. The code used to perform this task is included in Appendix 3 of this thesis.

The main data-parsing program, of which the RMS program described above is a function, extracts the data from the Microsoft Excel file and stores it in arrays in MATLAB. The RMS calculations are completed and the correct time scale is calculated and used to generate plots. The program then saves a copy of the plots, and the data used to create them in the directory that the program resides.

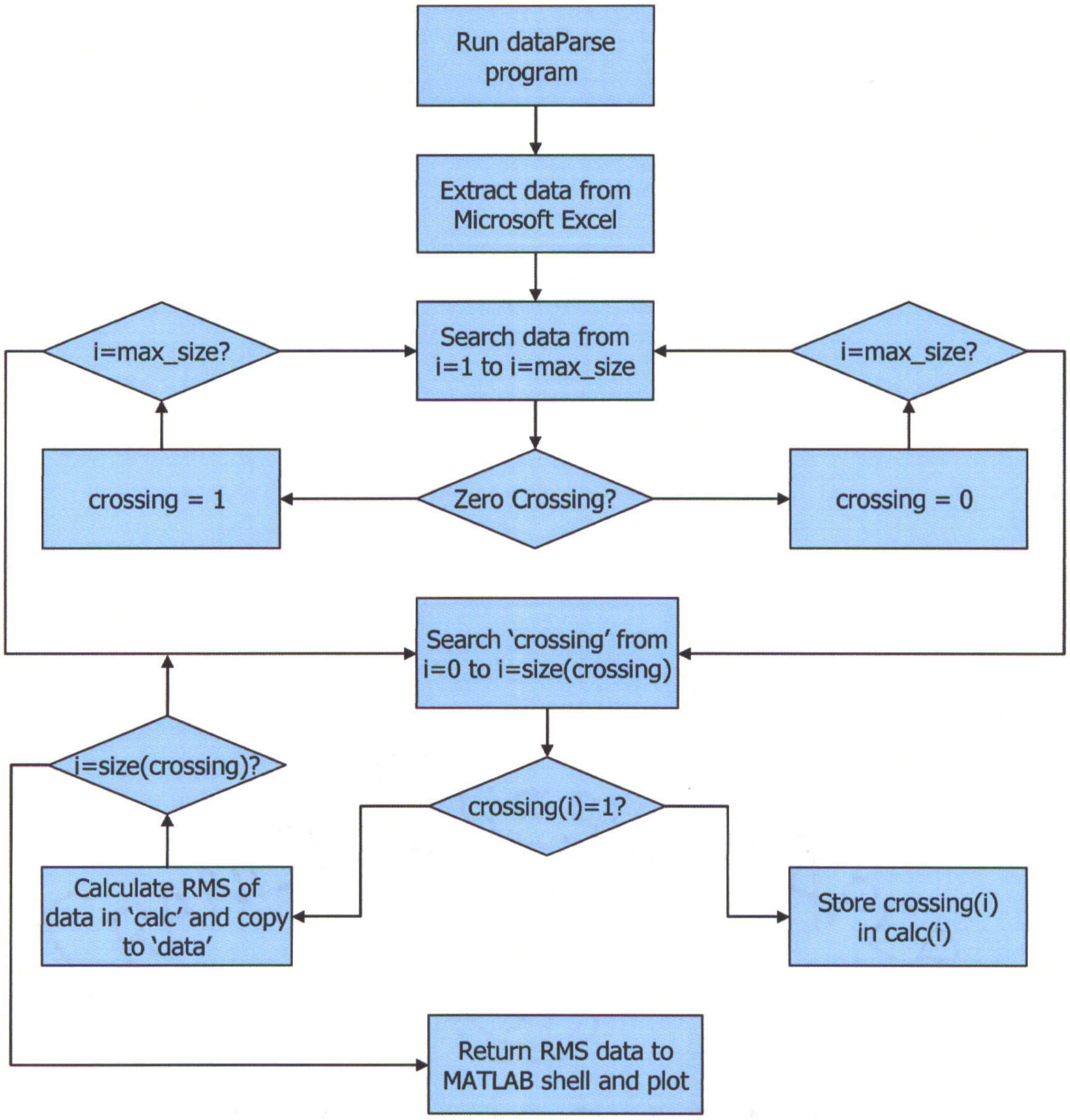


Figure 3.8: *Flowchart of RMS calculations in MATLAB*

After the data extraction is completed, the photovoltaic voltage is used to determine the arc-tube voltage, line voltage, and current just before and after lamp extinguishment. The cycle after the arc-tube has extinguished is noted on the spreadsheet along with the prior thirty cycles of data. This data is plotted against the steady state arc tube voltage of the lamp to see how the magnitude of the RMS voltage sag correlates with it. In the results section, this data will be explained in greater detail.

3.2 Results

The laboratory test procedure described in the previous section has been performed on the following five (5) 100 Watt HPS ballasts from Advance Transformer: High-Reactance High Power Factor, Regulated Lag, Constant Wattage Auto-transformer, Constant Wattage Isolation Transformer, and Reactor (NPF). Several different lamps with arc-tube voltages ranging from 45 to 78 volts were chosen for testing. The primary goal was to find a correlation between the magnitude of the line voltage when the arc tube extinguishes (from the voltage sag induced by the PTC) and the lamp voltage. The results of this experiment show that the magnitude of the voltage sag needed to extinguish a lamp lessens as a lamp ages. Furthermore, this phenomenon remains true for all of the ballasts tested, and supports published data on the susceptibility of HPS lamps to voltage sags throughout their lifetime [33].

3.2.1 *100 Watt HPS*

After correlating the actual last cycle before extinction as well as the 10, 20, and 30 cycle averages to lamp voltage it was found that using 30 cycles yields the best R^2 value across all five (5) ballast types. Table 3.1 lists the various ballasts and the R^2 results that were achieved for each. The 30-cycle average produces an R^2 value greater than 0.95 for all ballasts. This is superior to the other three correlations. Therefore, the following plots show the results achieved by the ballasts using the average of the last 30 cycles before the arc tube is extinguished. Each data point represents an individual test. There were five lamps in each testing series and three tests were performed on each lamp. Plots displaying the last cycle and 10 and 20 cycle average data are located in Appendix 5.

Table 3.1: *R^2 values correlating arc tube voltage to lamp shut-off voltage*

	CWA	CWI	Reg. Lag	HX-HPF	Reactor
Last cycle	0.945	0.949	0.824	0.938	0.725
10 cycle avg.	0.992	0.991	0.932	0.962	0.930
20 cycle avg.	0.995	0.988	0.960	0.961	0.915
30 cycle avg.	0.988	0.978	0.972	0.985	0.971

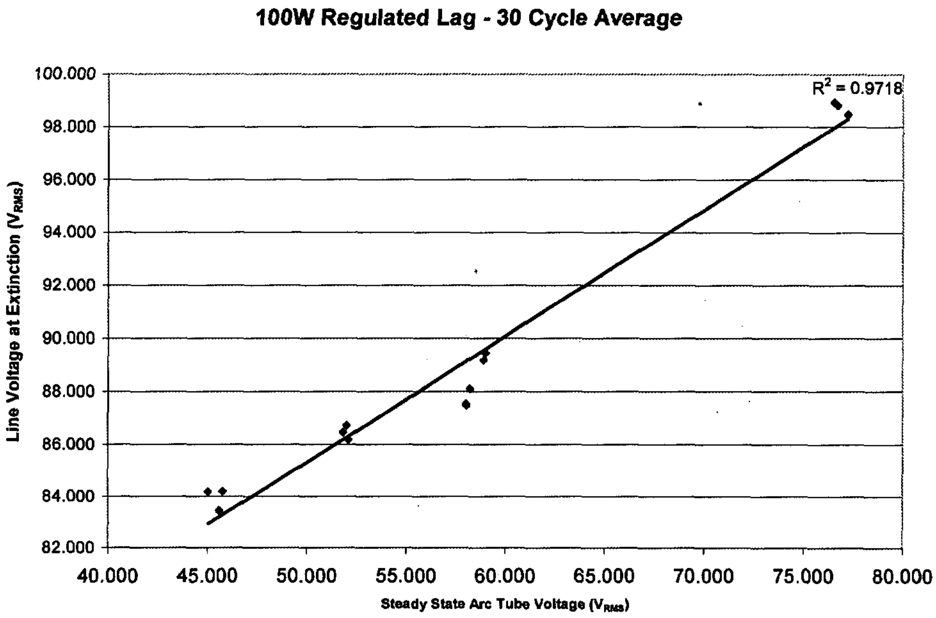


Figure 3.9: *100W Regulated Lag Ballast: ceramic PTC results*

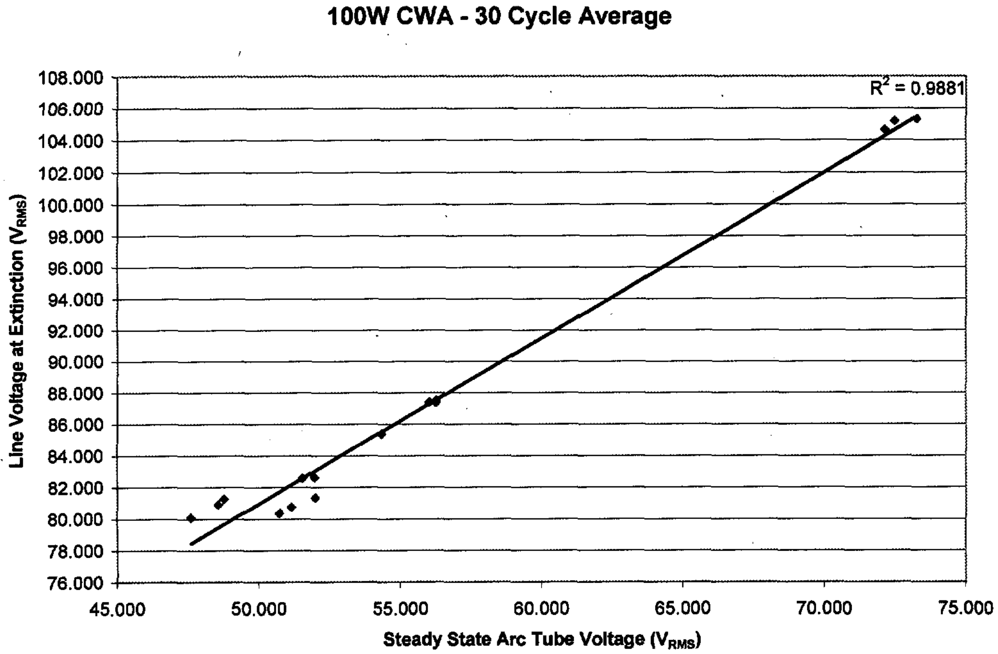


Figure 3.10: *100W CWA ballast: ceramic PTC test results*

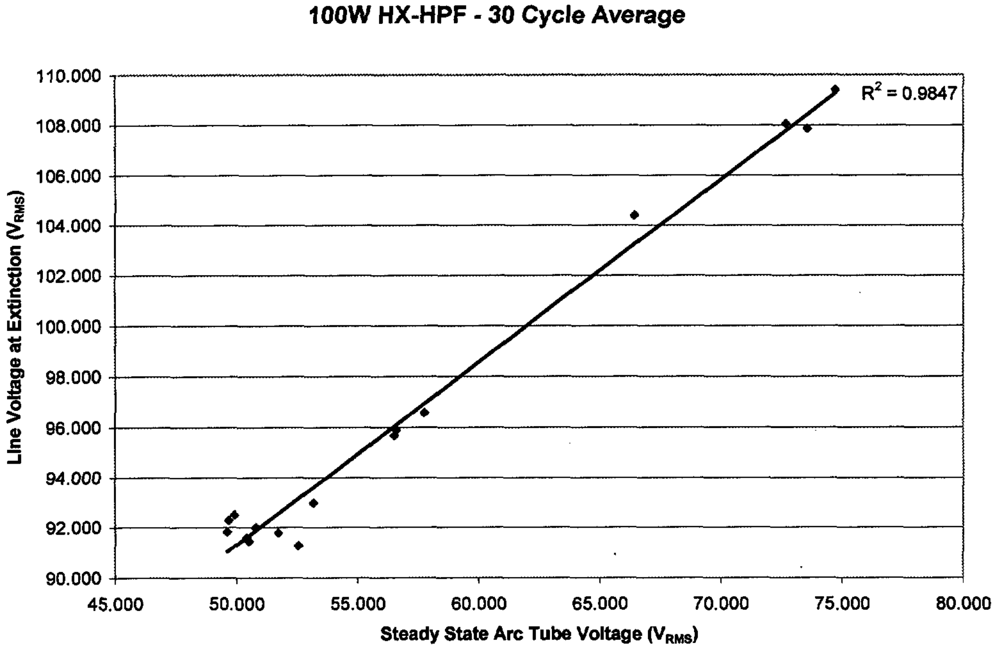


Figure 3.11: *100W HX-HPF ballast: ceramic PTC results*

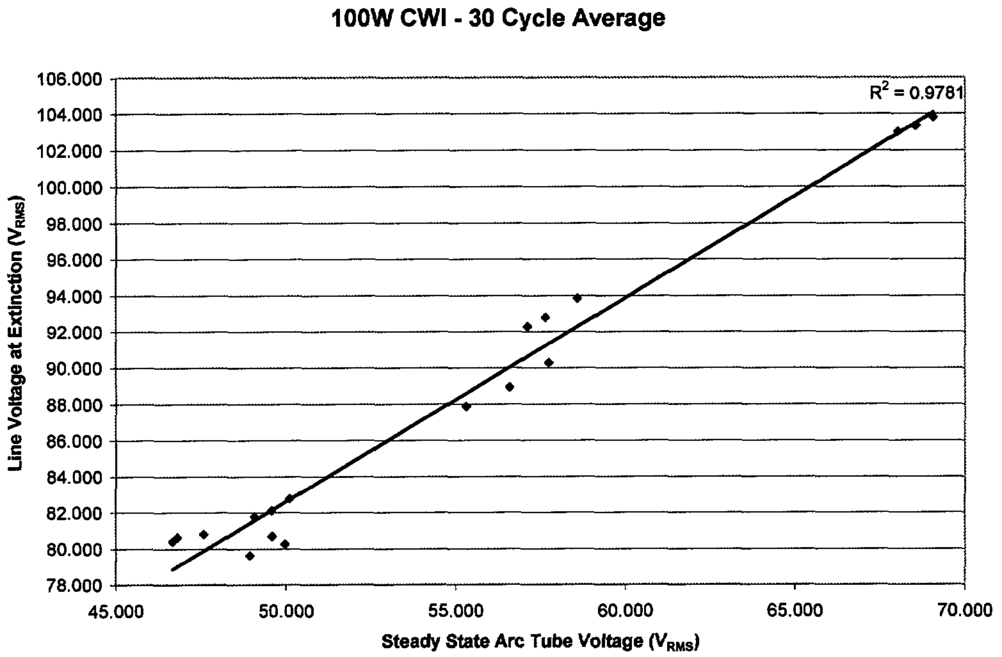


Figure 3.13: *100W CWI ballast: ceramic PTC results*

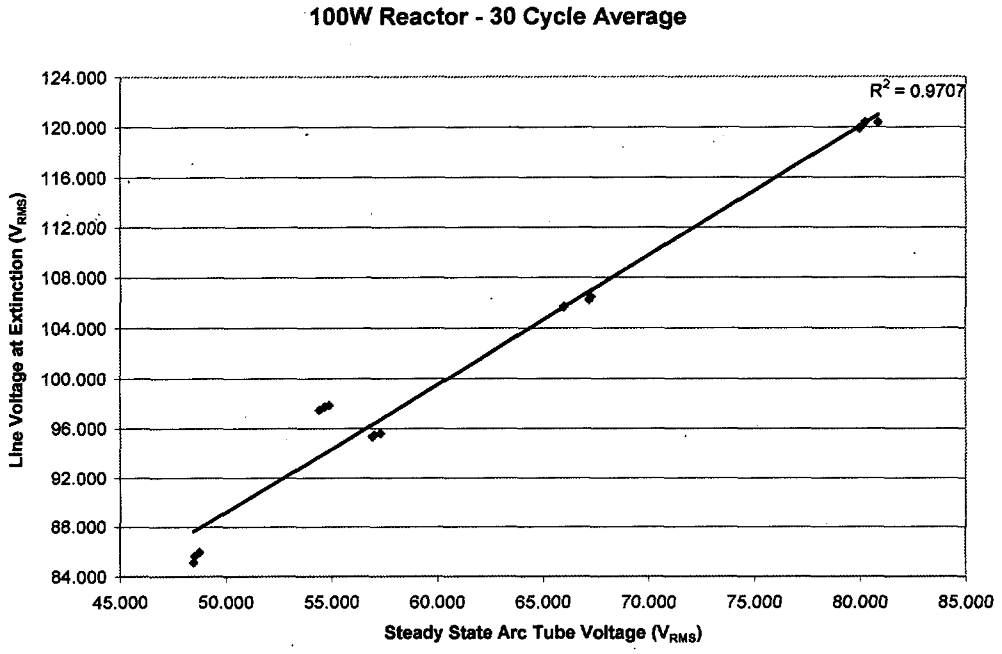


Figure 3.12: *100W Reactor ballast: ceramic PTC test results*

3.2.2 *Conclusion*

Creating and measuring a temporary voltage sag that forces a high pressure sodium lamp arc to extinguish is a powerful concept that can be used to estimate the age of a lamp. Each of the correlations shown in Figures 3.8-3.12 is much stronger than the original insertion resistance correlations derived from the early parts of this research endeavor (see Figure 3.2). If implemented in an intelligent and cost effective manner, this concept could be used by utility companies to track the remaining life of lamps installed on their respective lighting systems. A test could simply be run in the morning when a lamp would normally be switched off by its photocontrol as the sun rises. This prevents any unnecessary ignitions of the lamp which could lead to shorter lamp life.

Additional tests were performed with higher wattage lamps, however, the CPTC used in the 100 Watt tests tripped almost immediately due to the large amount of current that is present (3+ Amperes) in 250W and 400W ballast/lamp systems. Two CPTC's were connected to the lamp in parallel to try and remedy this problem. The results that were taken from this showed that the voltage sag occurs too slowly and allows the ballast time to recover and keep the lamp ignited until the voltage drops to a level that no longer gives the ballast enough power to operate.

3.2.3 *Future Work*

As a continuation of this research, another CPTC will have to be chosen with appropriate trip parameters that will cause the voltage sag to occur at a rate similar to the 100 Watt tests. Only with this data will it be known for sure that higher wattage lamps will react in the same manner as lower wattage lamps using a CPTC. It can be speculated that there will not be a problem however, because in a paper by Dorr (1997), it was demonstrated that 400 Watt lamps are more susceptible to voltage sags as lamp voltage rises.

CHAPTER 4
PRACTICAL IMPLEMENTATION OF A HPS LAMP ASSET MANAGEMENT SYSTEM

4.1 Smart Lamp Replacement

There are several advantages of implementing a Smart Lamp Replacement system over the present "Group Re-lamping" system. First, customer service is improved. Aside from emergencies and unexpected problems, customers would no longer need to call the utility company to report a failed streetlamp. The utility will already have data that will project when the lamp should be replaced and thus perform the task at a convenient time before the failure occurs. Second, extending the life of streetlamps from 4 to 5 years to approximately 8 years will save utilities hundreds of thousands of dollars annually (per 100,000 lights) based on an economic study performed (see Appendix 6). This is also based on data provided by PHI lighting on the costs of the present utility system method of maintaining streetlights.

The goal of "Smart Lamp Replacement" is to provide utility companies with the information they need to actively maintain the lighting system with little need for customer input. If utilities knew the status of all of the streetlights on their respective systems at all times, it would sharply decrease the need for unexpected trips to various locations. Replacements could be planned in zones as is done now with only lamps near the end of their useful life being replaced. In addition, replacements could be completed in conjunction with other more pressing work that needs to be done in a particular area (i.e. storm recovery, reconductoring, transformer replacement, etc...). These are the reasons a smart photocontrol system is needed and the following sections will describe how the technology developed during this research and described in this thesis could contribute to its realization.

4.1.1 *Smart Photocontrol Specifications and Requirements*

A consortium consisting of PHI Lighting, Dark to Light Photocontrols, Public Service Electric and Gas (PSE&G), and Conectiv met with Rowan University in October of 2002 to discuss the requirements and design constraints of the prototype smart photocontrol data acquisition system (SPDAQ). Table 4.1 summarizes the features that were considered during the development of the prototype system.

Though determining lamp life is of primary importance, the scope of desired capabilities of the SPDAQ is much wider. A feature that is very much desired by various members of the consortium is the ability to control the time of day/night the lamp turns off and on. This would include the ability to disable the lamp for customer non-payment. Since this would require the service person to send data to the photocontrol a transceiver is needed. Another option requested be in the SPDAQ prototype is the ability to monitor various ballast and lamp conditions other than lamp life, the most important of which include: power consumption, power quality (i.e. power factor, voltage regulation, harmonics, etc...), capacitor failure, photocontrol drifting (i.e. phototransistor becomes more/less sensitive to light), and inconsistent operation. When developing the first SPDAQ Rowan included as many of these features as possible within the time frame given to produce the product.

Table 4.1: *Smart photocontrol data acquisition system prototype requirements*

Smart Photocontrol Capabilities	
1. Lamp life monitor:	Implement PTC system and detect lamp arc extinguishment
2. Unique ID System:	Each photocontrol has a ID number stored in the microcontroller so it can be uniquely identified during communication
3. On/Off Control:	Change turn on/off times of streetlamp and turn off for customer non-payment.
4. Monitor ballast/lamp conditions:	Power to fixture, power quality, starter functionality, lamp condition (other than end of life), installed lamp size, capacitor failure, photocontrol drifting, inconsistent operation, vibration or impact, meter energy use.
5. Bi-directional half-duplex wireless communication:	Drive-by communication with photocontrol to collect data and/or change lamp turn on/off settings
Personal Digital Assistant (PDA) Capabilities	
1. GPS Receiver:	Record GPS location of the photocontrol during installation and use this information to aid in locating the device in the future.
2. Bar Code Reader:	Scan various bar codes associated with the luminaire, photocontrol, and utility pole to obtain information on the products. Store this information in a database.
3. Records service completion data:	Records service completion data to the Central Database of the utility company when the PDA is synchronized.
4. Communicate with photocontrol:	Must have the capability to communicate wirelessly with the photocontrol and save data in a database.
5. Received signal strength:	Strength of signal aids service person in finding the location of the photocontrol
PDA Database Capabilities	
1. Store fixture information:	Unique ID #, lamp type, ballast type, photocontrol and lamp installation dates, additional service dates, GPS location
2. Store lamp performance data:	PTC test reading, high and low line voltage at location, energy use, time (hours, days, and/or weeks) since last read.
3. Interface with Customer Information System:	Gather reported problems
4. Interface with the Internet:	Gather customer reported problems sent via the Internet
Miscellaneous Requirement	
1. Cost Benefit Analysis	Demonstrate the savings a utility company will incur during the phasing in of the Smart Photocontrol System.

4.2 Enabling Technology

The technology that will provide the means to implement the lamp life measurement portion of the asset management system can be embodied in a photocontrol. The current prototype does not include all of the functionality and requirements of a traditional photocontrol [34] since resources were focused on proving that the PTC concept is viable. The design is simple and is able to provide the voltage sag data needed to determine when a lamp should be replaced. The schematics and Bill of Materials for the first smart photocontrol prototype can be found in Appendix 7.

4.2.1 Core Hardware

The microcontroller chosen to implement the SPDAQ is the PIC18F252 from Microchip. The device is inexpensive yet provides the memory and I/O capabilities needed to control the SPDAQ circuit. The PIC18F series of microcontrollers can be programmed in ANSI C using the Microchip ICD2 (In-Circuit Debugger). This is an excellent feature that speeds development time and allows one to troubleshoot hardware and software with ease. The microcontroller is equipped with 23 I/O pins, all of which are used in the prototype design. There is 32kB of program memory along with an internal 256B EEPROM.

One of the more significant components utilized in the SPDAQ prototype is the Analog Devices ADE7753 single-phase power IC. The ADE7753 is a low-cost power-monitoring chip that has many capabilities and conveniences that eliminates the need for an oscilloscope as well as the abundance of post-processing in MATLAB that had to be done in previous test procedures [36]. The main purpose for the ADE7753 is to measure the real power being absorbed by the lamp. When the lamp arc extinguishes a significant drop in real power occurs. Therefore, this will determine when the arc tube has extinguished. There will be no photovoltaic cell near the luminare to show when the lamp arc has extinguished and determining real power is actually a superior alternative. The IC also has the ability to measure reactive power, RMS voltage, and RMS current. The power IC communicates with the microcontroller through the serial peripheral interface (SPI). SPI generally utilizes three wires to establish communication between two compatible devices. One of the wires is typically labeled Chip Select and is used to activate the device to be accessed. The remaining two SPI ports are entitled serial-data in (SDI) and serial-data out (SDO). As the names suggest, SDI receives serial data from the microcontroller and SDO provides data from the ADE7753 (or other SPI device) to the microcontroller. This device is very powerful and provides the functionality needed to monitor the power quality of the streetlighting fixture.

The flash memory on the microcontroller is not sufficient to store the magnitude of data that will be collected in the field during the prototype stages of the project. Therefore, an external EEPROM is used to store the data. A 25LC640 by Microchip is the chosen flash memory module for the prototype system. Like the ADE7753, the 25LC640 also operates on the three-wire SPI interface. It is capable of storing up to 64kb (8192 x 8 bits) of data.

The power supply has been designed to meet the maximum power requirements of the circuit (i.e. ~1 Watt), while conforming to a small footprint in order to keep the size of the prototype to a minimum. A center tap power transformer with a 120V primary and 10V/150mA secondary is used as the main component of the DC power supply. The center tap is utilized as the ground for digital components so there is minimal noise interference with the analog measurements taken by the power IC during a CPTC test. After rectification, the DC voltage is presented to 5 and 3.3 Volt voltage regulators to provide the appropriate power to the rest of the circuit.

4.2.2 CPTC Test Implementation

The microcontroller polls the voltage input provided by a silicon light sensor on the photocontrol that varies in voltage throughout the day and night. When a particular threshold is reached at dusk, the microcontroller performs a subroutine that applies 5 volts to an NPN transistor circuit and proceeds to activate a power relay thus providing power to the lamp. When a similar threshold is reached at dawn the microcontroller once again executes a subroutine that activates a second relay and deactivates the first relay. This puts the CPTC in series with the lamp circuit. The starting resistance for the CPTC is approximately 3.7 Ω [30], which may cause the lamp to dim slightly upon insertion. The current being drawn by the ballasts during testing are above the CPTC hold current of 0.46A, therefore, the thermistor begins to become heated and increase in resistance. Based on Ohm's Law (V = IR) it is known that an increase in the resistance of the CPTC will cause the voltage drop across the CPTC to increase. During the voltage sag, the ballast struggles to maintain the lamp arc. Once there is not enough potential available to provide the ballast with the power it needs to sustain the arc, it extinguishes. After extinction the activated relay is switched off, thus disconnecting power from the lamp/ballast circuit.

The schematic in Figure 4.1 illustrates the PTC and relay portion of the circuit. The port labeled "LINE" is voltage coming in from the line voltage of the power system. "120VAC" is a port through which current flows from the relays to the load.

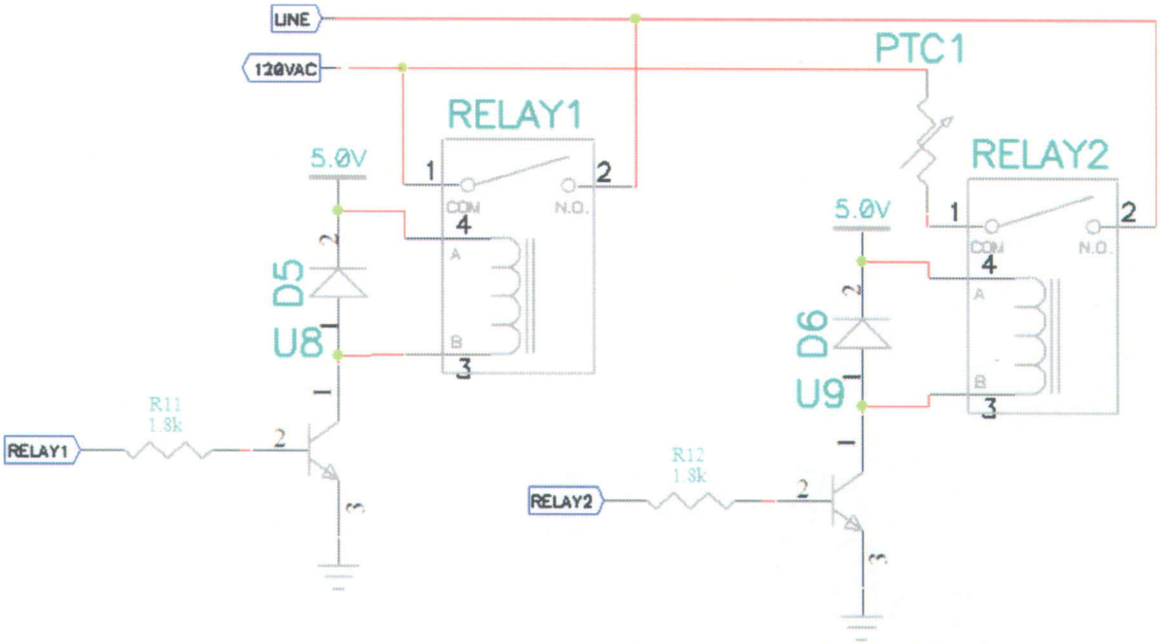


Figure 4.1: *CPTC and relay control portion of the SPDAQ prototype circuit.*

4.3 900 MHz Data Telemetry Circuit

A primary element of the SPDAQ prototype is its ability to send and receive data. Two scenarios involve a utility vehicle driving by the device to collect lamp life data and a service person sending commands to the SPDAQ's transceiver to change turn on/off times, shut off the lamp for non-payment, change PTC test frequency, etc. Driving past the fixture to collect lamp life data will be a passive process that will occur automatically without intervention by the driver. The transceiver in the vehicle will receive commands from the PDA commanding it to send a signal to that will prompt the SPDAQ transceiver to send lamp life data (i.e. 30 cycle average voltage sag data). When multiple lamps are present the PDA will place them in a queue and save the data being sent one at a time.

The following sections will give a detailed background of the transceiver circuit itself and will be followed by an explanation of the PDA interface functionality in the SPDAQ prototype system.

4.3.1 *Custom RF Design vs. Xemics Module*

The search for a transceiver with a transmission range of greater than 100 meters for approximately $3.00 (quantity of a million) led to Xemics Inc. During early trials the Texas Instruments TRF6901 was used, however, the maximum transmission range was approximately 100 meters. This meets the minimum requirements, but the prototype must guarantee greater than 100 meters in a real world environment including degradation factors such as signal multipath and fading. The XE1203 ensured reliable transmission with a range of several kilometers which is more than adequate. The schematic on the following page (Figure 4.2) is a design that was adapted from a Xemics reference board for the Xemics XE1203 transceiver. Minor modifications were made to make the board compatible to the main SPDAQ board. The physical board layout and bill of materials for the design is located in Appendix 6. Once the design layout was completed quotes were gathered for both manufacturing the boards and placing the surface mount components. The average cost of fabrication and assembly for five (5) transceiver boards was $800 to $1000. A tested transceiver module designed by Xemics and guaranteed to work cost just $52 per device. While fabricating the custom board in very large quantities would prove to be more cost-effective than purchasing the Xemics module, for low-volume prototype production the ready-made transceiver became the more attractive option.

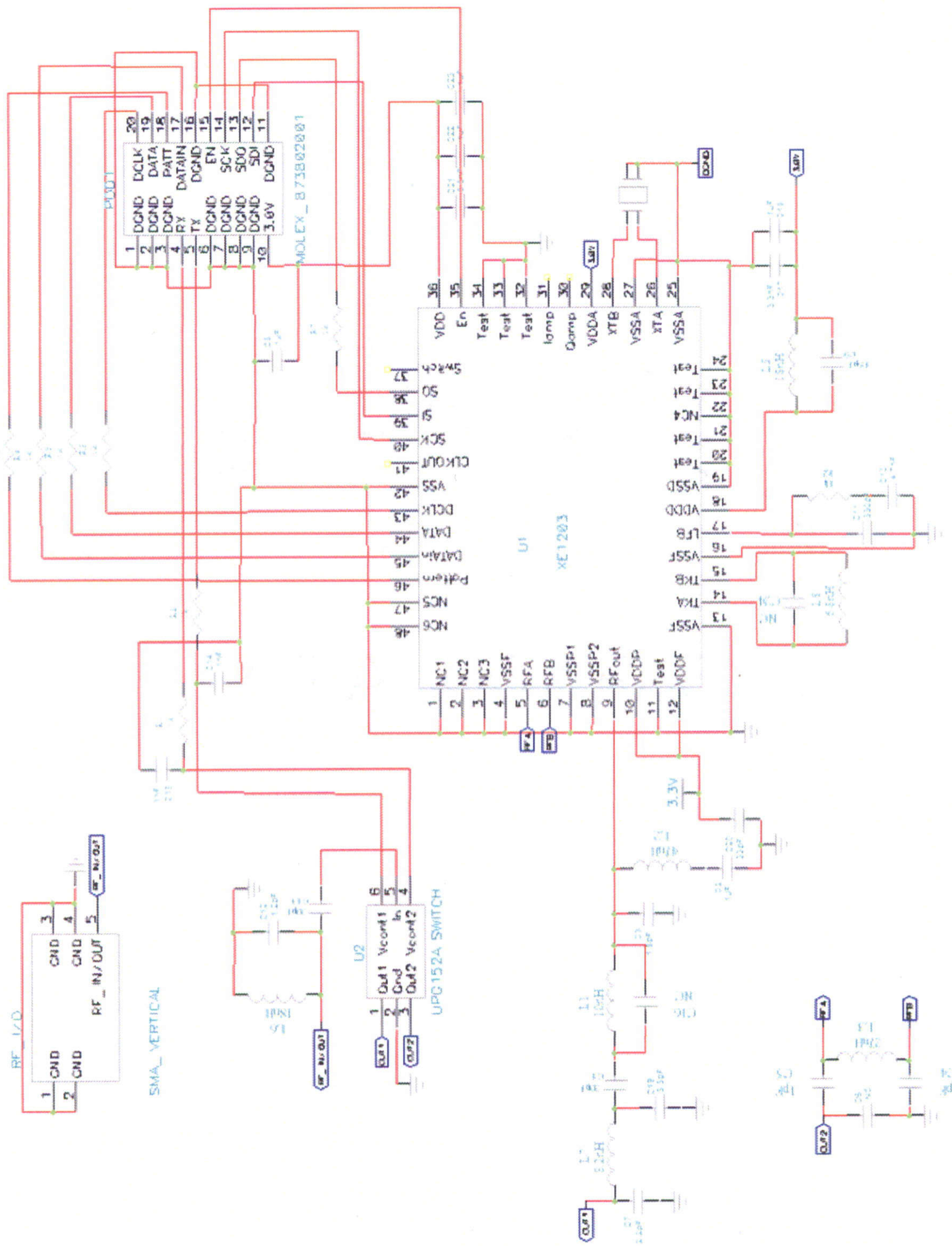


Figure 4.2: *Custom transceiver circuit schematic*

4.3.2 *Overview of Wireless Infrastructure*

The radio frequency chip chosen to implement the data telemetry system is the Xemics XE1203. It is a frequency shift keying (FSK) single-chip ultra-high frequency (UHF) transceiver designed to establish frequency-agile, half-duplex, bi-directional RF link with non-return to zero (NRZ) data coding [35]. In this application the XE1203 will operate in the 902-928 MHz portion of the unlicensed Industrial, Scientific, and Medical (ISM) band. This band is ideal for long-range data communication (up to 1km line of sight) while operating at a reasonable power level. Figure 4.3 is an internal block diagram of the IC [35].

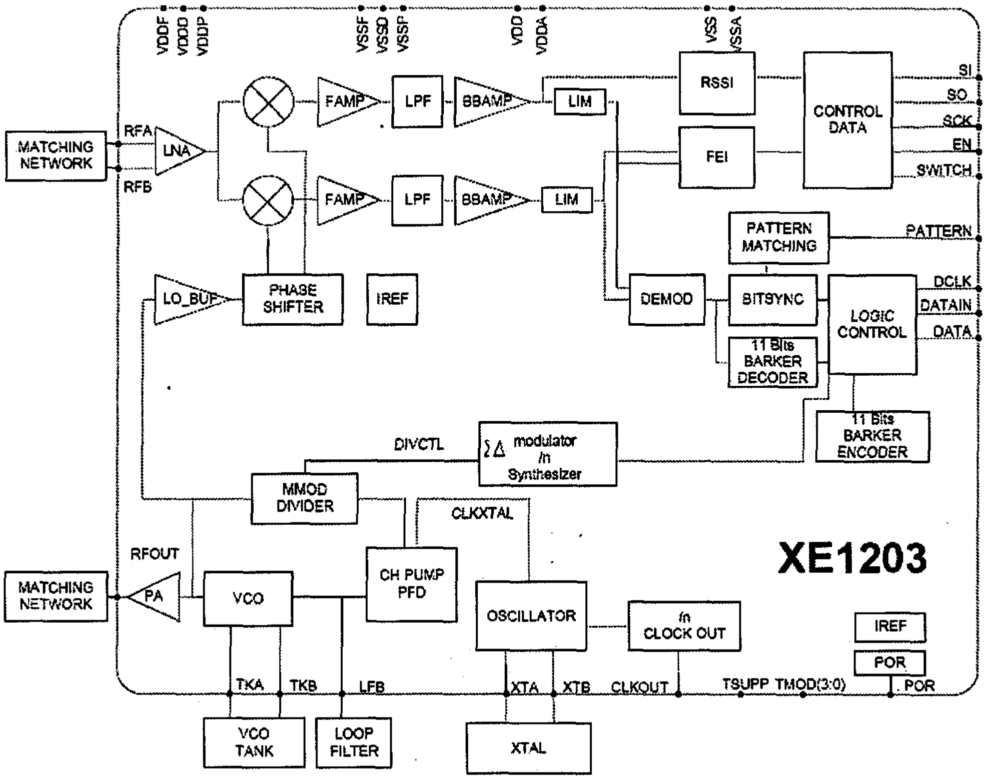


Figure 4.3: *XE1203 Transceiver Architecture*

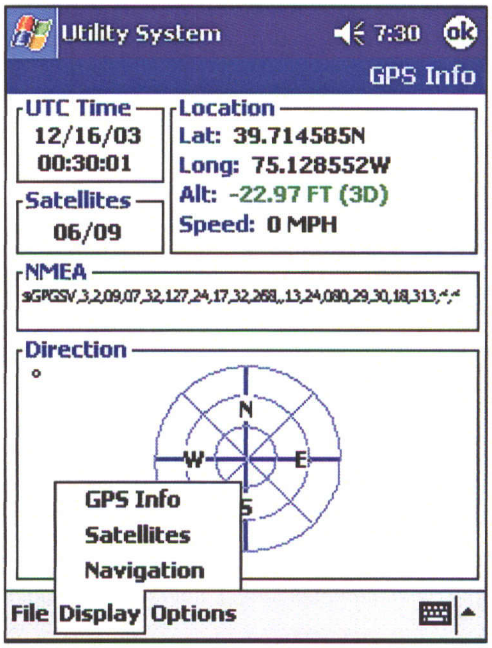
4.4 Data Collection

Data will be collected from SPDAQs installed on existing and new streetlamps. An integrated system of hardware and unifying software has been developed in Microsoft embedded Visual Basic (eVB) that will handle the installation of the SPDAQs and simultaneously build an eXtensible Markup Language (XML) database that will store all of the data collected during the prototype phase of the project. The main components of the utility vehicle side of the prototype system are a PDA (iPAQ H3970), barcode scanner (Symbol SPS3000), Bluetooth GPS receiver (Socket Communications), and a transceiver module (XE1203) that connects through the serial port of the PDA. Figure 4.4 contains the GPS receiver, barcode scanner (which fits around the PDA), and the PDA itself. The software aspects of the system have been shown to be effective in the field [37]; however, a more rugged version of the PDA will be required when put into production due to the high probability of the device being accidentally dropped or damaged during the installation of utility pole equipment [38].

Figure 4.4: *GPS (Left), PDA (Center), and Barcode Scanner Sleeve (Right)*

4.4.1 *Smart Photo Control Installation Process*

It is common for utility companies to use a geospatial information system (GIS) to keep track of assets on their power systems. The coordinates inside this system are derived from global positioning system (GPS) coordinates. Thus, an ideal method of finding and recording new and existing installations is to use a GPS to record location. The GPS receiver by Socket Communications is used for this purpose. Custom eVB software was developed that directly interfaces with the receiver and uses the GPS coordinates obtained from it to track the locations of the prototype SPDAQs being tested in the field. Figure 4.5 is a screenshot taken from the PDA (iPAQ H3970) that shows the location, time, and number of satellites in view. The National Marine Electronics Association (NMEA) string is being parsed in eVB, and a compass that, when activated, points in the direction the GPS receiver is moving.



UTC Time
12/16/03
00:30:01

Location
Lat: 39.714585N
Long: 75.128552W
Alt: -22.97 FT (3D)
Speed: 0 MPH

Satellites
06/09

NMEA
`$GPGSV,3,2,09,07,32,127,24,17,32,268,,13,24,080,29,30,18,313,*;*`

Direction
0

Figure 4.5: *GPS screenshot from PDA*

During the SPDAQ installation process it is important to record all of the necessary information so when the lamp life data is collected it can be associated with the correct fixture. A "wizard" program is included in the GPS program shown above. Figure 4.6 is the introduction screen that appears when the program is executed. This program begins explaining the process to the user. Upon pressing "next" the user is prompted to scan (via the barcode scanner connected to the serial port) or manually enter the barcode/pole number of the utility pole where the photo control is being installed as well as for the photo control itself. Figure 4.7 is a screenshot of the program. Following this step the GPS coordinates for the present location of the GPS receiver is automatically captured once a 3D fix is obtained. A 3D fix is obtained when there are at least 3 satellites being used to obtain the coordinates. This assures that the location data recorded is as accurate as possible. If the user is unsatisfied with the coordinates that were captured, the operator can press the "recapture" button to restart the process. In addition, below the "GPS Info." section is a list that allows the user to select the type of fixture being installed along with the wattage of the lamp. Figure 4.8 displays the location capture and light information screen. Once the summary screen is shown, as in Figure 4.9, the user can either choose to go back and correct any inaccurate or missing information, or press "Finish" to save the information into an XML database. A flow chart of the program and the eVB code is located in Appendix 7.


Utility System 7:27

Add New Wizard

Welcome to the Add New Photo-Controller Wizard!

This wizard will assist you in adding a new photo-controller to the database.

Step 1
Requests information about the photo-controller and pole's serial numbers
Step 2
Requests information about it's location and light information

Figure 4.6: *"Add New Photo Control Wizard" introduction screen shot*

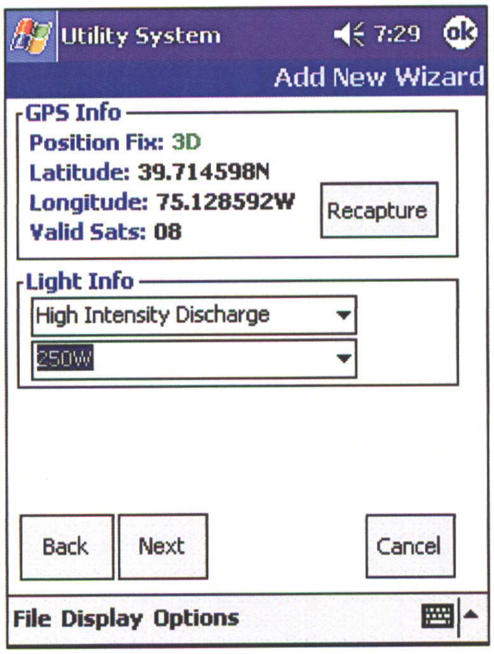

Utility System 7:28

Add New Wizard

Photo-Controller
○ **Manual Input**
● **Barcode Input**
Bar Code: 034138203323

Light Pole
○ **Manual Input**
● **Barcode Input**
Bar Code: 034138203323
Extra Info:

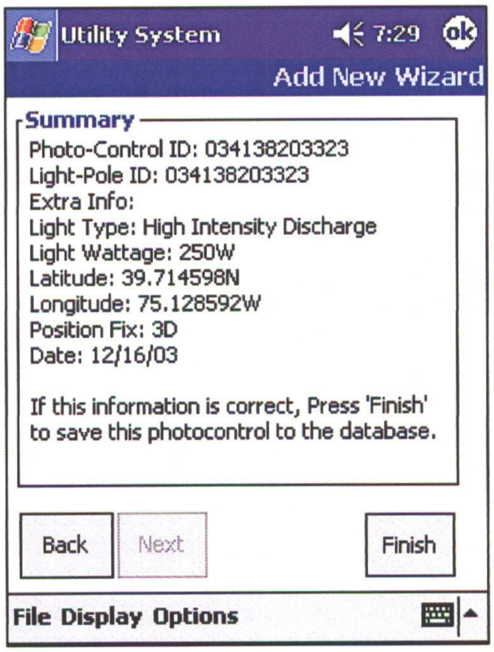
Figure 4.7: *Manual or barcode scanner data collection screen shot*



GPS Info
Position Fix: 3D
Latitude: 39.714598N
Longitude: 75.128592W
Valid Sats: 08

Light Info
High Intensity Discharge
250W

Figure 4.8: *GPS capture and light information screen shot*



Summary
Photo-Control ID: 034138203323
Light-Pole ID: 034138203323
Extra Info:
Light Type: High Intensity Discharge
Light Wattage: 250W
Latitude: 39.714598N
Longitude: 75.128592W
Position Fix: 3D
Date: 12/16/03

If this information is correct, Press 'Finish' to save this photocontrol to the database.

Figure 4.9: *XML database summary screen shot*

4.4.2 *Data Transfer Protocol*

The data collection process is initiated by a transceiver circuit connected to a PDA device in the utility vehicle. The transceiver located within the SPDAQ will be constantly evaluating any RF signals it may detect. The device will be programmed to look for a specific "wake-up" pattern that should be encoded into the beginning of every signal sent by the transceiver in the utility vehicle. Once the "wake-up" pattern has been recognized the first thing the microcontroller does is send an identifying message through the SPDAQ's transceiver (i.e. "I am SPDAQ-000175"). When recognized and prompted the microcontroller retrieves the requested data from the EEPROM on board the SPDAQ. It then passes this information onto the transceiver which will modulate and send it to the vehicle as it is driving by. The PDA that is attached to the transceiver module in the vehicle monitors all of the lamps in the area. If multiple lamps are detected at the same location, they are placed in a queue and accessed one at a time until all of the data has been collected. Once all of the information from the SPDAQs has been downloaded successfully, the SPDAQs are informed to "sleep" by the microcontroller on the utility vehicle side. After this the SPDAQs return to a sleep or off state for a specified amount of time so it does not interfere with the data collection of other lamps in the immediate area. Figure 4.10 provides a visual illustration of the data collection process.

Figure 4.10: *Illustration of vehicle communicating with smart photo control.*

4.5 Smart Photocontrol Data Acquisition (SPDAQ) Prototype Software Development

The majority of the software development for the SPDAQ prototype has been completed in ANSI C using a PIC18F252 microcontroller. Two modules work simultaneously to give the circuit full functionality. The first module consists of all of the code necessary to control the ADE7753 power IC and the EEPROM. The second module contains the code that operates the XE1203 transceiver module and controls the logic that implements the PTC test. In this thesis the modules will be treated separately at first and this section will end with explaining how the two will be integrated to act harmoniously.

4.5.1 *Capturing Real Energy Data*

The data capture circuit is located on the motherboard of the SPDAQ prototype shown in Figure 4.11. During the PTC test process the microcontroller must have the ability to realize when the lamp has extinguished once the voltage sag occurs. This is the primary function of the ADE7753 power IC. Upon providing power to the SPDAQ the measurement circuit is initialized by writing values to the mode register. This sets various parameters that configure the power IC to operate under the conditions of the SPDAQ circuit. After the initialization is completed, an interrupt is set, which detects the zero crossings of the 120-Volt AC line voltage after the PTC. This is used to synchronize V_{rms} measurements to minimize ripple in the collected data. The status of the interrupt is

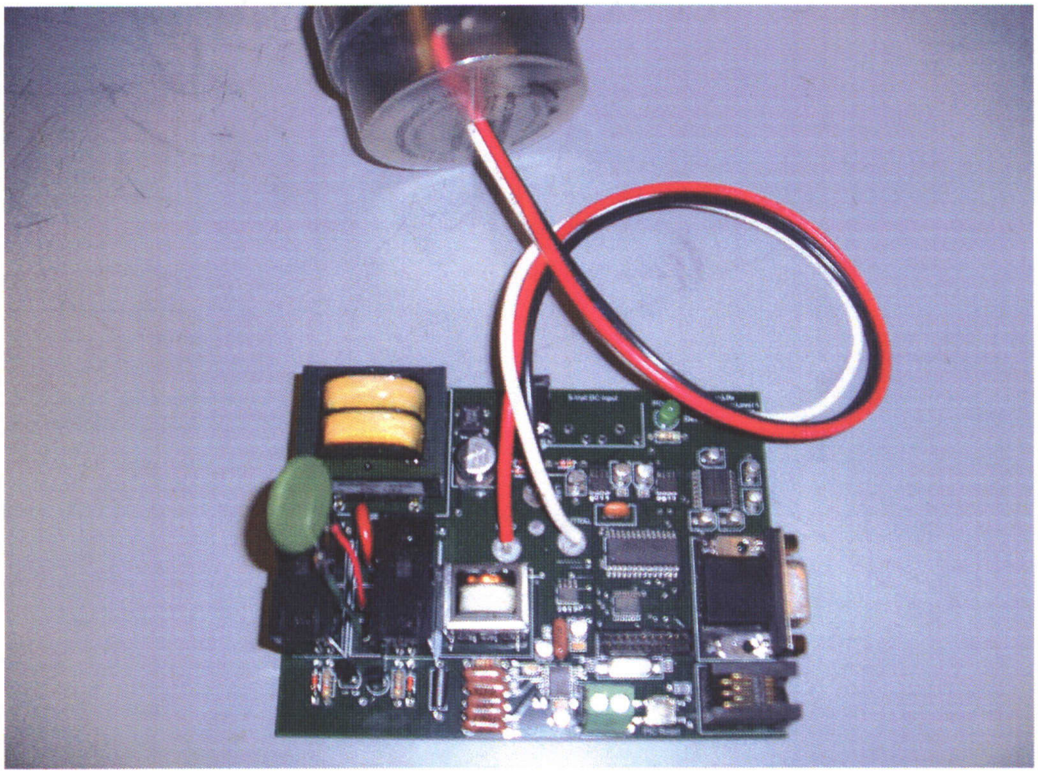


Figure 4.11: *Photograph of smart photo control prototype main board*

reset before and after V_{rms} readings to properly detect an interrupt condition. A detection is made if a particular bit in the status register is set or at a logic '1'. The value received after a logic '1' occurs is stored in the EEPROM. After V_{rms} is stored, an interrupt status for the line cycle accumulation register is enabled. This is used to detect when the active energy data from the energy-metering device is ready to be processed. The same process used to read the V_{rms} register is repeated to read the active energy register. The status of the interrupts is reset before and after active energy readings. When a logic '1' is detected the active energy register is read and the value recorded into the EEPROM. After there has been more than two energy and V_{rms} readings, the energy previous two energy values are compared to see if there is a significant accumulation in energy. Once the microcontroller determines that the energy accumulated has dropped significantly, the data capture process ceases and the last 30 cycles that were recorded are kept in the EEPROM for analysis.

The power IC now replaces the Agilent Infinium voltage and current probes previously shown in Figure 3.6. The data capture is automated and all of the post processing steps in MATLAB that were required are no longer needed. The power IC has been programmed to record V_{rms} and active energy readings every power line cycle. Therefore the data that was extracted from the instantaneous voltage and current readings obtained from the oscilloscope are now recorded directly. A flow chart that demonstrates the process of recording V_{rms} and active energy data is located in Appendix 8 of this thesis. Additionally, the C code in its entirety is also in Appendix 8.

4.5.2 *Transceiver Module Circuit*

The transceiver module is manufactured by Xemics, the designer of the XE1203 transceiver described in previous sections. The module connects to a header located on the SPDAQ prototype main board that facilitates several connections depicted in Figure 4.12. EN, SCK, SDI, and SDO are the serial peripheral interface (SPI) control paths. These paths are used to enable the transceiver, set all of the internal control registers, and read a few select registers that provide RF signal information (i.e. received signal strength and local oscillator frequency error indicator). There are nine pins connected to a ground plane located on one of the inner layers of the motherboard. A 3.3 Volt voltage regulator is providing the power to the transceiver. DCLK is a pulsed output provided by the transceiver that can be used by the microcontroller to sample the incoming data stream from the receiver. DATA and DATAIN have already been explained in section 4.3.3. RX and TX are connected to an RF switch that is external to the XE1203 chip.

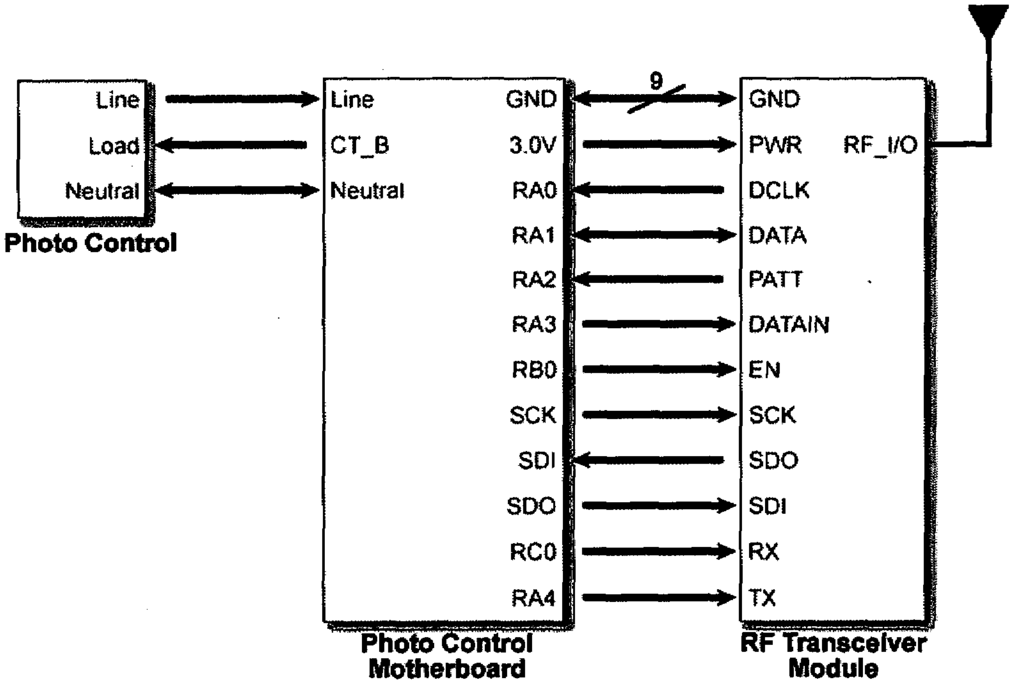
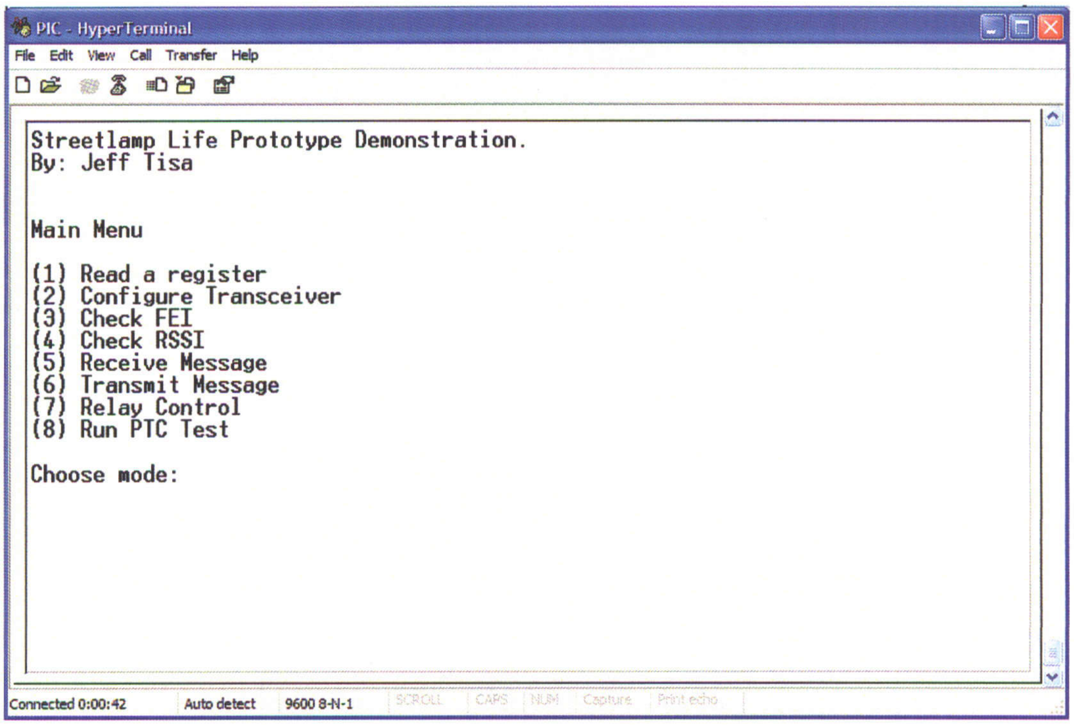


Figure 4.12: *Block diagram of the transceiver interface to the photocontrol motherboard*

This allows the transceiver to use a single antenna for both transmitting and receiving data. The microcontroller merely sends a logic '1' to the RX to receive or TX to transmit and a logic '0' to the other in order to properly setup the antenna.

One very useful feature of the XE1203 is its pattern recognition block. The transceiver can be programmed to search incoming data streams for particular codes that prelude the incoming data to determine whether the data is valid. PATT is an output of the transceiver that provides a logic '1' when the pattern has been matched and a logic '0' otherwise. The pattern recognition block is very helpful in reducing in-band interference.

The software for the transceiver is presently coded to function off of the HyperTerminal interface of a personal computer (PC). Upon booting the PIC microcontroller by providing power to the circuit, several initialization functions are executed. First, in accordance with the XE1203 datasheet, the SI and SCK pins are to a logic '1.' In addition, the 5V to 3.3V TTL level converter (Maxim MAX3001) is activated. This device converts the 5V logic signals of the microcontroller to the 3.3V logic signals needed by the transceiver. Next, the control registers are set to the default values required for proper operation in the 902-928MHz ISM band. After initialization has been completed the menu in Figure 4.15 appears. The user must select an option from the menu. The first option allows the user to read any of the transceiver's control registers. One simply enters the hexadecimal address of the register in the proper format and a function returns the value of that register. The second option allows the user to change the configuration of the transceiver without having to access the source code. This is used mainly for troubleshooting purposes. The third option checks the frequency error indicator (FEI) register. The FEI register provides an indication of the frequency



```
Streetlamp Life Prototype Demonstration.
By: Jeff Tisa

Main Menu

(1) Read a register
(2) Configure Transceiver
(3) Check FEI
(4) Check RSSI
(5) Receive Message
(6) Transmit Message
(7) Relay Control
(8) Run PTC Test

Choose mode:
```

Figure 4.13: *HyperTerminal screenshot of SPDAQ software program*

error of the local oscillator compared with the received carrier frequency. Two conditions must be met for proper operation of the FEI function:

1	$\beta = \frac{2 \cdot \Delta f}{BR} \geq 2$	β = modulation index Δf = frequency deviation of modulated signal BR = input data bit-rate
2	$BBW > f_{OFFSET} + BW_{SIGNAL}$	BBW = baseband filter bandwidth defined by the RTParam_BW register.
		f_{OFFSET} = difference between the carrier frequency and LO frequency.
		$BW_{SIGNAL} = \frac{BR}{2} + \Delta f$

$$Frequency\ Error = \left(\frac{BR}{8}\right) \cdot (\mathrm{int}(Dataout\_FEI(11:0)) \qquad \textit{Frequency error equation } (4.1)$$

Where:

$$Dataout\_FEI(11:0) = Dataout\_MSB\_fei(3:0) + Dataout\_LSB\_fei(7:0)$$

Upon satisfying these conditions, Equation 4.2 must be implemented to convert the binary values received from the register into the frequency error. In the equation, int(x) is the integer value of the signed binary representation of x.

The third option on the menu allows the user to check the received signal strength indicator (RSSI) register. The RSSI is based on the signal at the output of the base-band filter. The RSSI register provides one of four possible 2-bit values that correspond to a range shown in Table 4.1. The threshold values that correspond to VTHR1, VTHR2, and VTHR3, are selected with the RTParam_RSSIR configuration register bit. The overall RSSI range is typically 25 dB.

0	0	$V_{RFFIL} \leq VTHR1$
0	1	$VTHR1 < V_{RFFIL} \leq VTHR2$
1	0	$VTHR2 < V_{RFFIL} \leq VTHR3$
1	1	$VTHR3 < V_{RFFIL}$

Table 4.2: *RSSI status description*

The fourth menu option configures the transceiver to wait for a message from a corresponding transceiver module. It begins the process by processing incoming data from the receiver and searches for a predetermined preamble established in the pattern recognition configuration register. This allows the device to distinguish between real data and noise. Once a "match" has been found the transceiver outputs a logic '1' at the PATT port to the microcontroller. This triggers the microcontroller to begin polling the DATA pin of the transceiver for incoming data. The data is saved to a variable until a stop sequence is encountered. After all of the data has been received it is printed to the screen for the user to view and a confirmation message is sent so the remote device knows that the message was received successfully. The user then has the option to continue searching for data or return to the main menu.

The transmission option in the main menu allows the user to send a message to another transceiver. First, one enters a message into HyperTerminal and presses "Enter." The microcontroller configures the transceiver to transmit then sends the data via rs232 to the DATA or DATAIN pin, depending on whether the bidirectional DATA port option is set. After sending the message the XE1203 waits for a message from the remote device confirming the reception of the message. After the success or failure of the sent message is determined the user is prompted to either send another message or return to the main menu.

4.5.3 *Integration of the Transceiver and ADE7753*

The final two options on the menu in Figure 4.13 ("Relay Control" and "Run PTC Test") are used when executing the PTC test or controlling the relays. The relay control option simply allows the user to switch the relays on and off at will. The "Run PTC Test" option turns on the connected lamp and delays for 15 minutes to allow for arc tube stabilization. After 15 minutes has passed the microcontroller switches the PTC into the circuit and closes the first relay. This begins the voltage sag process. At this time the ADE7753 power IC is monitored and the testing process proceeds as described in previous sections of this thesis. Once the test is complete, the data is saved to the EEPROM and can be recalled to be sent wirelessly upon request.

4.6 Smart Photocontrol Data Acquisition (SPDAQ) System Cost Estimations

The target price of the final production SPDAQ when manufactured in excess of 10,000 units is $30. The cost analysis in Appendix 5 uses this price for the SPDAQ when calculating the money utility companies will save if they implement the smart lamp replacement system. The cost of the first prototype is shown in Table 4.2 along with the estimated costs of the SPDAQ if produced in quantities of 100, 1,000, and 10,000 units. The cost of the first real prototype far exceeds the $30 goal because only 5 units were fabricated and just 3 were assembled. The Table indicates that the cost of fabrication decreases dramatically once the design is manufactured in quantities of 100 or more. Similarly, the cost of parts decreases significantly once quantities reach 1,000.

Quantity	5	100	1,000	10,000
Parts	$119.67	$119.67	$53.01	$45.71
Fabrication	$101.02	$11.34	$7.09	$6.67
Total (Unit Price)	$220.69	$130.83	$58.10	$52.38

Table 4.3: *Cost of the first prototype along with the estimated cost of a similar field prototype if produced in larger quantities.*

The estimated cost, per unit, of 10,000 prototypes is $52.38. This still exceeds the price goal of $30 mentioned above. The circuit used to generate this price is a proof of concept model, therefore, the design process focused mainly on "proving" that the SPDAQ system could be done at a reasonable cost. Given the complexity of the prototype, $52.38 is an optimistic starting point. Now that the SPDAQ concept has become a reality, full attention should be given to reducing the cost to a minimum during the next revision of the prototype circuit in Appendix 6. Several suggestions to aid in completing this task are included in the "Future Work" section in Chapter 5.

CHAPTER 5
CONCLUSION

High Intensity Discharge lighting has provided efficient lighting for almost a century. The modern High Pressure Sodium lamp is at the forefront of efficacy and is the most widely used in the United States. Due to the inefficient method of group re-lamping by utilities a significant portion of the life and economic value of these lamps is not being realized. Implementing a smart photocontrol data acquisition (SPDAQ) system will allow utilities to seamlessly keep track of where there lamps are in their life cycle. Equipping a vehicle that travels often through their service area (i.e. meter reading trucks) with a PDA and transceiver module will ensure that data can be colleted wirelessly from SPDAQs on a consistent basis. This data can be uploaded into the utility asset management system and viewed to determine when lamps will need to be replaced. The voltage sag data shows that the utilities must replace the lamps when the data points taken by the SPDAQs begin to approach the nominal line voltage in an area. This provides an avenue for planning and will prevent the unexpected streetlight outages from customers that interrupt the daily activities of a utility company. Additionally, there will be savings in labor charges for replacing lamps because utilities can now more intelligently group lamp replace. Also, crews can replace lamps near the end of their life while in a nearby area performing other maintenance. No longer will a truck and entire crews have to be put together for the task of simply replacing an isolated streetlight.

5.1 Summary of Accomplishments

The goals and objectives described above have been addressed in this thesis as follows:

1. The method of determining the advancement in lamp life of HPS lamps, called "insertion resistance," has been transformed into a commercially viable solution that can be implemented within the confines of a photocontrol. The ceramic PTC is a variable resistor that effectively inserts a resistance that gradually increases until the lamp arc extinguishes. This is similar to the original idea that inserts different resistances until one is found that turns the lamp off. If the resistance values that were used to extinguish the lamp arc by lowering the line voltage are plotted against lamp voltage (actual indicator of lamp life), a linear correlation is seen. The work of this thesis has taken this rudimentary method of guessing and transformed it into a test that shows consistent results every time. The CPTC effectively does the same job as inserting a resistor, however, one is more concerned about the voltage of the line when the lamp arc extinguishes rather than the value of the resistance itself. This is a more simplistic solution and very attractive to implement over the previous method.
2. In parallel with the discovery of a better way to accomplish the "insertion resistance" theory, several advances were made in designing a circuit that would make such a smart photocontrol data acquisition (SPDAQ) system possible. The advent of the ADE7753 power monitoring IC has provided a means of determining when the lamp has turned off once the PTC is in line with the HPS lamp circuit. Monitoring real energy accumulation is ideal because the

ballast/lamp combination is using significantly less power once the lamp arc is extinguished.

3. A wireless communication scheme for the SPDAQ prototype has been a prime request of the consortium that provided the funding for this research and development endeavor. The unlicensed 900MHz ISM band was decided upon for data communication because of its rather long range communication ability at a relatively low power level. It is ideal for a data telemetry application such as drive-by data collection. Eventually, the XE1203 transceiver was decided upon based upon its costs and appropriateness in the implementation of a pilot system. Software was developed to successfully communicate data and send commands back and forth between two Xemics units.
4. An initial prototype circuit that contains near full photocontrol functionality has been completed after several revisions over the past eighteen months. The circuit is capable of being powered by either a separate DC source or directly from the streetlamp fixture that is to be monitored. The circuit contains all of the switching elements and components required to implement the PTC tests that were previously done using the oscilloscope and MATLAB. It eliminates the need for post-processing of the scope data and will greatly simplify the collection of additional data to further show the validity of this concept in the future.
5. A prototype PDA interface to a GPS receiver and the transceiver circuit has been completed. This program allows the user to view GPS data from any Bluetooth receiver as well as enter new photocontrol data through either scanning the barcode of a pole via a connection to the PDA serial port or entering the

information manually. It also saves the data to an efficient XML database within the PDA and allows one to recall the information entered at any time. The interface to the transceiver is in the beginning stages, however, rs232 communication has been established and the microcontroller is capable of sending data it has received wirelessly to the PDA.

6. A patent is being developed and will be submitted in the next 3 months.

5.2 Recommendations for Future Work

Several areas of this thesis should be pursued further if a true field prototype is to come to fruition. First, testing of various lamp wattages on different ballasts must be continued. The labor intensive process involved in this task should be eased once the prototype circuit is fully implemented. In addition, revisions to the circuit disclosed in this thesis should be made to correct errors and increase its cost-effectiveness. The most important of which include:

1. The addition of a pull-up resistor in the ADE7753 circuit (from IRQ to the 5-volt rail).
2. Correcting the head size for the transceiver module to fit properly on the board without modification
3. Eliminating the 9-volt battery section from the circuit
4. Replacing the metal-film resistors with carbon film resistors. The low-tolerance of 0.1% is not a necessity for this application and costs will be reduced dramatically.
5. Choosing relays that operate on 5-volts and have a smaller footprint..

6. Including a silicon photo sensor and connect it to the microcontroller.
7. Connecting the enable of the MAX3001E TTL translator to the 5-volt power rail. Even better, eliminate the MAX3001E altogether (e.g. Use a 5 volt transceiver module instead of the 3.3 volt XE1203, use a different TTL translator to reduce costs).
8. Creating a round circuit board pattern with holes for mounting onto a standard photocontrol body.
9. Connecting the SPI ports of the EEPROM directly to I/O ports on the microcontroller instead of the SPI bus.

In the software realm of the project, the final integration that will give the prototype full functionality must be completed. The transceiver can communicate, however, its operation is not seamless and there are bugs in the code that should be addressed. The main transceiver problem is eliminating interference and sending and receiving "clean" data on a consistent basis.

Upon the completion of the circuit revisions and software corrections that will lead to a field worthy prototype, it is of utmost importance to acquire real-time field data. Smart photocontrols need to be installed by PSEG and on campus at Rowan University. Those continuing this work should use the PDA and its corresponding transceiver module to collect this data on a weekly basis to determine whether data is being saved and retrieved appropriately. Given that the collected data is accurate, it can then be used to further show the validity of this concept and how it can quickly aid in helping utility companies in their struggle to reduce costs and provide more efficient and effective street lighting systems.

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TABLE OF APPENDICES

Appendix A: Influences on HPS Lamp Voltage Rise

Beginning with the ratio of sodium and mercury contained in the amalgam mixture located behind the electrode of the lamp, a chain of influences encompasses the primary cause of arc tube voltage rise, changes in electric field strength. The electric field strength of a high pressure sodium arc discharge is directly influenced by the partial vapor pressure of the sodium and mercury. The partial vapor pressure, and therefore the electric field strength, is primarily dependant upon the sodium-mercury ratio and temperature of the amalgam. Figure 1 is a representation of data collected by Jacobs [22] that displays the electric field strength as a function of the mercury vapor pressure for three different sodium pressures. The inner diameter of the discharge tube used is 7.8 millimeters, schematically shown in the upper left corner for the figure. The data was obtained using a spectral power distribution of sodium D lines that exhibits a relationship between the sodium P_{Na} and mercury P_{Hg} vapor pressures.

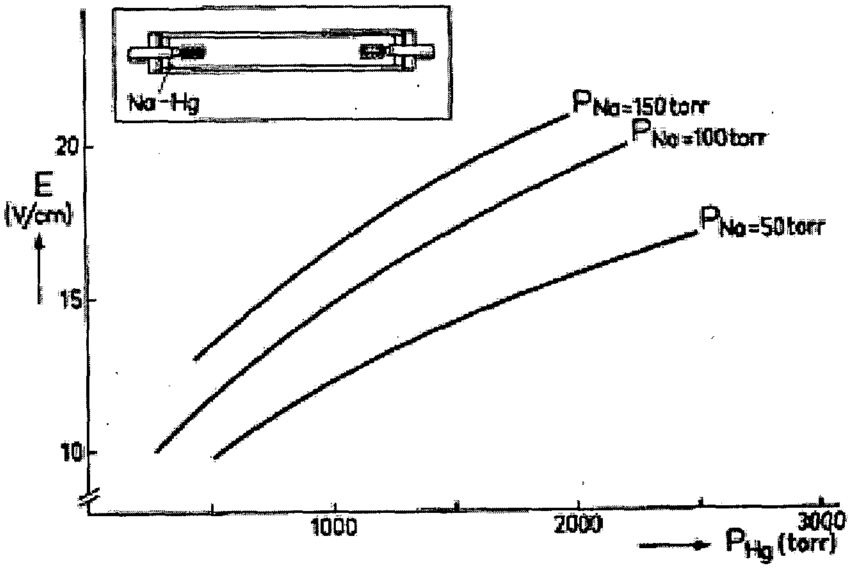


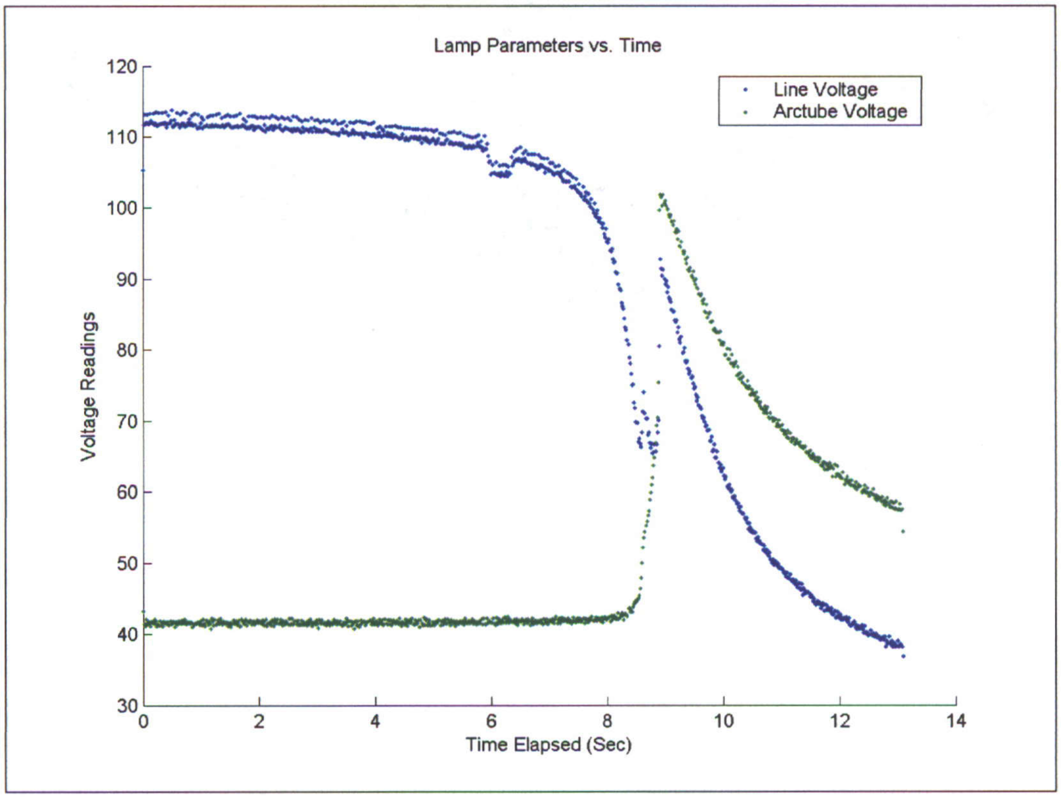
Figure 1: *Electric field strength of an HPS lamp vs. partial vapor pressure of mercury*

In conclusion, the primary factor that causes arc tube voltage rise is changes in electric field strength. Through the partial pressures of sodium and mercury influenced by the temperature and composition of the amalgam, as a lamp ages the arc tube voltage rises steadily until it is no longer supported by the ballast.

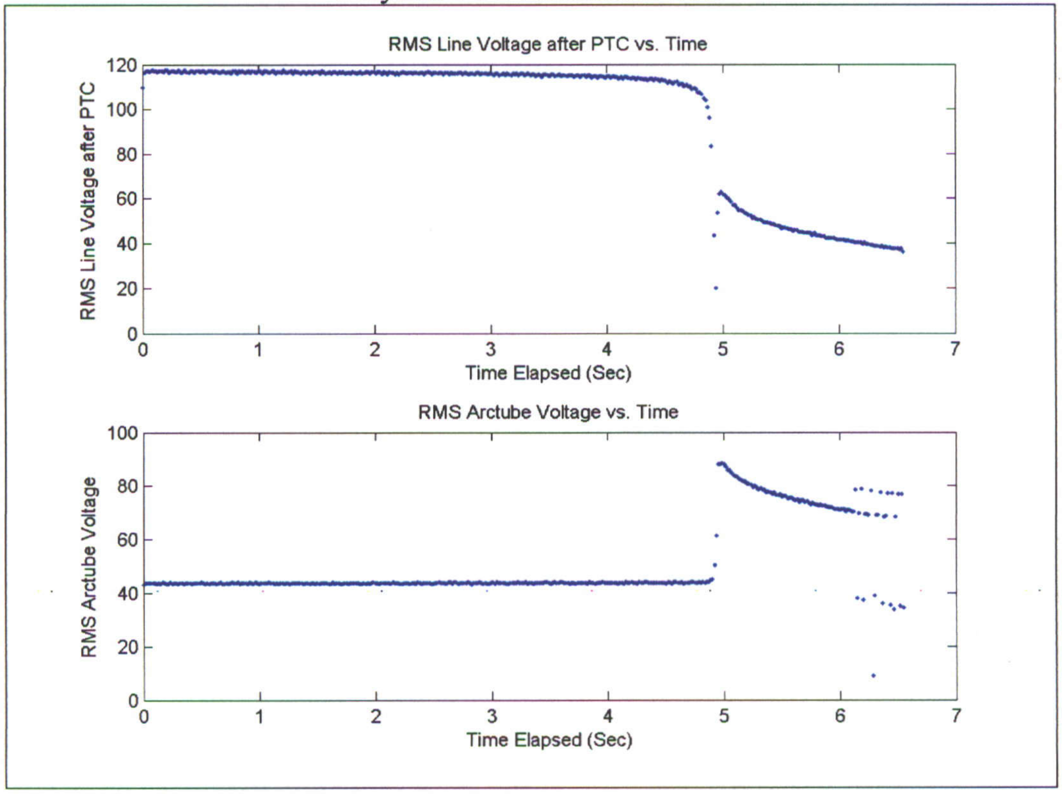
Appendix B: Polymer PTC vs. Ceramic PTC Data

CWA Ballast

Ceramic PTC Thermistor Test

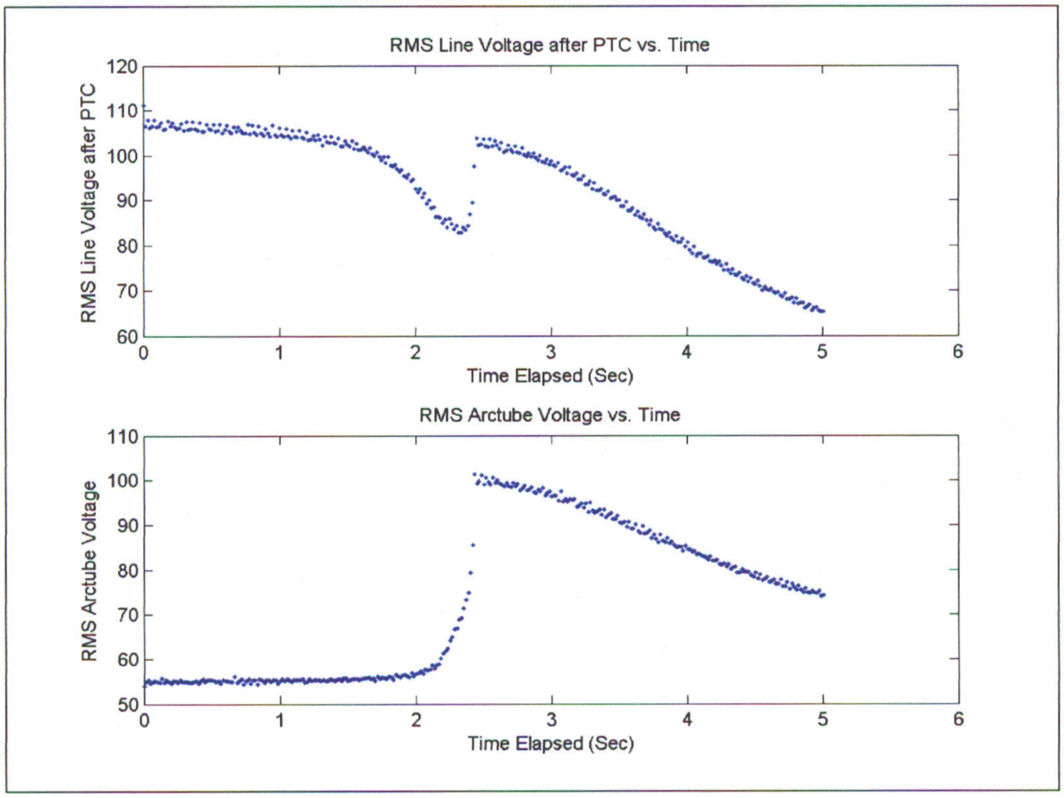


Polymer PTC Thermistor Test

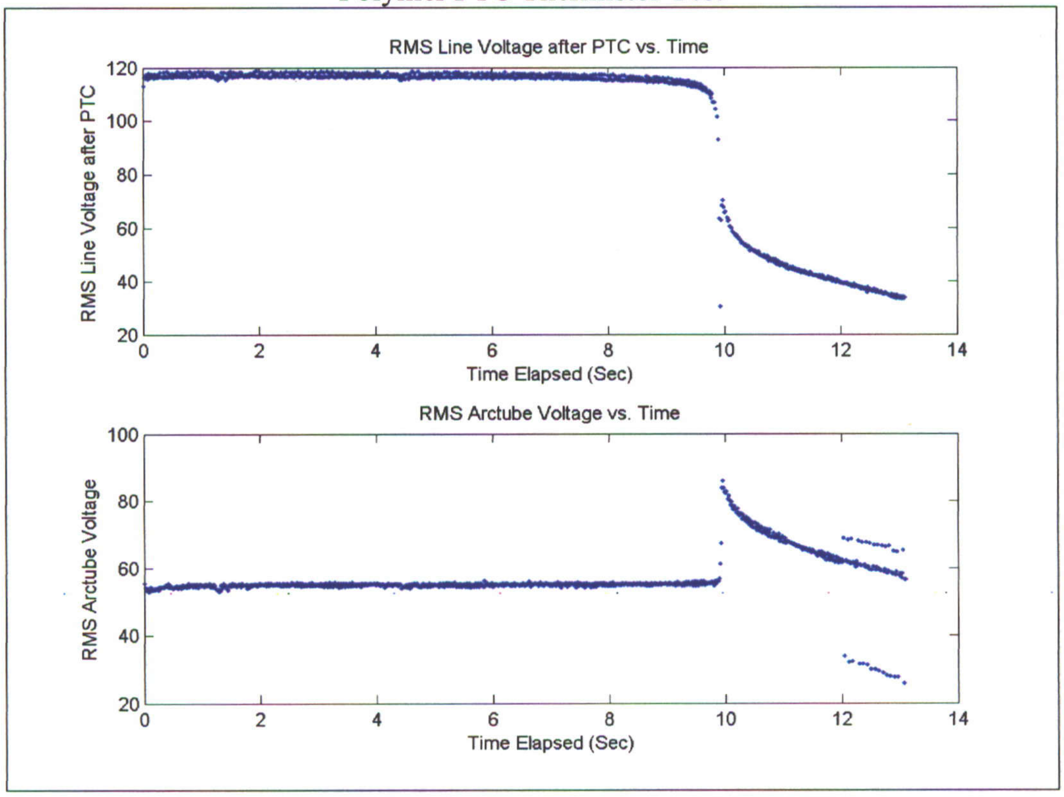


CWI Ballast

Ceramic PTC Thermistor Test

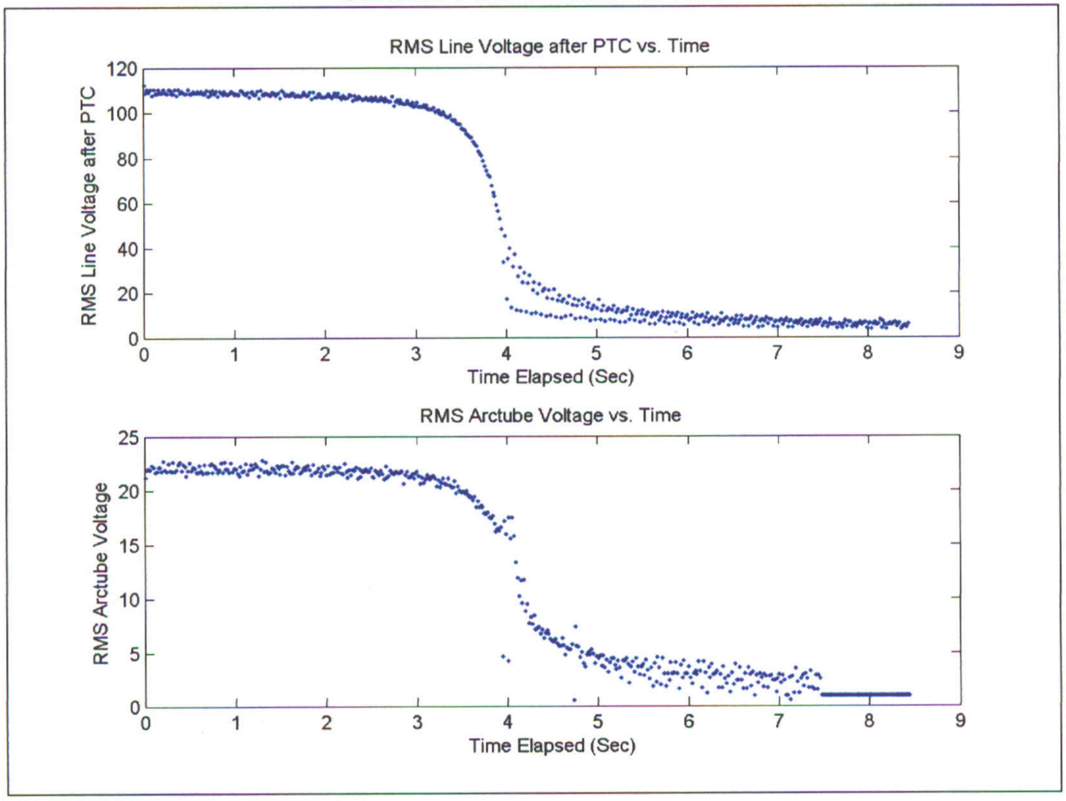


Polymer PTC Thermistor Test

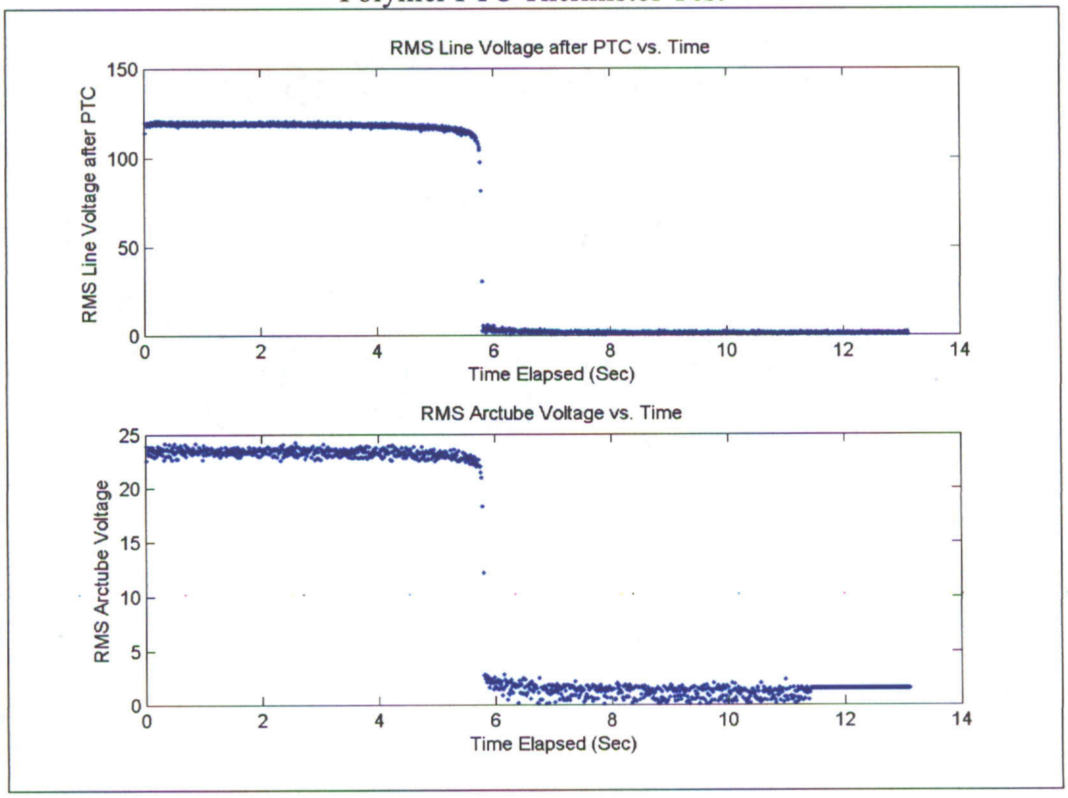


Regulated Lag Ballast

Ceramic PTC Thermistor Test



Polymer PTC Thermistor Test



Appendix C: Test Protocol

PROTOCOL FOR HPS LAMP LIFE TESTING
USING A PTC THERMISTOR

Rev. January 20, 2005

by Jeffrey Tisa

Equipment Used

- ✓ HP Infinium Oscilloscope with 3 10x probes
- ✓ HP clamp-on current probe (check that battery is operational)
- ✓ PC with GPIB I/O capabilities
- ✓ Microsoft Excel
- ✓ Infinium software plug-in for Excel
- ✓ Ballast, enclosure, and PTC
- ✓ Set of high pressure sodium lamps of the appropriate wattage for the ballast being used.

Test Preparation

1. Calibrate the three voltage probes

    a. Attach ground wire to ground terminal of oscilloscope
    b. Attach probe to calibration port (near the ground terminal)
    c. Use the mouse to click on the channel setup menu, and then proceed to enter the "port calibration" menu.
    d. Upon pushing calibration the scope will ask you to verify that you have completed the above steps. Press yes.
    e. If all goes well, the probe will be properly calibrated. If an error occurs, repeat the above steps. If that does not work, replace the probe.

2. The current probe should already be calibrated. If it is not reading zero on the scope when there is not current flowing, use the black dial on the probe to set it to zero.

3. Attach the voltage probes to test points

    a. Probe 1: Line voltage - load side of PTC
    b. Probe 2: LEAVE PROBE 2 DISCONNECTED AT THIS POINT. IF IT IS CONNECTED WHEN YOU START THE LAMP, THE PROBE MAY BE RUINED BY THE HIGH VOLTAGE.
    c. Probe 3: Clamp current probe around the 120 volt wire that is connected to the mains. Make sure the arrow on the current probe is facing in the direction that the current will be flowing.

   d. Probe 4: Clip the ground wire of the probe to one side of the photovoltaic cell and clip the signal clamp to the opposite side.

4. Load the setup file

   a. Click on "File" then "Load Setup File..."
   b. Select the file titled "Streetlight.set." This will automatically configure the oscilloscope settings. (Sampling rate, number of samples, time per division, etc...)

5. Prepare to begin test

   a. Install lamp into base
   b. Turn on the main power switch
   c. Make sure the PTC switch is OFF
   d. Turn on the switch for the ballast to be tested
   e. If required, push red button to ignite lamp
   f. After ignition, connect probe number 2 to the lamp voltage wire
      i. If ballast is an isolation transformer or regulated lag, you must connect the ground wire of the probe to the wire connected to the ground of the mogul base of the lamp. For any other type of ballast, the probe ground is not necessary.

6. Wait fifteen minutes for lamp to stabilize, 30 minutes if lamp is 250 Watts or higher.

7. Enter the date, time, and steady state values in the spreadsheet like the example below:

6-Jan-2005				
Time	**S.S. Line**	**S.S. Arc tube**	**S.S. Current**	**S.S. Delta T**
2:21 PM	120.578 V	48.7567 V	1.97675 A	5.49 ms

8. Switch the PTC into the circuit, then turn main power switch off.

9. Watch oscilloscope indicators for the following pattern

   a. Scope will gather data for about 14 seconds then dump the data onto the screen. About six seconds before the data appears on the screen, the indicator that is boxed (Trig'd) in Figure 1 is lit. Once the light turns off, the latest data has been put on the scope screen.
   b. Once the lamp is extinguished, press the stop button (also seen in Figure 1) after the first time the Trig'd light turns on and off, respectively. This can be tricky until you get the hang of it. See Dr. Jansson or his graduate assistant if you cannot get it.

c. If you stopped it at the correct time, you should be able to scroll through the data on the scope and see the disturbance that occurs when the lamp is extinguished. If you can't see this, stop now and redo the test.

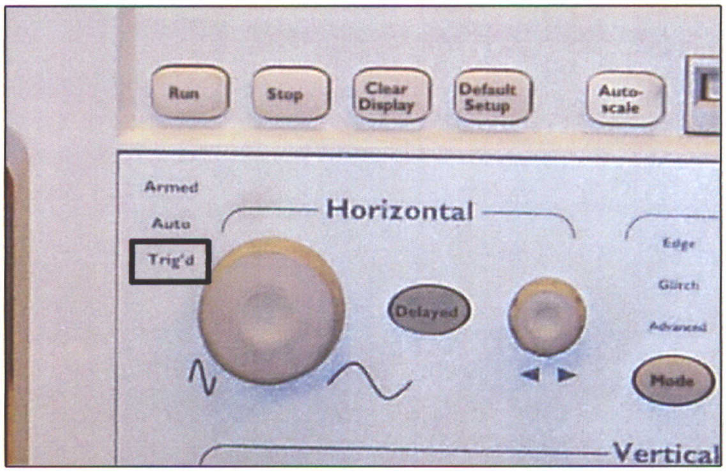


Figure 1: *Picture of Trig'd indicator on oscilloscope*

10. Use the waveform capture button on the Infinium plug-in for Excel to get the data from the oscilloscope. Excel will automatically create a new worksheet containing the oscilloscope data. Simply cut and paste the data onto the original worksheet below the steady state numbers that you recorded during step 7.

11. On the worksheet skip two rows to the right and redo another test in the same manner. Each lamp must be tested three times for repeatability. Try not to spread the three tests apart more than few hours.

Appendix D: MATLAB Code for Data Parser

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%RMS DATA PARSER                                    %%
%%%by: Jeffrey Tisa, May 2004                         %%
%%%Converts lamp life test data in a Microsoft Excel  %%
%%%spreadsheet to RMS.  Then the data is saved to the %%
%%%directory in which this file is located.  Finally, %%
%%%plots for each of the three tests are generated    %%
%%%and saved in .png format in the current directory. %%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

function y = autoparse(file,sheet)

disp('Extracting data...');
datain = strcat(file,'.xls');
[numeric,text]=xlsread(datain,sheet);
lw = size(numeric);
sample=2500;
elapsed_time = lw(1)/sample;
clear text;

disp('Parsing data...');
for i=1:lw(1)
    line1(i)=numeric(i,2);
    line2(i)=numeric(i,9);
    line3(i)=numeric(i,16);
    arctube1(i)=numeric(i,3);
    arctube2(i)=numeric(i,10);
    arctube3(i)=numeric(i,17);
    pv1(i)=numeric(i,4);
    pv2(i)=numeric(i,11);
    pv3(i)=numeric(i,18);
    current1(i)=numeric(i,5);
    current2(i)=numeric(i,12);
    current3(i)=numeric(i,19);
end

clear numeric;

disp('Calculating RMS values for test 1...');
rms_test1=rms(line1,arctube1,pv1,current1);
clear line1 arctube1 pv1 current1;
disp('Calculating RMS values for test 2...');
rms_test2=rms(line2,arctube2,pv2,current2);
clear line2 arctube2 pv2 current2;
disp('Calculating RMS values for test 3...');
rms_test3=rms(line3,arctube3,pv3,current3);
clear line3 arctube3 pv3 current3;

clear i j;
beep;
```

```
disp('Calculating time scale...');
format long;
size_test1 = length(rms_test1);
size_test2 = length(rms_test2);
size_test3 = length(rms_test3);
step1 = elapsed_time/(size_test1-1);
step2 = elapsed_time/(size_test2-1);
step3 = elapsed_time/(size_test3-1);
time1 = (0:step1:elapsed_time)';
time2 = (0:step2:elapsed_time)';
time3 = (0:step3:elapsed_time)';

save (strcat(file));

disp('Plotting results...');
format short;
rms_test1(1:size_test1,3)=10.*rms_test1(1:size_test1,3);
rms_test2(1:size_test2,3)=10.*rms_test2(1:size_test2,3);
rms_test3(1:size_test3,3)=10.*rms_test3(1:size_test3,3);
rms_test1(1:size_test1,4)=10.*rms_test1(1:size_test1,4);
rms_test2(1:size_test2,4)=10.*rms_test2(1:size_test2,4);
rms_test3(1:size_test3,4)=10.*rms_test3(1:size_test3,4);

figure(1)
plot(time1,rms_test1,'.');
axis([0 15 -5 400]);
axis tight;
title('RMS Magnitude vs. Time - Test 1');
xlabel('Time (Seconds)');
ylabel('Magnitude (RMS)');
legend('Line Voltage (Volts)','Arc Tube Voltage (Volts)','PV Voltage↙
(Volts*10)','Line Current (Amps*10)',0);
print('-dpng',(strcat(file,'_test1.png')));

close all;

figure(2)
plot(time2,rms_test2,'.');
axis([0 15 -5 400]);
axis tight;
title('RMS Magnitude vs. Time - Test 2');
xlabel('Time (Seconds)');
ylabel('Magnitude (RMS)');
legend('Line Voltage (Volts)','Arc Tube Voltage (Volts)','PV Voltage↙
(Volts*10)','Line Current (Amps*10)',0);
print('-dpng',(strcat(file,'_test2.png')));

close all;

figure(3)
plot(time3,rms_test3,'.');
```

```
axis([0 15 -5 400]);
axis tight;
title('RMS Magnitude vs. Time - Test 3');
xlabel('Time (Seconds)');
ylabel('Magnitude (RMS)');
legend('Line Voltage (Volts)','Arc Tube Voltage (Volts)','PV Voltage↙
(Volts*10)','Line Current (Amps*10)',0);
print('-dpng',(strcat(file,'_test3.png')));


close all;
clear all;
```

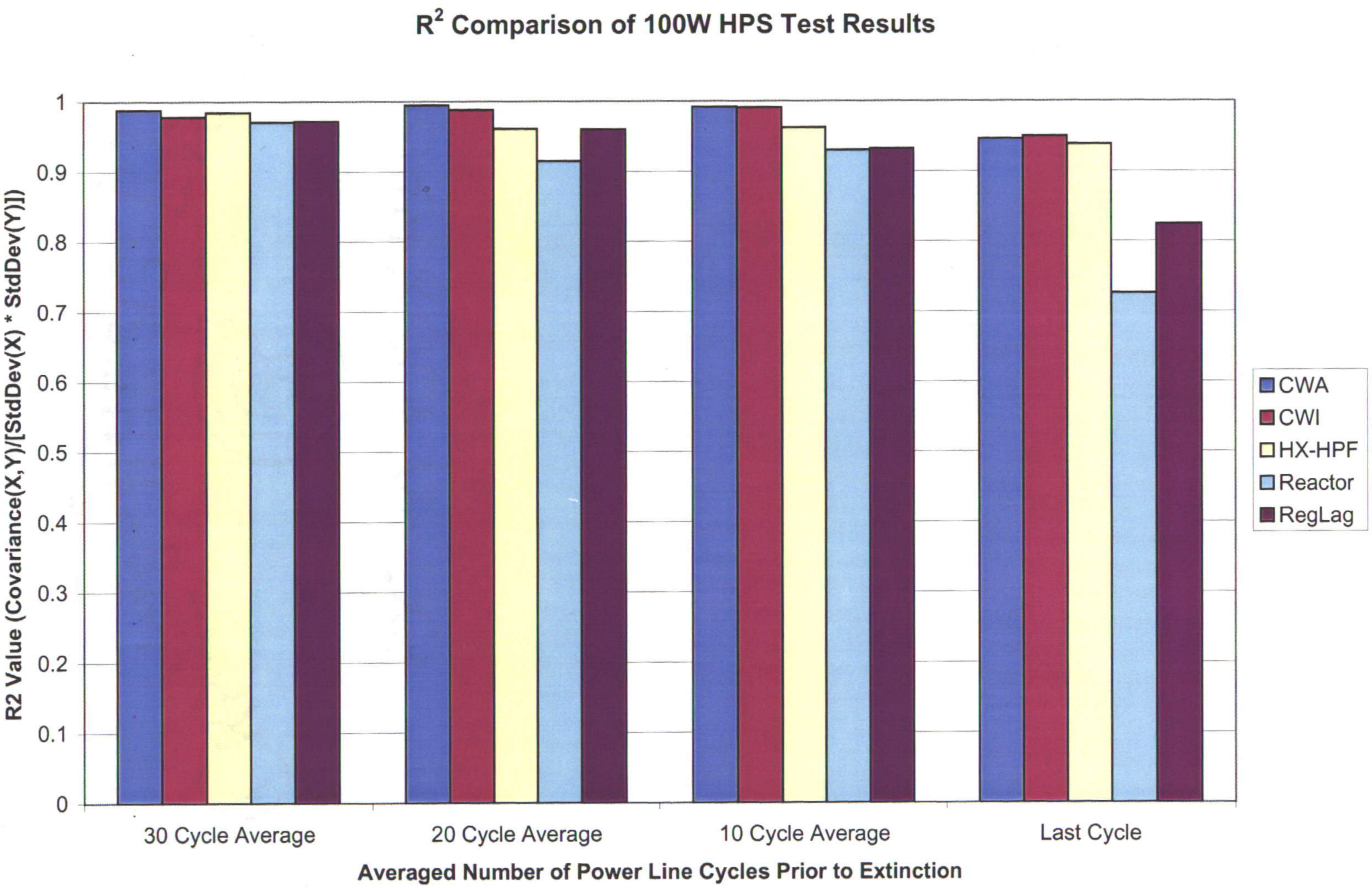
```
function data = rms(v_data,a_data,pv_data,c_data)

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%% Calculates RMS value of a sinusoidal waveform. %%
%%% by: Jeffrey Tisa, May 28, 2004                 %%
%%% y = rms(data)                                  %%
%%% data = name of signal                          %%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


voltage = v_data;
arctube = a_data;
pv = pv_data;
current = c_data;

crossing=0;
max_size = length(voltage);


%Searches data and places a "1" when a zero crossing
%is detected.  All other points are denoted as 0's.
for i=2:max_size
    if voltage(i-1) < 0 & voltage(i) > 0
        crossing(i,1) = 1;
    elseif voltage((i) == 0)
        crossing(i,1) = 1;
    else
        crossing(i,1) = 0;
    end
end


b = 1;
v = 1;
z = 1;
count = 1;

%Begin at the beginning of a cycle
while (crossing(b) == 0)
     b=b+1;
end

data=0;

%Loop cycles through data. If data point is not a
%zero crossing, store point in accumulator "calc"
%until a "1" is found in "crossing."
for (z=(b+1):max_size)
    if crossing(z) == 0
        calc(v,1) = voltage(z);
        v = v + 1;
```

```
        z = z + 1;

%if data point is a zero crossing get data from
%signal and calculate RMS of data in accumulator
%"calc."
    elseif crossing(z) == 1
        calc(v,1) = voltage(z);
        squared = calc.^2;
        v_rms = sqrt(mean(squared));
        data(count,1) = v_rms;
        count=count+1;
        z=z+1;
        clear calc;
        v = 1;
    end
end

b = 1;
v = 1;
z = 1;
count = 1;

%Begin at the beginning of a cycle
while (crossing(b) == 0)
     b=b+1;
end

%Loop cycles through data if data point is not a
%zero crossing store point in accumulator "calc"
%until a "1" is found in "crossing."
for (z=(b+1):max_size)
    if crossing(z) == 0
        calc(v,1) = arctube(z);
        v = v + 1;
        z = z + 1;

%if data point is a zero crossing get data from signal
%and calculate RMS of data in accumulator "calc."
    elseif crossing(z) == 1
        calc(v,1) = arctube(z);
        squared = calc.^2;
        a_rms = sqrt(mean(squared));
        data(count,2) = a_rms;
        count=count+1;
        z=z+1;
        clear calc;
        v = 1;
    end
end

b = 1;
```

```
v = 1;
z = 1;
count = 1;

%Begin at the beginning of a cycle
while (crossing(b) == 0)
     b=b+1;
end

%Loop cycles through data if data point is not a
%zero crossing, store point in accumulator "calc"
%until a "1" is found in "crossing."
for (z=(b+1):max_size)
    if crossing(z) == 0
        calc(v,1) = pv(z);
        v = v + 1;
        z = z + 1;

%If data point is a zero crossing get data from
%signal and calculate RMS of data in accumulator "calc."
    elseif crossing(z) == 1
        calc(v,1) = pv(z);
        squared = calc.^2;
        pv_rms = sqrt(mean(squared));
        data(count,3) = pv_rms;
        count=count+1;
        z=z+1;
        clear calc;
        v = 1;
    end
end

b = 1;
v = 1;
z = 1;
count = 1;

%Begin at the beginning of a cycle. Loop cycles through
%data. If data point is not a zero crossing, store point
%in accumulator "calc" until a "1" is found in "crossing."
while (crossing(b) == 0)
     b=b+1;
end

for (z=(b+1):max_size)
    if crossing(z) == 0
        calc(v,1) = current(z);
        v = v + 1;
        z = z + 1;

%if data point is a zero crossing, get data from signal
```

```
%and calculate RMS of data in accumulator "calc."
    elseif crossing(z) == 1
        calc(v,1) = current(z);
        squared = calc.^2;
        c_rms = sqrt(mean(squared));
        data(count,4) = c_rms;
        count=count+1;
        z=z+1;
        clear calc;
        v = 1;
    end
end
```

Appendix E: Arc Tube and Extinction Voltage Correlation Plots


R² Comparison of 100W HPS Test Results

CWA Ballast: PTC Test Data

	Lamp A, Test 1				Lamp A, Test 2				Lamp A, Test 3			
CYCLES	**Line Voltage (V)**	**Arctube Voltage (V)**	**PV Voltage (V)**	**Current (A)**	**Line Voltage (V)**	**Arctube Voltage (V)**	**PV Voltage (V)**	**Current (A)**	**Line Voltage (V)**	**Arctube Voltage (V)**	**PV Voltage (V)**	**Current (A)**
1	89.388	49.081	2.4565	0.94775	89.493	49.115	2.2079	0.94686	89.524	49.041	2.1649	0.95179
2	89.423	50.025	2.4723	0.95769	89.983	49.99	2.2198	0.95387	88.044	49.44	2.1442	0.93141
3	88.371	50.467	2.4289	0.95399	88.427	50.256	2.1877	0.94424	87.702	47.532	2.1618	0.94644
4	87.003	49.718	2.4432	0.94426	86.945	49.749	2.1824	0.94654	86.16	49.121	2.13	0.94189
5	87.682	48.67	2.4364	0.94849	87.076	48.688	2.1908	0.94727	85.026	49.924	2.1336	0.94523
6	85.646	50.875	2.4069	0.94735	85.792	50.929	2.1695	0.95106	85.34	49.055	2.1162	0.94091
7	85.135	50.109	2.4262	0.95213	85.672	50.272	2.1635	0.95124	83.599	48.917	2.1058	0.94034
8	83.358	49.931	2.3686	0.94655	83.557	50.691	2.1326	0.94146	83.624	49.666	2.0977	0.94679
9	82.819	49.612	2.3605	0.94424	83.075	50.034	2.1201	0.9388	81.142	50.237	2.0673	0.93583
10	82.246	50.982	2.3772	0.94162	82.326	50.811	2.1304	0.94626	80.54	50.52	2.0629	0.92736
11	80.863	51.241	2.3415	0.94174	80.537	51.725	2.0843	0.93049	80.14	50.766	2.0536	0.93377
12	80.681	51.952	2.3284	0.94996	80.695	51.798	2.1	0.93795	78.429	50.181	2.0202	0.92245
13	78.171	51.746	2.3061	0.9274	79.706	52.126	2.0667	0.93564	78.288	49.996	2.0164	0.92179
14	78.066	51.137	2.2833	0.93852	77.726	51.905	2.0273	0.93482	76.504	51.283	1.986	0.91046
15	76.715	51.168	2.2388	0.91904	76.57	51.751	1.9955	0.92047	75.873	51.933	1.9623	0.91451
16	76.179	52.035	2.2203	0.9252	76.416	52.134	1.9796	0.91629	74.936	52.498	1.9014	0.90696
17	75.013	53.475	2.1874	0.91778	75.411	53.088	1.9342	0.90834	75.219	53.081	1.8865	0.90703
18	76.003	53.852	2.1294	0.90266	75.71	54.349	1.8948	0.89991	74.21	54.408	1.8332	0.8871
19	73.612	55.109	2.0612	0.89639	74.501	54.975	1.8507	0.89141	75.298	55.387	1.7845	0.87524
20	75.317	56.548	1.9896	0.87313	76.201	57.02	1.7709	0.8708	75.817	56.617	1.7102	0.86311
21	75.914	58.035	1.8803	0.86629	76.604	58.231	1.6954	0.85366	77.077	59.15	1.6202	0.84333
22	79.594	61.296	1.7609	0.81408	80.017	61.542	1.6004	0.80942	78.94	61.093	1.5646	0.79959
23	79.663	63.513	1.7208	0.77692	80.124	64.201	1.555	0.76055	79.34	63.677	1.5178	0.74825
24	79.956	64.84	1.6779	0.73454	79.717	65.892	1.5315	0.72166	78.538	63.931	1.5119	0.7285
25	78.273	66.225	1.6701	0.72008	78.153	67.137	1.5162	0.70952	78.707	66.485	1.4763	0.69318
26	78.354	68.463	1.6215	0.68152	78.58	69.104	1.4922	0.67826	76.873	67.517	1.4702	0.67563
27	79.166	70.53	1.5843	0.65017	78.798	71.111	1.4785	0.65943	77.368	69.604	1.454	0.65152
28	78.617	73.505	1.5499	0.63098	80.353	75.174	1.4419	0.61758	78.522	72.893	1.4173	0.61975
29	80.559	77.975	1.5047	0.59347	81.463	79.4	1.4123	0.59494	78.754	75.829	1.397	0.58947
30	84.747	87.989	1.465	0.53895	87.756	94.026	1.3263	0.5184	82.541	84.093	1.3547	0.55244
31	102	105.59	1.1129	0.43797	103.2	105.56	1.102	0.43948	100.27	104.27	1.1075	0.44056

PER TEST	**Line Voltage (V)**	**SS Arctube Voltage (V)**	**SS Line Voltage (V)**	**SS Current (A)**	**Line Voltage (V)**	**SS Arctube Voltage (V)**	**SS Line Voltage (V)**	**SS Current (A)**	**Line Voltage (V)**	**SS Arctube Voltage (V)**	**SS Line Voltage (V)**	**SS Current (A)**
Last Cycle	84.75	48.56	119.177	0.93	87.76	48.76	119.143	0.93	82.54	47.61	118.322	0.92
10 Cycle Avg.	79.48				80.16				78.67			
20 Cycle Avg.	78.27				78.75				77.57			
30 Cycle Avg.	80.88				81.25				80.07			

CWA Ballast: PTC Test Data

	Lamp B, Test 1				Lamp B, Test 2				Lamp B, Test 3			
CYCLES	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)
1	87.996	52.612	2.2508	0.96486	86.099	52.549	2.2083	0.95678	86.908	51.817	2.2124	0.95493
2	86.042	53.11	2.2251	0.96255	85.438	51.738	2.2004	0.95473	86.027	52.07	2.2018	0.95444
3	86.163	53.324	2.2346	0.96323	85.546	52.414	2.2079	0.95627	85.994	52.789	2.1912	0.9478
4	84.167	53.73	2.2066	0.95926	84.096	52.696	2.1732	0.94888	84.696	52.817	2.1717	0.95226
5	83.783	54.48	2.2037	0.95929	84.311	53.715	2.146	0.95874	84.174	53.107	2.1742	0.94588
6	83.709	54.448	2.2059	0.9612	81.55	53.14	2.1243	0.94282	82.179	51.856	2.134	0.94226
7	81.987	53.546	2.1701	0.94448	82.081	52.925	2.1248	0.95067	82.968	52.41	2.1497	0.93722
8	81.843	53.696	2.1476	0.94603	80.337	53.448	2.097	0.93775	80.897	53.704	2.1068	0.94011
9	80.096	54.758	2.1005	0.94703	79.037	54.727	2.0905	0.93802	79.251	53.619	2.085	0.92996
10	80.819	55.475	2.1076	0.93225	79.468	55.009	2.0515	0.93956	79.907	53.601	2.0627	0.93446
11	78.904	55.576	2.0477	0.93266	77.481	55.253	2.0041	0.92046	78.247	53.675	2.0163	0.91512
12	78.888	55.894	2.021	0.92169	77.433	55.56	1.9806	0.91871	78.4	53.282	1.9936	0.91339
13	77.716	56.33	1.9843	0.91363	77.133	55.476	1.9277	0.9026	77.288	54.532	1.9567	0.90934
14	78.898	56.876	1.9311	0.90636	77.019	56.142	1.8807	0.90183	77.681	55.619	1.9216	0.89259
15	77.442	57.987	1.8827	0.89155	77.66	57.491	1.8197	0.88147	77.581	56.597	1.8598	0.88218
16	79.189	59.204	1.8192	0.87233	78.373	59.153	1.7345	0.87253	77.218	57.47	1.798	0.87084
17	79.519	60.886	1.7343	0.85726	80.245	60.983	1.6662	0.82533	78.056	59.746	1.7189	0.85075
18	81.248	63.026	1.6562	0.81222	80.557	63.681	1.6088	0.79415	81.184	62.088	1.6424	0.80006
19	80.915	65.166	1.6325	0.77615	80.096	64.051	1.5619	0.75576	80.284	62.902	1.6126	0.77682
20	80.566	65.483	1.5995	0.75056	80.137	65.589	1.5476	0.72714	79.905	65.03	1.5719	0.73927
21	80.265	66.998	1.576	0.72125	78.8	66.231	1.5346	0.72213	78.659	65.19	1.5621	0.72592
22	79.444	68.098	1.5616	0.70001	78.462	67.853	1.5081	0.69469	78.65	66.597	1.5412	0.69172
23	79.042	69.589	1.531	0.67389	78.465	69.308	1.5009	0.65815	78.395	67.749	1.518	0.67087
24	79.103	71.097	1.5202	0.64769	77.893	70.818	1.4773	0.64049	77.957	69.447	1.5204	0.65835
25	78.845	72.753	1.5047	0.62474	78.248	72.441	1.4502	0.62179	77.385	70.19	1.4921	0.6309
26	80.206	74.807	1.4721	0.5953	78.842	74.606	1.441	0.58711	78.286	72.985	1.4535	0.59041
27	79.223	76.801	1.4421	0.58172	79.516	77.256	1.4046	0.56129	77.758	74.376	1.439	0.57742
28	81.7	80.301	1.4213	0.55524	80.542	81.018	1.3595	0.54497	78.899	76.803	1.4199	0.54804
29	83.86	84.822	1.3662	0.52113	83.992	86.189	1.3171	0.49928	81.583	81.132	1.377	0.52331
30	88.311	93.403	1.3075	0.48689	92.749	102.83	1.2106	0.44296	83.736	85.723	1.3509	0.49768
31	101.78	104.7	1.1132	0.42225	102.42	104.97	1.0968	0.43828	92.889	102.51	1.1967	0.42915

PER TEST	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	*Line* Voltage (V)	*SS Arctube* Voltage (V)	*SS Line* Voltage (V)	*SS Current* (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)
Last Cycle	88.31	51.98	118.843	0.95	92.75	51.14	118.801	0.95	83.74	50.73	118.61	0.95
10 Cycle Avg.	81.00				80.75				79.13			
20 Cycle Avg.	80.16				79.68				78.86			
30 Cycle Avg.	81.33				80.72				80.34			

CWA Ballast: PTC Test Data

	Lamp C, Test 1				Lamp C, Test 2				Lamp C, Test 3			
CYCLES	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)
1	91.672	56.02	2.5165	0.96448	90.811	51.856	2.6442	0.95321	91.13	51.254	2.6308	0.94974
2	92.088	53.521	2.5291	0.96834	89.015	53.612	2.626	0.94069	89.538	53.544	2.6025	0.94527
3	90.468	55.886	2.4928	0.96696	89.7	52.953	2.6359	0.94586	89.587	53.069	2.628	0.94603
4	90.43	55.402	2.5285	0.96162	87.828	53.16	2.6069	0.93758	87.919	52.609	2.5868	0.94284
5	89.668	55.578	2.4818	0.96043	86.793	53.165	2.5851	0.94027	87.298	52.809	2.5735	0.94028
6	88.44	55.295	2.4841	0.95895	86.749	53.595	2.6017	0.95434	87.178	52.894	2.5872	0.94682
7	88.55	55.669	2.4696	0.95877	85.347	54.645	2.5653	0.93497	85.715	53.841	2.5547	0.93741
8	87.181	56.132	2.4332	0.95597	85.137	54.114	2.585	0.93951	84.83	53.202	2.5447	0.93817
9	87.341	57.1	2.4442	0.96223	82.926	53.667	2.5567	0.93509	84.605	53.531	2.5423	0.93338
10	85.3	55.914	2.4251	0.94567	82.895	53.639	2.516	0.93766	82.778	53.579	2.4929	0.93406
11	84.643	55.649	2.4019	0.9512	82.473	54.768	2.5174	0.93308	82.973	54.775	2.5123	0.93149
12	84.577	57.06	2.387	0.96051	80.807	55.134	2.4735	0.92763	82.036	54.58	2.474	0.92362
13	83.353	58.078	2.3647	0.94095	80.714	55.464	2.4659	0.92396	80.096	54.44	2.4469	0.91773
14	83.771	57.936	2.328	0.94557	78.7	55.414	2.423	0.91559	78.897	54.393	2.4225	0.91273
15	81.577	57.363	2.3154	0.93745	79.206	55.148	2.3858	0.90775	79.233	54.896	2.4	0.91162
16	82.099	57.057	2.2835	0.929	77.617	55.43	2.3603	0.90555	78.087	56.116	2.3299	0.9046
17	80.514	57.93	2.2461	0.92676	78.324	56.908	2.3025	0.8919	78.471	57.008	2.3004	0.89917
18	81.505	59.326	2.2036	0.91113	77.191	57.561	2.2362	0.88809	77.47	57.864	2.2337	0.88602
19	80.137	60.11	2.1471	0.90362	78.645	59.197	2.1599	0.87388	78.285	59.094	2.1604	0.87146
20	81.649	61.376	2.0809	0.88994	78.888	61.151	2.0456	0.8526	78.339	60.439	2.0703	0.85908
21	81.161	62.797	2.0042	0.87512	81.691	63.409	1.931	0.80803	80.829	63.007	1.9583	0.81676
22	83.312	65.358	1.8961	0.8366	81.632	65.329	1.8589	0.77388	81.493	63.977	1.8779	0.78834
23	84.253	67.698	1.8203	0.80758	80.787	66.772	1.8149	0.74172	81.796	65.977	1.8044	0.74038
24	83.573	69.517	1.7721	0.76979	80.791	68.841	1.7822	0.70561	80.827	66.967	1.7796	0.72896
25	85.018	70.963	1.7475	0.73322	80.192	69.938	1.7642	0.69539	79.808	68.947	1.7578	0.69798
26	84.264	73.032	1.7039	0.72632	79.924	71.213	1.7187	0.66578	80.483	70.464	1.7183	0.66284
27	83.585	74.629	1.6925	0.69239	81.068	74.519	1.6793	0.62356	80.066	71.923	1.6852	0.65124
28	85.801	78.111	1.6427	0.65457	81.487	76.8	1.642	0.61025	80.832	74.388	1.6482	0.62475
29	85.886	80.877	1.5968	0.62886	83.103	81.579	1.5638	0.57348	81.867	77.861	1.5925	0.5786
30	88.728	87.859	1.5314	0.58378	88.32	91.494	1.4607	0.51451	84.013	83.86	1.5333	0.55064
31	98.455	106.6	1.3107	0.4714	102.06	104.57	1.0982	0.42803	93.175	103.98	1.2944	0.46445

PER TEST	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)
Last Cycle	88.73	54.32	118.30	0.96	88.32	51.9652	119.08	0.94	84.01	51.5337	119.02	0.94
10 Cycle Avg.	84.56				81.90				81.20			
20 Cycle Avg.	83.47				80.58				80.30			
30 Cycle Avg.	85.35				82.63				82.55			

CWA Ballast: PTC Test Data

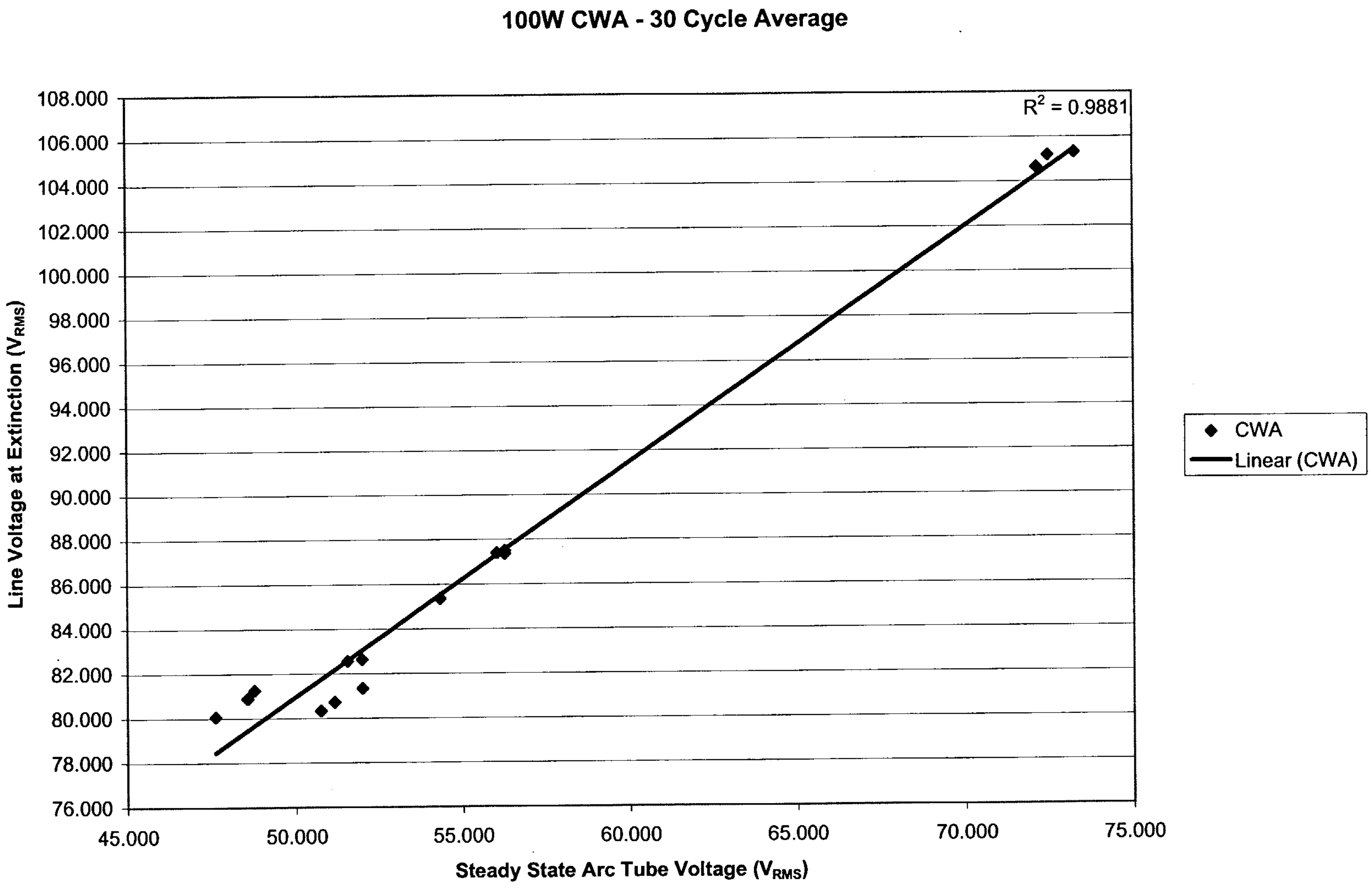
	Lamp D, Test 1				Lamp D, Test 2				Lamp D, Test 3			
CYCLES	**Line Voltage (V)**	**Arctube Voltage (V)**	**PV Voltage (V)**	**Current (A)**	**Line Voltage (V)**	**Arctube Voltage (V)**	**PV Voltage (V)**	**Current (A)**	**Line Voltage (V)**	**Arctube Voltage (V)**	**PV Voltage (V)**	**Current (A)**
1	93.27	57.727	2.5966	0.96793	92.734	58.146	2.5742	0.96706	92.85	56.756	2.5544	0.96064
2	91.482	58.322	2.5686	0.96273	93.333	58.255	2.5646	0.96168	92.484	57.426	2.5799	0.96089
3	92.178	58.083	2.5665	0.96814	91.489	57.329	2.5489	0.95737	91.421	57.561	2.5368	0.95623
4	90.165	57.35	2.5374	0.9575	90.923	58.083	2.5353	0.94633	90.588	58.124	2.5157	0.94981
5	89.921	58.304	2.5377	0.94627	90.819	58.871	2.529	0.96209	90.871	58.164	2.5232	0.95782
6	89.877	58.719	2.5269	0.9611	89.687	57.883	2.492	0.95342	89.483	57.608	2.4802	0.94961
7	88.652	58.62	2.4877	0.95121	90.088	58.355	2.492	0.95252	89.956	59.08	2.4872	0.95092
8	88.922	58.028	2.5	0.94785	87.888	58.657	2.4642	0.94525	88.24	58.764	2.4595	0.94635
9	87.244	58.887	2.4617	0.94517	88.906	59.63	2.473	0.95011	87.719	58.258	2.4603	0.94174
10	86.637	59.454	2.4374	0.93964	87.225	59.011	2.4343	0.93935	87.565	58.107	2.4403	0.94521
11	87.066	60.057	2.4358	0.94114	86.368	58.725	2.419	0.93761	86.038	58.935	2.3936	0.92803
12	85.563	59.455	2.4022	0.93688	86.594	59.383	2.4127	0.92595	86.685	59.642	2.3897	0.92589
13	86.066	59.521	2.3874	0.92869	85.089	60.555	2.3477	0.92053	84.894	60.361	2.3466	0.91855
14	84.29	60.414	2.3222	0.91797	85.081	61.084	2.3391	0.91852	85.903	60.136	2.3219	0.91959
15	85.358	61.696	2.2896	0.90998	84.845	60.79	2.2956	0.90751	84.212	60.122	2.2897	0.9121
16	84.113	62.203	2.2495	0.90861	84.385	61.041	2.2377	0.90465	84.539	61.25	2.2411	0.89676
17	84.526	62.989	2.1895	0.89155	84.523	62.05	2.2054	0.89009	83.839	61.944	2.1876	0.88576
18	83.523	63.283	2.1501	0.8755	83.763	63.357	2.1219	0.88209	84.877	63.701	2.1178	0.87238
19	85.297	64.406	2.0698	0.86482	85.046	64.931	2.0606	0.86073	84.309	65.028	2.0422	0.86256
20	84.857	66.02	1.9726	0.85259	84.895	66.722	1.9816	0.84681	86.321	66.033	1.9603	0.83043
21	85.658	68.365	1.9185	0.81931	86.895	68.415	1.9143	0.81092	85.544	67.591	1.8911	0.81428
22	87.26	69.8	1.8478	0.77388	85.717	69.214	1.851	0.7924	85.776	69.624	1.844	0.78325
23	85.438	71.311	1.8184	0.75551	85.536	70.798	1.8147	0.76522	86.482	70.866	1.7883	0.74557
24	85.026	72.373	1.7788	0.7301	86.76	72.659	1.7766	0.72663	84.819	72.597	1.7629	0.73173
25	86.533	74.408	1.7411	0.70463	85.24	74.041	1.7444	0.70975	84.919	73.917	1.7212	0.7058
26	85.291	76.314	1.7114	0.69059	86.286	75.996	1.7135	0.66786	86.293	76.19	1.6836	0.664
27	87.171	78.901	1.6647	0.65213	85.974	78.086	1.6712	0.65248	85.595	78.467	1.666	0.65156
28	87.367	81.444	1.6203	0.62715	87.005	81.938	1.6104	0.62068	86.945	82.031	1.6037	0.61311
29	88.929	86.374	1.5526	0.59556	89.768	86.629	1.5441	0.58082	89.547	86.781	1.5192	0.57743
30	92.751	93.897	1.4476	0.53951	91.859	92.762	1.4488	0.54649	93.004	95.308	1.426	0.53361
31	105.2	106.9	1.1153	0.44197	104.6	107.54	1.1097	0.45175	105.08	105.14	1.0743	0.45775

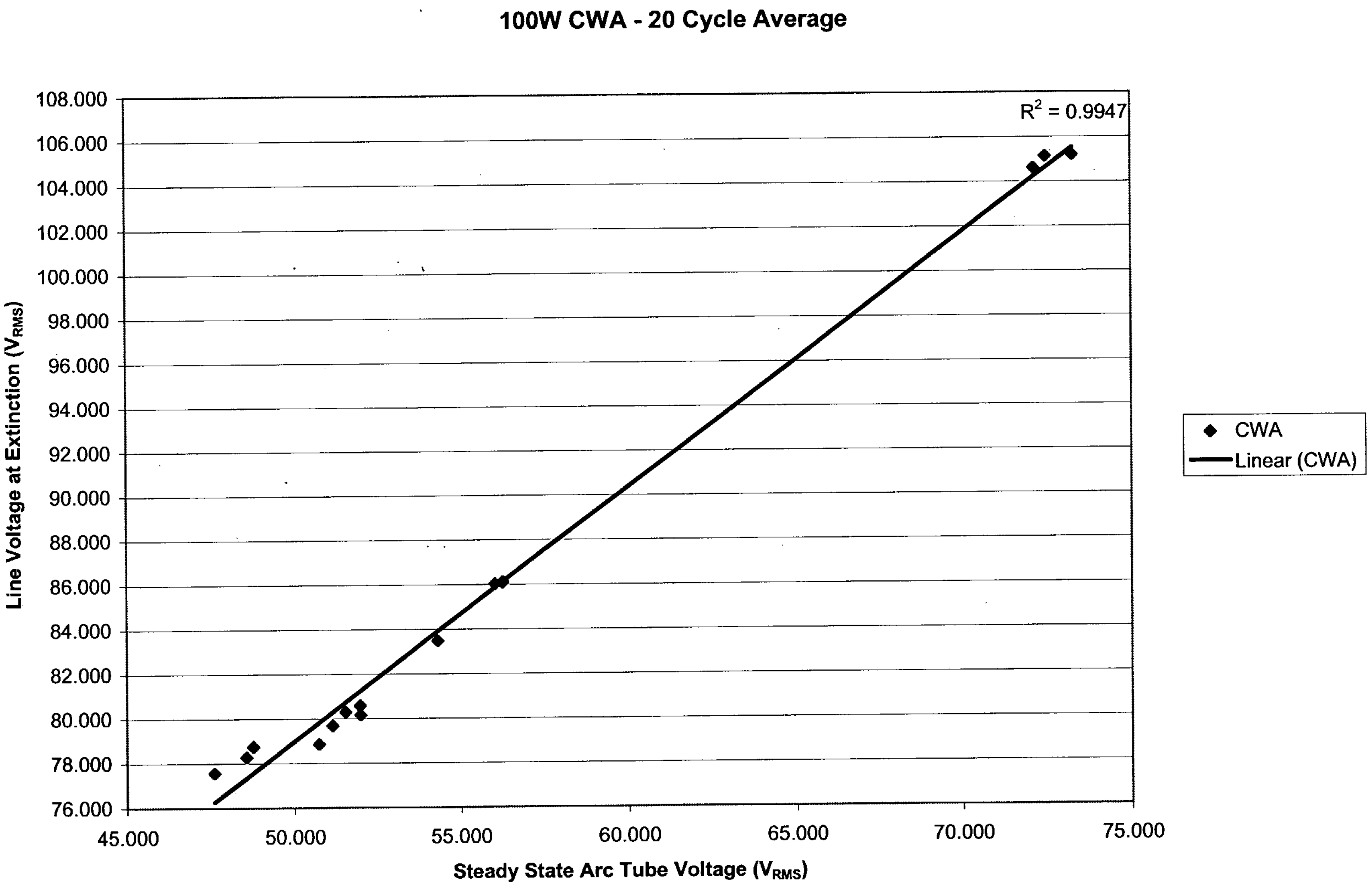
PER TEST	***Line* Voltage (V)**	***SS Arctube* Voltage (V)**	***SS Line* Voltage (V)**	***SS Current* (A)**	***Line* Voltage (V)**	***SS Arctube* Voltage (V)**	***SS Line* Voltage (V)**	***SS Current* (A)**	**Line Voltage (V)**	**SS Arctube Voltage (V)**	**SS Line Voltage (V)**	**SS Current (A)**
Last Cycle	92.75	56.26	118.99	1.00	91.86	56.26	119.13	0.98	93.00	56.02	119.20	0.98
10 Cycle Avg.	87.14				87.10				86.89			
20 Cycle Avg.	86.10				86.08				86.03			
30 Cycle Avg.	87.35				87.49				87.39			

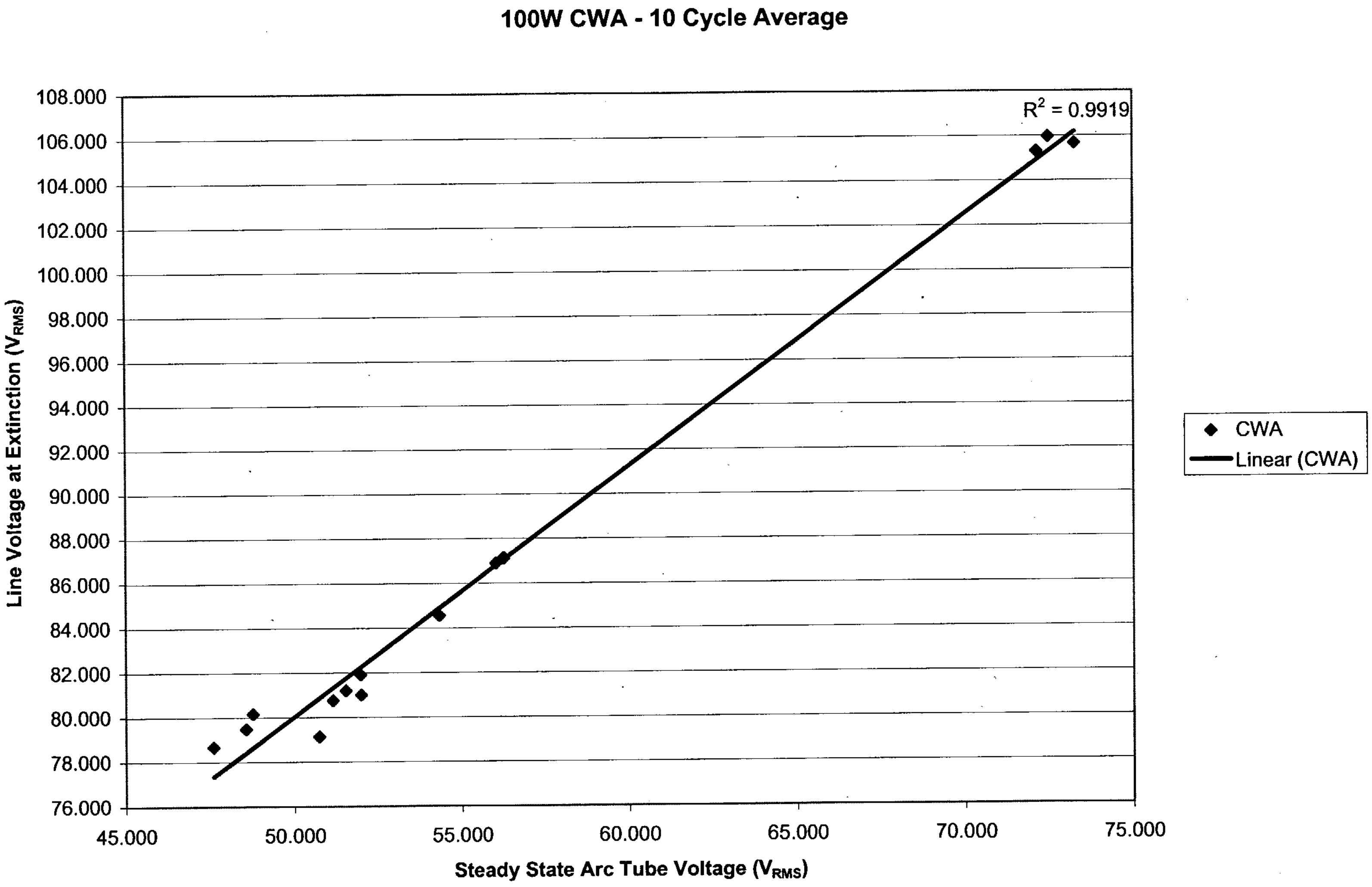
CWA Ballast: PTC Test Data

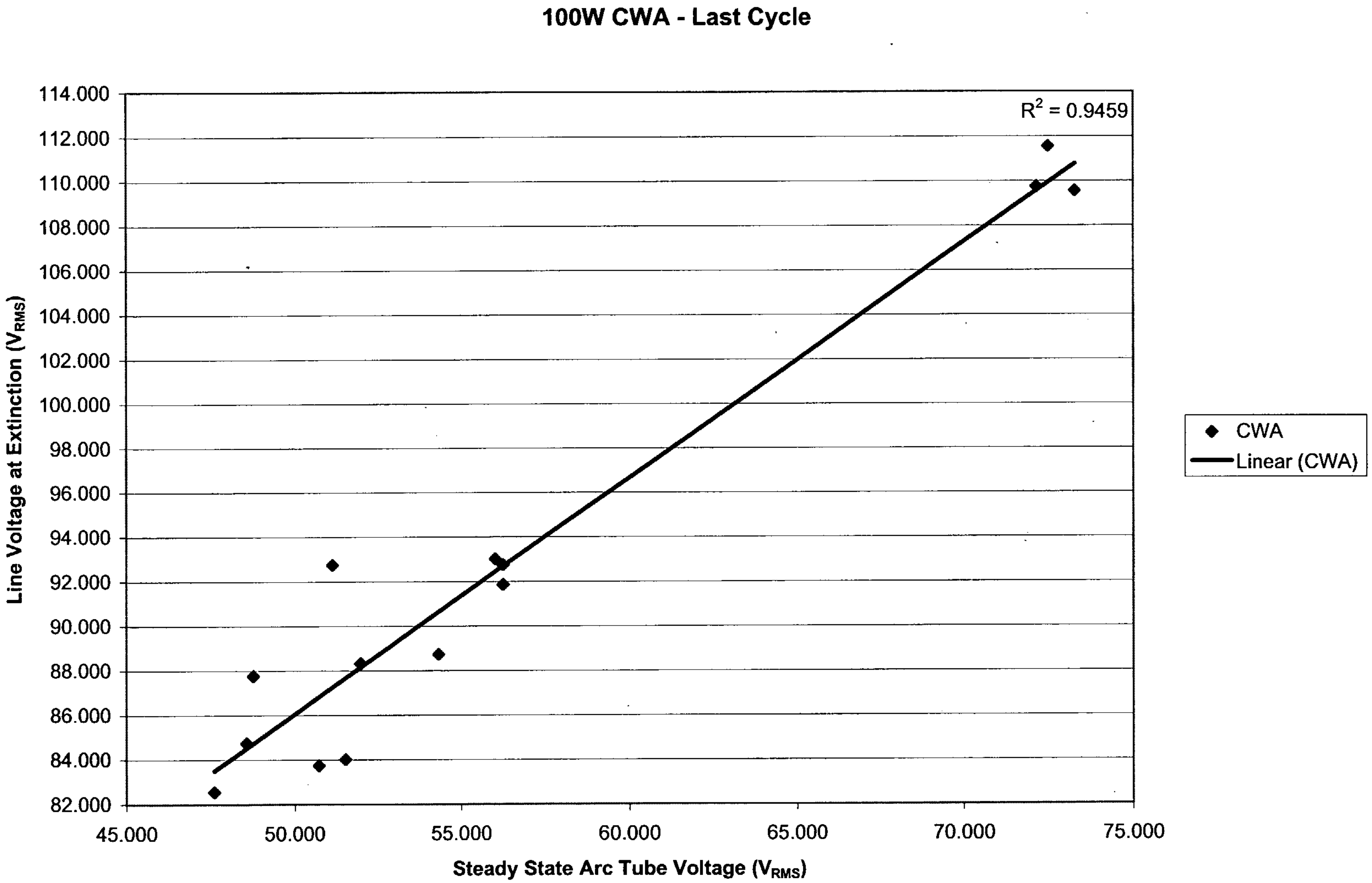
	Lamp E, Test 1				Lamp E, Test 2				Lamp E, Test 3			
CYCLES	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)
1	105.34	73.131	2.2033	1.0337	106.38	73.075	2.1839	1.0276	106.06	72.664	2.1568	0.99871
2	106.96	73.005	2.2115	1.0309	105.25	73.423	2.1722	1.0029	104.56	72.626	2.1348	1.0214
3	105.72	73.662	2.1846	1.0302	104.57	73.615	2.1549	1.0193	104.47	73.244	2.1362	1.0262
4	105.47	74.1	2.1854	1.0159	106.38	73.092	2.1503	1.0375	105.22	73.285	2.1355	1.0317
5	106.82	73.242	2.1847	1.0273	104.24	72.805	2.145	1.0212	104.36	72.57	2.1153	1.0219
6	104.76	74.002	2.1681	1.0286	104.72	73.751	2.1493	1.0137	104.19	73.097	2.1081	0.99969
7	104.65	74.539	2.1637	1.0319	105.89	74.029	2.1539	1.0198	105.54	73.955	2.0985	1.0052
8	106.1	73.595	2.161	1.0379	104.69	73.345	2.1216	1.01	103.72	72.837	2.0948	1.014
9	104.73	73.753	2.1498	1.0096	106.05	74.597	2.1234	1.025	103.81	73.71	2.0656	1.0077
10	104.8	74.564	2.1315	1.0093	104.4	74.409	2.1036	1.0111	105.02	74.404	2.0616	1.0074
11	106.3	74.902	2.1309	1.0001	104.48	74.086	2.0804	1.0027	104.1	73.958	2.0542	1.0069
12	104.4	74.156	2.0962	1.0152	105.59	74.485	2.0856	1.0135	104.7	73.817	2.0481	0.9937
13	105.71	75.024	2.106	1.018	104.38	74.864	2.0658	1.0125	103.62	74.807	2.0226	0.98419
14	104.06	75.41	2.0894	1.0192	103.56	74.751	2.0512	1.0095	104.02	74.86	2.0092	0.9957
15	104.07	74.841	2.0816	0.99909	104.82	75.001	2.0314	0.99991	104.32	74.746	2.0116	0.99756
16	105.52	75.204	2.0615	1.0211	103.63	75.532	2.0163	0.99397	103.54	74.992	2.0004	0.98545
17	104.05	76.393	2.0323	0.99893	103.65	75.562	1.9976	0.9916	103.13	75.477	1.9591	1.004
18	103.8	76.35	2.0246	0.99818	104.82	75.918	1.994	0.99321	104.56	75.46	1.9406	0.99941
19	105.02	76.346	2.0101	1.0041	103.66	76.367	1.9534	0.98814	103.69	75.997	1.9237	0.98226
20	104.33	76.829	1.9776	0.98923	104.43	77.195	1.9373	0.98961	103.17	76.367	1.9002	0.98992
21	103.89	77.357	1.9503	0.98822	103.69	77.364	1.8852	0.97853	103.95	77.397	1.8863	0.97588
22	105.05	78.312	1.9266	1.0001	103.99	77.635	1.8766	0.9794	103.36	77.724	1.8433	0.96558
23	104.09	78.173	1.8822	0.97717	104.64	78.85	1.8272	0.96003	104.44	77.893	1.8012	0.96097
24	105.42	78.637	1.8569	0.97258	103.92	79.644	1.7867	0.9574	103.07	78.97	1.7572	0.96426
25	104.35	79.93	1.7991	0.9648	104.88	80.772	1.7265	0.94831	103.85	80.634	1.7091	0.9569
26	104.88	81.762	1.7245	0.94395	106.01	82.497	1.6585	0.9263	105.42	81.982	1.6419	0.93422
27	105.96	83.47	1.6531	0.92722	105.72	84.984	1.5798	0.91883	105.1	83.724	1.5518	0.90605
28	105.95	85.772	1.58	0.91439	106.46	89.157	1.4637	0.87551	105.85	87.418	1.4783	0.87743
29	107.47	90.44	1.4713	0.85123	108.79	96.112	1.3354	0.80126	108.35	94.018	1.3279	0.7997
30	109.56	99.172	1.2764	0.76314	111.55	109.71	0.99894	0.65287	109.73	106.78	1.1032	0.68066
31	112.99	112.85	0.7207	0.59817	116.7	105.51	0.23845	0.52122	115.31	106.06	0.2789	0.51852

PER TEST	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)
Last Cycle	109.56	73.26	119.15	1.08	111.55	72.48	118.70	1.08	109.73	72.14	118.42	1.07
10 Cycle Avg.	105.66				105.97				105.31			
20 Cycle Avg.	105.19				105.13				104.60			
30 Cycle Avg.	105.31				105.17				104.63			


100W CWA - 30 Cycle Average
R^2 = 0.9881
108.000
106.000
104.000
102.000
100.000
98.000
96.000
94.000
92.000
90.000
88.000
86.000
84.000
82.000
80.000
78.000
76.000
Line Voltage at Extinction (V$_{RMS}$)
45.000
50.000
55.000
60.000
65.000
70.000
75.000
Steady State Arc Tube Voltage (V$_{RMS}$)
◆ CWA
Linear (CWA)


100W CWA - 20 Cycle Average
R^2 = 0.9947
Line Voltage at Extinction (V$_{RMS}$)
108.000
106.000
104.000
102.000
100.000
98.000
96.000
94.000
92.000
90.000
88.000
86.000
84.000
82.000
80.000
78.000
76.000
45.000
50.000
55.000
60.000
65.000
70.000
75.000
Steady State Arc Tube Voltage (V$_{RMS}$)
◆ CWA
Linear (CWA)


100W CWA - 10 Cycle Average



100W CWA - Last Cycle
R² = 0.9459
Line Voltage at Extinction (V_RMS)
114.000
112.000
110.000
108.000
106.000
104.000
102.000
100.000
98.000
96.000
94.000
92.000
90.000
88.000
86.000
84.000
82.000
45.000
50.000
55.000
60.000
65.000
70.000
75.000
Steady State Arc Tube Voltage (V_RMS)
CWA
Linear (CWA)

CWI Ballast: PTC Test Data

	Lamp A, Test 1 - October 24, 2004, 12:45PM				Lamp A, Test 2 - October 24, 2004, 1:30PM				Lamp A, Test 3 - October 24, 2004, 1:45PM			
CYCLES	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)
1	90.067	48.008	2.2284	0.89938	91.773	47.958	2.1871	0.90055	90.255	47.743	2.1545	0.89853
2	91.027	48.964	2.2464	0.91045	90.047	47.554	2.1651	0.89453	91.017	47.595	2.1746	0.90228
3	89.444	49.128	2.2168	0.90232	89.303	47.257	2.1628	0.90131	88.538	47.145	2.1458	0.90057
4	88.674	47.778	2.2123	0.90122	90.108	47.593	2.1672	0.90333	89.18	46.494	2.1634	0.91116
5	89.267	47.725	2.2204	0.92035	87.478	48.563	2.1469	0.90775	87.549	48.476	2.1101	0.89957
6	87.207	49.487	2.1768	0.9139	87.967	47.138	2.1607	0.90933	86.431	48.728	2.1092	0.89584
7	85.651	49.406	2.1804	0.90623	85.811	47.38	2.0955	0.90064	86.446	47.112	2.1106	0.90977
8	86.329	47.646	2.1795	0.91717	84.791	48.971	2.1104	0.90226	84.749	47.544	2.0876	0.90865
9	84.103	48.621	2.1279	0.90584	84.479	48.05	2.1076	0.91544	84.489	48.069	2.0953	0.91514
10	83.553	49.132	2.1538	0.92138	83.172	48.196	2.0695	0.90533	82.615	48.896	2.0344	0.90795
11	82.177	49.717	2.0994	0.91605	83.031	48.959	2.0749	0.92089	81.998	48.921	2.0212	0.91085
12	81.516	49.817	2.1076	0.93205	80.556	48.703	2.0182	0.91074	80.688	49.325	2.0152	0.91851
13	79.795	49.617	2.0597	0.91958	79.72	48.903	1.9769	0.91541	80.217	49.042	1.9844	0.91307
14	79.561	49.243	2.0326	0.91852	79.427	49.642	1.9718	0.91403	77.999	49.006	1.9455	0.90732
15	76.672	49.482	1.973	0.91543	77.762	50.339	1.9492	0.91614	76.439	49.208	1.8932	0.91498
16	77.086	50.32	1.9464	0.92202	76.699	51.03	1.8669	0.91726	76.57	50.047	1.8677	0.91002
17	75.42	51.402	1.8963	0.92096	75.13	51.487	1.8384	0.90894	74.79	51.055	1.8084	0.91219
18	75.122	52.184	1.8461	0.91849	75.083	52.509	1.7729	0.91264	75.18	51.95	1.7242	0.90704
19	73.536	53.538	1.7495	0.915	75.279	53.515	1.6921	0.89927	75.609	53.007	1.6286	0.89377
20	75.734	54.27	1.6154	0.90219	74.809	55.135	1.5556	0.8883	75.684	54.428	1.5067	0.87282
21	76.705	57.018	1.5009	0.86629	77.022	57.111	1.4441	0.84538	77.585	57.286	1.4084	0.81614
22	77.566	59.193	1.411	0.79251	77.221	58.365	1.3858	0.79726	76.722	58.562	1.3479	0.77964
23	76.773	59.933	1.3578	0.77183	76.119	59.658	1.3202	0.76534	76.159	59.228	1.3274	0.74998
24	75.839	61.662	1.3244	0.73352	76.329	60.588	1.2734	0.72271	75.789	61.296	1.2681	0.71549
25	76.257	62.793	1.289	0.69735	75.744	61.891	1.2477	0.70268	74.644	62.495	1.2128	0.69313
26	76.413	64.546	1.246	0.67176	75.519	63.68	1.212	0.67486	74.883	63.969	1.1847	0.66147
27	76.471	66.656	1.195	0.6425	75.639	65.669	1.1701	0.64385	75.726	66.224	1.1432	0.6265
28	76.285	68.622	1.1557	0.60789	75.828	66.884	1.1329	0.61006	75.821	67.52	1.1093	0.60608
29	78.276	72.215	1.0818	0.58075	76.704	70.273	1.0754	0.5765	77.502	71.423	1.0439	0.56673
30	81.412	78.859	0.97507	0.51794	79.907	75.309	0.98508	0.54327	80.908	77.435	0.96003	0.52444
31	96.191	102.46	0.54519	0.42111	91.106	99.55	0.63553	0.44621	93.304	100.48	0.57682	0.43131

PER TEST	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)
Last Cycle	81.412	47.581	119.295	0.832	79.907	46.806	119.216	0.832	80.908	46.671	119.335	0.831
10 Cycle Avg.	77.20				76.60				76.57			
20 Cycle Avg.	77.43				77.18				77.05			
30 Cycle Avg.	80.80				80.62				80.41			

CWI Ballast: PTC Test Data

	Lamp B, Test 1 - October 24, 2004, 2:05PM				Lamp B, Test 2 - October 27, 2004, 5:40PM				Lamp B, Test 3 - October 27, 2004, 6:35PM			
CYCLES	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)
1	88.824	50.708	2.1133	0.92266	88.373	51.7	2.2751	0.93378	88.059	49.621	2.2098	0.9277
2	87.23	50.65	2.1178	0.92504	88.668	50.699	2.2718	0.94406	86.904	50.311	2.182	0.9244
3	87.865	51.081	2.112	0.93414	86.863	51.072	2.2249	0.93204	86.894	50.491	2.1889	0.94105
4	86.321	51.37	2.0713	0.92541	86.812	51.166	2.2409	0.93908	85.162	50.751	2.148	0.93662
5	85.746	52.052	2.0729	0.93698	84.999	51.582	2.2047	0.93005	84.725	50.897	2.137	0.93475
6	84.242	51.37	2.0404	0.92986	84.406	51.791	2.1644	0.9406	83.738	51.587	2.1316	0.9415
7	83.323	51.381	2.0011	0.93068	83.73	52.82	2.1853	0.94552	82.052	50.269	2.1058	0.93375
8	83.029	51.218	2.0177	0.93665	81.909	51.919	2.1488	0.93707	81.966	51.128	2.0827	0.94219
9	80.973	52.097	1.9574	0.93416	82.281	51.792	2.1275	0.94129	81.053	51.765	2.0462	0.94067
10	81.815	52.781	1.9308	0.91983	80.124	52.474	2.0766	0.93687	79.34	51.981	1.993	0.92563
11	79.183	53.555	1.8726	0.9223	80.326	52.682	2.0468	0.94704	78.294	52.809	1.9382	0.93341
12	79.451	53.785	1.8308	0.92326	78.667	53.321	1.976	0.93538	77.985	53.247	1.8898	0.92583
13	78.434	54.278	1.7696	0.91655	78.699	53.97	1.9365	0.92411	77.337	54.093	1.8389	0.92501
14	78.526	55.406	1.6727	0.90263	77.311	54.536	1.8691	0.9224	77.976	55.149	1.7482	0.90553
15	78.892	56.577	1.5804	0.88751	78.327	55.806	1.7828	0.91017	77.833	55.94	1.6282	0.89132
16	78.816	57.612	1.5099	0.86385	77.61	56.731	1.6575	0.8936	77.978	57.124	1.5383	0.85385
17	78.354	58.162	1.4171	0.82038	79.356	58.931	1.5746	0.85557	78.067	57.903	1.4549	0.80872
18	79.022	60.117	1.3962	0.78451	78.55	59.166	1.5097	0.8158	78.119	59.741	1.4308	0.77636
19	77.486	60.287	1.3303	0.75968	77.556	59.933	1.462	0.78957	76.615	59.677	1.3802	0.75568
20	76.383	61.852	1.3046	0.72841	78.118	61.063	1.4183	0.75442	75.658	60.986	1.3476	0.72964
21	77.221	62.673	1.262	0.69428	76.594	62.367	1.3737	0.73023	76.07	62.09	1.3011	0.69464
22	75.957	63.605	1.2445	0.67779	76.043	63.13	1.3416	0.69907	74.936	63.449	1.2619	0.67615
23	75.389	64.797	1.1915	0.6464	76.289	64.854	1.3049	0.66622	74.599	63.965	1.2337	0.6441
24	76.764	66.595	1.1663	0.61485	75.846	65.076	1.2616	0.64853	75.537	65.975	1.1864	0.61784
25	75.933	67.749	1.1177	0.6072	76.296	67.081	1.2248	0.61987	74.941	66.489	1.1562	0.60493
26	76.041	69.111	1.0856	0.57107	75.63	68.055	1.1801	0.60004	75.172	68.543	1.1121	0.5817
27	78.222	72.197	1.015	0.5396	76.59	70.398	1.1219	0.57157	76.934	70.938	1.0509	0.54321
28	79.106	74.438	0.95117	0.51481	77.428	72.008	1.0759	0.54179	77.799	73.71	1.0121	0.52345
29	81.936	79	0.88515	0.48095	80.473	76.07	0.99331	0.51579	80.501	77.622	0.92842	0.49639
30	89.993	90.279	0.69762	0.42767	83.701	80.684	0.89954	0.48101	86.157	85.736	0.77511	0.44391
31	101.61	98.645	0.24185	0.40475	95.233	100.7	0.53734	0.40069	100.8	97.948	0.24644	0.40948

PER TEST	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)
Last Cycle	89.993	49.589	119.276	0.868	83.701	49.969	118.581	0.866	86.157	48.936	118.939	0.861
10 Cycle Avg.	78.66				77.49				77.26			
20 Cycle Avg.	78.56				77.97				77.43			
30 Cycle Avg.	80.68				80.25				79.61			

CWI Ballast: PTC Test Data

	Lamp C, Test 1 - October 27, 2004, 7:00PM				**Lamp C, Test 2 - October 27, 2004, 7:20PM**				**Lamp C, Test 3 - October 27, 2004, 7:37PM**			
CYCLES	**Line Voltage (V)**	**Arctube Voltage (V)**	**PV Voltage (V)**	**Current (A)**	**Line Voltage (V)**	**Arctube Voltage (V)**	**PV Voltage (V)**	**Current (A)**	**Line Voltage (V)**	**Arctube Voltage (V)**	**PV Voltage (V)**	**Current (A)**
1	91.948	51.481	0.85632	0.94388	91.948	49.479	0.7806	0.92405	90.214	51.449	0.78112	0.91876
2	90.084	51.382	0.83893	0.93797	90.291	50.012	0.79661	0.91505	90.656	50.731	0.79984	0.93427
3	89.313	51.477	0.83062	0.93538	89.178	51.365	0.7737	0.92064	89.424	51.171	0.78504	0.93464
4	89.871	51.703	0.8277	0.93978	89.436	50.24	0.79118	0.93526	88.394	50.494	0.7724	0.92465
5	88.099	51.856	0.80883	0.93725	87.71	50.748	0.76729	0.92857	87.696	51.402	0.76032	0.93776
6	87.325	52.152	0.80417	0.93841	87.788	50.985	0.76359	0.93413	86.575	51.728	0.75658	0.92502
7	87.389	52.243	0.80687	0.94341	85.797	50.38	0.74709	0.92945	86.776	52.329	0.75968	0.93054
8	85.837	51.488	0.78876	0.94723	85.131	51.157	0.74609	0.93088	84.884	51.321	0.74619	0.92644
9	85.969	52.611	0.78612	0.94723	85.324	51.8	0.74363	0.93417	85.011	51.15	0.72786	0.94272
10	83.837	53.098	0.78304	0.9395	82.634	51.68	0.72471	0.93577	83.097	51.921	0.71298	0.93284
11	83.051	52.794	0.76048	0.93455	82.817	51.846	0.71563	0.93262	81.9	52.859	0.72084	0.93186
12	82.983	53.365	0.73864	0.94158	81.019	51.43	0.69774	0.92733	82.475	53.529	0.68869	0.9355
13	81.998	53.242	0.71985	0.93227	81.214	52.125	0.6916	0.92586	80.696	53.802	0.67804	0.93237
14	80.819	53.49	0.71429	0.93281	79.695	53.069	0.66562	0.9271	79.911	54.043	0.65622	0.92412
15	79.929	54.054	0.68205	0.92716	79.54	53.753	0.63855	0.91384	79.407	54.266	0.62956	0.91839
16	79.919	55.624	0.64304	0.91443	77.873	54.439	0.63505	0.91397	79.255	54.33	0.60624	0.91193
17	78.775	56.252	0.62641	0.91459	78.043	55.158	0.58943	0.90773	77.816	55.191	0.59082	0.89827
18	79.652	57.617	0.58524	0.90401	78.175	56.972	0.5565	0.89715	79.563	56.996	0.52994	0.88194
19	80.42	59.579	0.54713	0.87041	78.963	58.306	0.51095	0.86431	79.174	58.443	0.51325	0.85424
20	79.661	59.772	0.52263	0.83444	79.121	58.561	0.47516	0.82422	79.939	60.329	0.47312	0.80831
21	79.104	61.408	0.5017	0.80107	77.926	60.499	0.45952	0.79315	78.807	60.274	0.46946	0.78144
22	79.638	62.049	0.50075	0.76345	78.321	61.376	0.44565	0.76071	78.082	62.103	0.4458	0.75891
23	78.464	63.483	0.47477	0.7446	77.081	62.431	0.44717	0.73709	78.233	62.343	0.4458	0.72039
24	77.578	64.201	0.45876	0.71713	76.525	63.234	0.42723	0.70595	77.22	64.268	0.43455	0.70098
25	78.112	65.743	0.44914	0.67855	77.289	64.851	0.41216	0.67732	76.783	64.743	0.41839	0.67993
26	77.737	66.972	0.42292	0.66461	76.426	65.986	0.41195	0.65935	77.564	67.422	0.41313	0.64491
27	77.934	69.382	0.42032	0.63657	76.684	68.23	0.39276	0.62551	77.821	68.932	0.39186	0.61939
28	80.227	71.736	0.40974	0.60356	77.93	70.826	0.38088	0.59517	78.342	71.688	0.39653	0.58949
29	81.759	75.803	0.37297	0.5676	79.868	73.997	0.36892	0.5594	81.865	76.419	0.36166	0.55979
30	85.592	83.845	0.31694	0.52436	83.171	80.182	0.32619	0.51887	85.538	83.744	0.31984	0.50647
31	103.77	100.75	0.15078	0.42345	96.29	102.03	0.21517	0.43	102.5	99.075	0.16845	0.42088
PER TEST	**Line Voltage (V)**	**SS Arctube Voltage (V)**	**SS Line Voltage (V)**	**SS Current (A)**	**Line Voltage (V)**	**SS Arctube Voltage (V)**	**SS Line Voltage (V)**	**SS Current (A)**	**Line Voltage (V)**	**SS Arctube Voltage (V)**	**SS Line Voltage (V)**	**SS Current (A)**
Last Cycle	85.592	50.116	118.808	0.876	83.171	49.080	118.894	0.863	85.538	49.587	118.432	0.867
10 Cycle Avg.	79.61				78.12				79.03			
20 Cycle Avg.	80.17				78.88				79.52			
30 Cycle Avg.	82.77				81.76				82.10			

CWI Ballast: PTC Test Data

	Lamp D, Test 1 - October 21, 2004, 2:50PM				Lamp D, Test 2 - October 22, 2004, 5:45PM				Lamp D, Test 3 - October 22, 2004, 6:50PM			
CYCLES	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)
1	96.72	58.849	2.401	0.98218	95.03	57.857	2.5655	0.96493	95.414	56.463	2.5538	0.96823
2	95.5	58.668	2.3838	0.97998	94.661	57.957	2.5424	0.96859	93.814	56.389	2.5214	0.95626
3	94.782	59.12	2.3631	0.97549	95.099	58.106	2.5696	0.97342	93.212	57.165	2.5119	0.95789
4	95.336	59.634	2.3678	0.9735	93.581	57.775	2.5351	0.97568	93.286	56.677	2.5192	0.97271
5	94.03	58.899	2.3478	0.97849	92.825	58.518	2.5148	0.96957	92.019	56.586	2.4749	0.95265
6	93.368	59.043	2.3219	0.97206	93.247	58.902	2.5325	0.97731	92.571	57.459	2.4816	0.9639
7	93.674	60.082	2.3291	0.98713	91.68	58.103	2.4906	0.96486	90.574	57.401	2.4703	0.96064
8	92.036	60.439	2.3045	0.97282	91.899	58.582	2.4979	0.96582	90.164	57.005	2.4519	0.95028
9	92.988	59.94	2.3007	0.9711	90.578	59.286	2.4791	0.96915	90.231	56.595	2.4355	0.96599
10	91.028	59.7	2.2734	0.97188	90.074	59.887	2.4312	0.96429	88.616	58.071	2.4208	0.96133
11	90.592	60.413	2.2597	0.97032	89.958	59.421	2.4272	0.96509	88.899	58.479	2.4091	0.95654
12	91	61.209	2.2251	0.97845	88.599	59.081	2.4104	0.95509	87.163	58.743	2.3733	0.95165
13	88.977	61.004	2.2197	0.96225	88.903	59.352	2.3949	0.96272	87.509	58.542	2.343	0.94922
14	90.004	61.001	2.1914	0.96182	87.212	60.659	2.3419	0.95588	85.583	58.464	2.3039	0.94477
15	88.245	61.396	2.1469	0.95785	87.993	61.54	2.3194	0.94326	86.383	59.743	2.2513	0.93648
16	88.813	62.764	2.1187	0.94424	85.749	61.649	2.2629	0.94321	84.687	60.274	2.2094	0.93185
17	87.577	62.859	2.0743	0.94379	86.438	61.844	2.2454	0.93321	85.428	61.601	2.166	0.92189
18	87.916	64.021	2.0398	0.9268	85.917	62.327	2.1673	0.92803	83.935	62.421	2.1172	0.90918
19	87.311	64.369	1.9956	0.91416	86.32	64.41	2.0952	0.89884	84.265	63.344	2.04	0.88909
20	87.003	64.923	1.9563	0.89548	85.243	65.499	2.0555	0.87953	85.454	64.305	1.9693	0.86178
21	87.676	67.047	1.9107	0.87411	85.056	66.237	1.9985	0.8585	84.168	66.231	1.9372	0.83437
22	86.725	67.493	1.8763	0.8499	86.365	67.268	1.9531	0.8173	85.027	66.104	1.9064	0.80142
23	88.219	68.807	1.8263	0.81558	84.701	68.116	1.9303	0.79291	83.824	67.719	1.8649	0.77805
24	86.65	69.74	1.7974	0.79323	86.055	69.452	1.8877	0.77051	82.958	68.421	1.8429	0.73735
25	86.314	70.869	1.7755	0.76634	85.013	70.53	1.8642	0.74705	84.576	70.849	1.7936	0.70728
26	87.897	73.034	1.7357	0.73245	84.786	72.127	1.8163	0.71766	83.676	71.649	1.7715	0.69119
27	86.448	74.312	1.7103	0.71579	86.875	74.489	1.7756	0.68067	84	74.088	1.7066	0.6561
28	87.643	76.655	1.6619	0.68118	86.377	76.625	1.7177	0.65189	85.91	77.141	1.6641	0.61986
29	91.036	81.574	1.6198	0.63191	88.62	80.693	1.6431	0.60433	89.17	82.597	1.5882	0.57475
30	92.761	87.38	1.5221	0.58678	92.814	87.95	1.5393	0.55575	93.157	90.722	1.4478	0.52162
31	102.59	104.68	1.2666	0.48326	104.26	103.66	1.2299	0.45213	108.3	102.28	1.0733	0.43614

PER TEST	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)
Last Cycle	92.761	57.756	118.622	0.947	92.814	56.586	119.225	0.936	93.157	55.310	119.619	0.924
10 Cycle Avg.	88.14				86.67				85.65			
20 Cycle Avg.	88.44				86.95				85.79			
30 Cycle Avg.	90.28				88.92				87.86			

CWI Ballast: PTC Test Data

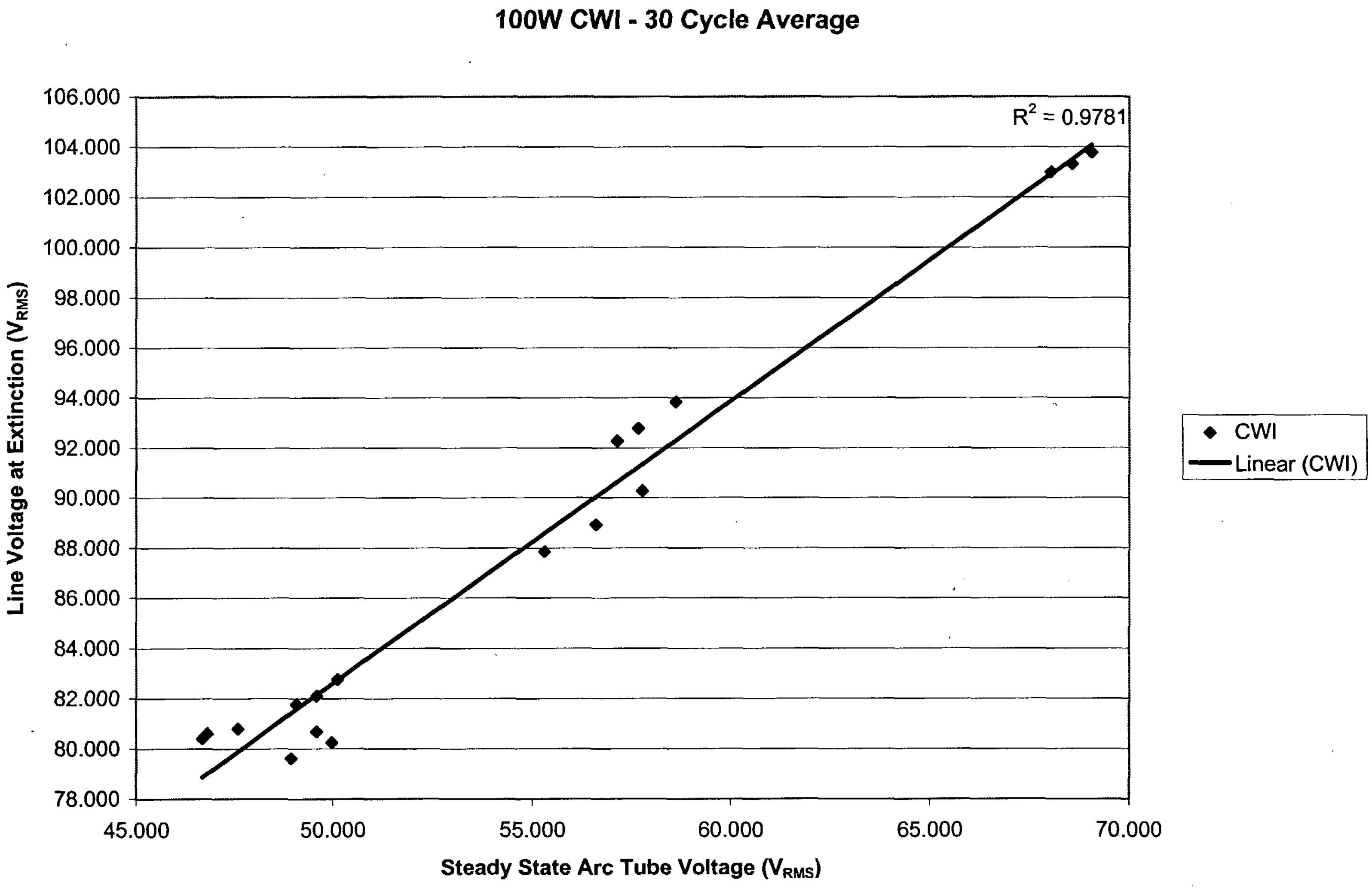
	Lamp E, Test 1 - November 4, 2004, 1:31PM				Lamp E, Test 2 - November 4, 2004, 1:55PM				Lamp E, Test 3 - November 4, 2004, 2:12PM			
CYCLES	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)
1	104.46	70.13	2.02	1.03	104.91	69.01	1.98	1.02	105.15	69.51	2.01	1.05
2	106.26	70.08	2.02	1.04	104.13	69.53	1.97	1.04	104.22	68.97	1.98	1.03
3	104.88	70.21	2.01	1.04	104.83	69.97	1.99	1.02	103.42	69.35	1.95	1.02
4	104.70	70.36	1.99	1.03	104.10	69.90	1.98	1.02	104.88	69.67	1.98	1.03
5	105.33	71.47	1.98	1.03	103.66	69.51	1.96	1.03	103.97	69.08	1.97	1.02
6	104.51	69.71	1.97	1.02	104.81	70.41	1.97	1.03	103.96	69.49	1.95	1.03
7	104.17	70.27	1.96	1.01	103.79	70.32	1.94	1.02	104.06	70.13	1.95	1.02
8	105.06	71.01	1.98	1.01	102.94	69.61	1.93	1.02	103.40	69.69	1.92	1.03
9	103.95	71.09	1.95	1.02	104.47	71.30	1.93	1.02	102.81	69.39	1.92	1.01
10	103.33	70.46	1.95	1.02	103.66	71.10	1.91	1.02	103.88	70.45	1.92	1.03
11	104.37	71.55	1.93	1.02	103.16	70.43	1.90	1.00	102.96	70.43	1.91	1.01
12	103.61	71.74	1.91	1.03	104.23	70.74	1.88	1.02	102.54	70.36	1.89	1.01
13	103.31	71.75	1.91	1.01	102.48	71.23	1.87	1.01	103.29	70.95	1.87	1.02
14	104.15	71.71	1.89	1.02	102.65	71.68	1.86	1.00	102.50	71.41	1.84	1.00
15	103.04	72.57	1.88	1.02	103.67	71.32	1.84	1.01	103.52	71.50	1.83	1.01
16	102.54	72.99	1.86	1.01	102.51	72.27	1.81	1.00	101.98	71.49	1.83	1.00
17	103.50	73.05	1.83	1.01	103.28	72.88	1.81	1.00	102.11	71.99	1.79	1.01
18	102.69	73.18	1.81	1.00	102.43	72.89	1.79	1.00	102.84	72.38	1.77	1.00
19	103.82	73.85	1.79	0.99	102.11	73.28	1.77	0.98	101.73	72.75	1.75	0.99
20	102.37	74.48	1.78	1.00	102.96	74.39	1.73	0.99	102.03	73.10	1.71	0.96
21	102.10	73.95	1.74	0.99	101.70	74.76	1.70	0.99	102.66	74.38	1.69	0.98
22	102.17	74.94	1.71	0.99	101.97	74.41	1.67	0.95	101.54	75.00	1.68	0.97
23	103.17	76.52	1.69	0.97	102.57	75.96	1.64	0.96	101.38	74.46	1.64	0.96
24	102.33	77.07	1.66	0.95	101.71	77.01	1.62	0.95	102.56	76.14	1.62	0.93
25	103.87	77.55	1.61	0.94	102.38	77.68	1.57	0.94	101.71	76.93	1.57	0.92
26	102.37	78.65	1.58	0.92	103.27	78.61	1.52	0.90	101.69	77.47	1.55	0.91
27	102.63	80.26	1.54	0.90	102.23	80.47	1.49	0.89	102.57	79.68	1.48	0.91
28	105.01	82.34	1.47	0.88	103.18	81.73	1.44	0.86	102.43	80.98	1.44	0.86
29	103.49	85.64	1.40	0.84	104.57	86.40	1.36	0.81	104.26	84.19	1.37	0.83
30	106.24	91.76	1.28	0.77	105.42	93.20	1.22	0.75	104.31	89.15	1.28	0.79
31	112.44	109.67	0.70	0.57	112.51	109.49	0.60	0.55	109.75	105.66	0.93	0.61

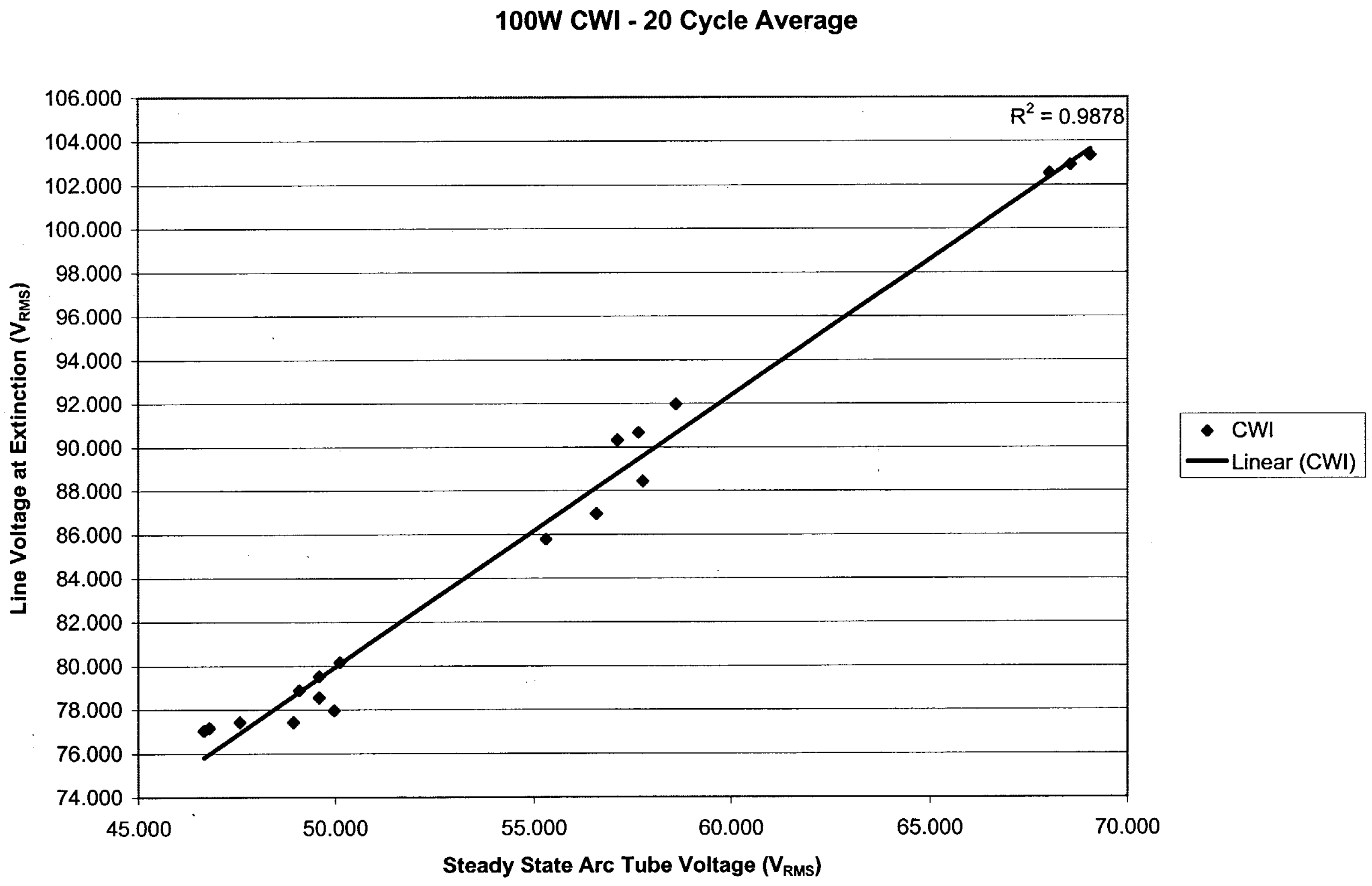
PER TEST	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)
Last Cycle	106.240	69.056	118.439	1.054	105.420	68.556	118.400	1.053	104.310	68.032	117.957	1.048
10 Cycle Avg.	103.34				102.90				102.51			
20 Cycle Avg.	103.34				102.92				102.53			
30 Cycle Avg.	103.78				103.33				103.01			

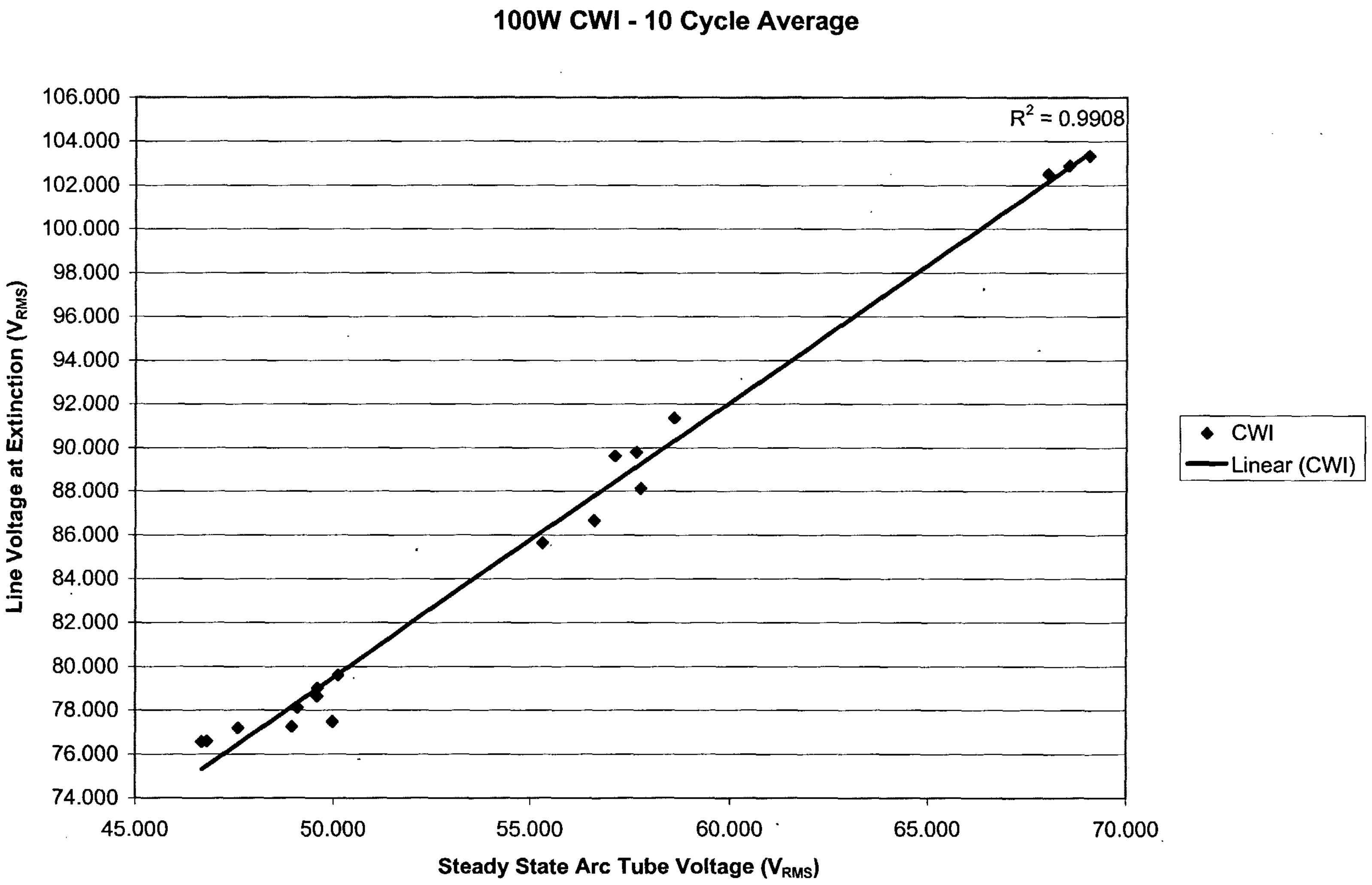
CWI Ballast: PTC Test Data

	120204-1, Test 1 - December 7, 2004, 12:00PM				120204-1, Test 2 - December 7, 2004, 12:20PM				120204-1, Test 3 - December 7, 2004, 12:40PM			
CYCLES	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)
1	99.345	58.759	1.9382	0.96074	98.628	57.77	1.9113	0.95406	97.502	58.144	1.8823	0.94987
2	99.839	59.386	1.9736	0.97284	99.112	58.423	1.9143	0.95657	99.168	57.857	1.8959	0.96045
3	98.153	59.803	1.9398	0.96551	98.164	58.207	1.8925	0.95322	96.669	57.655	1.8617	0.95154
4	97.937	59.302	1.9128	0.96155	96.979	57.81	1.8786	0.95622	96.458	57.572	1.87	0.94758
5	98.564	59.171	1.9315	0.97124	98.149	58.416	1.8948	0.96594	96.833	57.712	1.8742	0.97183
6	97.436	59.023	1.9028	0.96577	96.456	59.014	1.8644	0.96112	95.754	58.594	1.8344	0.95166
7	96.525	59.812	1.8925	0.96133	96.011	58.71	1.853	0.957	96.429	58.876	1.8479	0.95602
8	96.783	59.774	1.896	0.96771	96.129	58.643	1.8569	0.96747	94.584	57.791	1.8286	0.95297
9	95.531	58.836	1.8685	0.96171	94.755	58.316	1.8277	0.95353	93.924	58.52	1.8083	0.95397
10	95.539	60.414	1.8503	0.9672	95.486	59.535	1.8246	0.9612	94.354	59.348	1.805	0.96622
11	95.684	61.108	1.8555	0.96493	93.351	59.589	1.7911	0.95559	93.599	59.109	1.7702	0.95199
12	94.173	60.215	1.8026	0.96205	93.155	58.964	1.7871	0.96025	92.342	58.207	1.7529	0.95973
13	94.367	59.579	1.8268	0.97704	93.35	59.023	1.7831	0.961	93.218	58.981	1.7543	0.95172
14	92.679	60.668	1.7913	0.96013	92.446	60.453	1.7493	0.95972	91.284	59.66	1.7228	0.95493
15	92.73	61.665	1.7749	0.95415	92.45	60.644	1.7425	0.96154	91.688	60.102	1.7025	0.95456
16	92.474	62.058	1.7459	0.95958	90.785	60.437	1.7032	0.95383	90.237	60.364	1.6847	0.94761
17	91.098	61.523	1.7141	0.95326	90.024	59.779	1.6841	0.95085	89.904	60.042	1.6538	0.94382
18	91.503	61.225	1.6853	0.96072	91.063	60.808	1.6675	0.9501	90.157	60.874	1.616	0.94959
19	90.187	62.084	1.6391	0.94194	89.04	61.834	1.6187	0.94844	88.634	61.445	1.5597	0.94653
20	91.029	63.399	1.615	0.94636	89.823	62.689	1.5888	0.94212	89.142	62.642	1.5313	0.92658
21	89.633	64.123	1.5639	0.94094	88.319	63.443	1.532	0.93198	88.34	63.456	1.4798	0.92472
22	89.025	65.175	1.5103	0.93175	89.589	64.54	1.4642	0.92039	89.104	64.542	1.4276	0.91952
23	90.209	66.565	1.4469	0.91378	87.872	65.393	1.4132	0.91274	88.008	65.19	1.3593	0.90045
24	89.406	67.038	1.3812	0.90084	88.537	65.721	1.3229	0.88977	88.362	66.372	1.2956	0.8705
25	90.711	69.801	1.2874	0.8524	89.715	69.25	1.2631	0.85946	89.427	69.436	1.2277	0.83335
26	89.834	71.704	1.2509	0.82654	89.145	70.095	1.2362	0.82384	88.399	70.432	1.1941	0.80126
27	90.628	73.566	1.1973	0.7869	89.923	72.223	1.1905	0.79219	89.938	72.575	1.1242	0.77066
28	92.083	76.845	1.1389	0.73986	90.728	74.689	1.1158	0.74991	89.217	74.335	1.0975	0.74317
29	93.193	81.417	1.0658	0.70923	90.551	78.298	1.051	0.7172	90.8	78.954	1.0167	0.69515
30	98.729	95.109	0.85561	0.6029	93.504	85.028	0.95469	0.64408	94.545	87.438	0.90113	0.62418
31	111.69	103	0.17435	0.4736	105.76	106.58	0.53196	0.50095	109.47	106.64	0.3747	0.45832

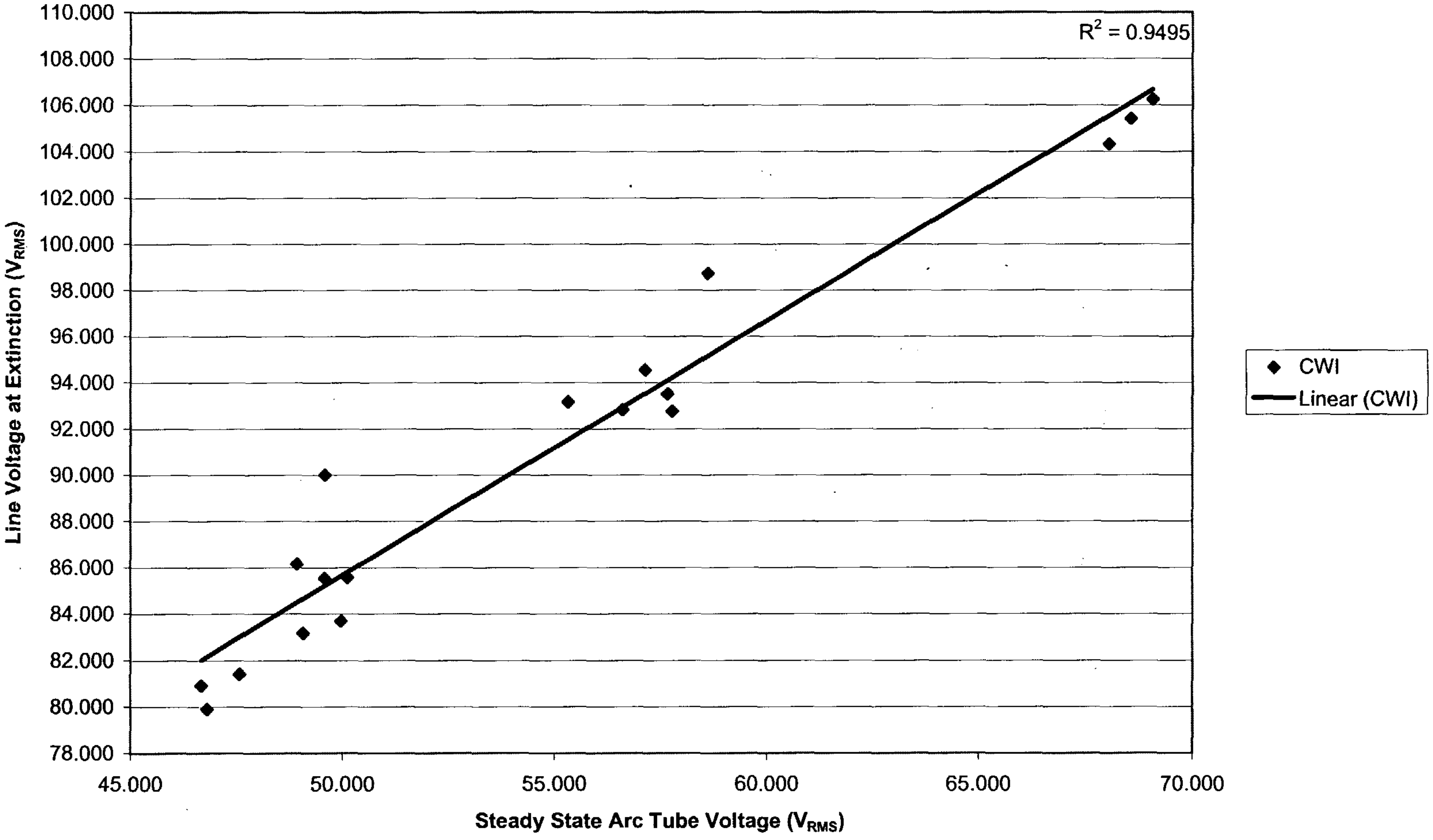
PER TEST	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)
Last Cycle	98.729	58.595	120.036	0.945	93.504	57.649	119.847	0.938	94.545	57.113	110.494	0.935
10 Cycle Avg.	91.35				89.79				89.61			
20 Cycle Avg.	91.97				90.67				90.32			
30 Cycle Avg.	93.83				92.77				92.27			


100W CWI - 30 Cycle Average
R^2 = 0.9781
106.000
104.000
102.000
100.000
98.000
96.000
94.000
92.000
90.000
88.000
86.000
84.000
82.000
80.000
78.000
45.000
50.000
55.000
60.000
65.000
70.000
Line Voltage at Extinction (V$_{RMS}$)
Steady State Arc Tube Voltage (V$_{RMS}$)
CWI
Linear (CWI)


100W CWI - 20 Cycle Average
R² = 0.9878
Line Voltage at Extinction (V_RMS)
106.000
104.000
102.000
100.000
98.000
96.000
94.000
92.000
90.000
88.000
86.000
84.000
82.000
80.000
78.000
76.000
74.000
45.000
50.000
55.000
60.000
65.000
70.000
Steady State Arc Tube Voltage (V_RMS)
◆ CWI
Linear (CWI)


100W CWI - 10 Cycle Average
R² = 0.9908
106.000
104.000
102.000
100.000
98.000
96.000
94.000
92.000
90.000
88.000
86.000
84.000
82.000
80.000
78.000
76.000
74.000
Line Voltage at Extinction (V_RMS)
45.000
50.000
55.000
60.000
65.000
70.000
Steady State Arc Tube Voltage (V_RMS)
◆ CWI
Linear (CWI)

100W CWI - Last Cycle



HX-HPF Ballast: PTC Test Data

	Lamp A, Test 1				Lamp A, Test 2				Lamp A, Test 3			
CYCLES	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)
1	96.85	51.47	1.82	0.82	98.33	51.61	0.67	0.82	98.94	51.17	0.66	0.84
2	96.73	51.60	1.80	0.83	97.71	51.43	0.66	0.85	97.75	51.43	0.67	0.83
3	97.49	50.91	1.80	0.83	98.59	51.21	0.65	0.84	97.42	51.54	0.66	0.83
4	96.35	51.55	1.79	0.82	97.40	51.95	0.67	0.83	98.10	51.46	0.66	0.83
5	95.93	51.53	1.79	0.82	96.94	51.75	0.65	0.83	96.55	51.75	0.64	0.81
6	96.53	51.53	1.76	0.83	97.68	51.81	0.65	0.85	96.44	51.70	0.64	0.81
7	95.36	52.20	1.77	0.82	95.86	52.23	0.64	0.82	96.95	51.96	0.65	0.83
8	94.80	51.96	1.77	0.83	95.80	52.23	0.64	0.83	95.08	52.14	0.63	0.82
9	95.68	51.97	1.76	0.82	95.93	52.11	0.63	0.84	95.11	51.87	0.65	0.82
10	93.99	52.74	1.75	0.80	94.73	52.64	0.64	0.82	95.46	52.34	0.64	0.82
11	93.65	52.54	1.74	0.82	94.34	52.39	0.63	0.84	94.20	52.60	0.62	0.82
12	94.07	52.50	1.72	0.83	95.23	52.90	0.63	0.83	93.80	52.81	0.63	0.81
13	92.87	52.70	1.72	0.80	93.11	53.24	0.62	0.82	94.26	52.68	0.63	0.82
14	92.84	53.41	1.71	0.81	92.75	53.07	0.61	0.81	92.73	53.07	0.61	0.81
15	93.44	53.30	1.69	0.82	93.53	53.52	0.62	0.84	92.63	53.17	0.61	0.82
16	91.06	53.33	1.70	0.81	92.17	53.74	0.61	0.81	93.03	53.12	0.60	0.81
17	91.17	53.50	1.66	0.81	91.84	53.45	0.60	0.83	91.28	53.91	0.60	0.81
18	90.85	53.78	1.67	0.80	90.94	54.19	0.60	0.82	90.76	53.78	0.60	0.81
19	91.16	54.55	1.62	0.81	91.76	54.80	0.58	0.82	91.67	54.30	0.59	0.79
20	89.73	54.30	1.63	0.81	89.75	54.62	0.60	0.82	89.88	55.04	0.57	0.80
21	89.25	54.67	1.62	0.81	89.94	55.05	0.57	0.81	89.68	54.78	0.58	0.81
22	89.78	55.48	1.58	0.81	90.36	56.07	0.57	0.84	88.62	55.54	0.56	0.80
23	88.42	56.03	1.57	0.82	88.91	56.27	0.55	0.82	88.90	55.90	0.56	0.81
24	87.83	56.44	1.54	0.80	88.37	56.93	0.54	0.80	87.38	55.91	0.55	0.81
25	86.94	56.52	1.53	0.81	87.16	57.65	0.54	0.83	87.32	57.51	0.53	0.79
26	87.91	57.45	1.47	0.84	87.53	58.73	0.52	0.82	86.60	58.03	0.54	0.81
27	86.06	58.19	1.45	0.81	86.42	59.70	0.51	0.83	87.63	59.29	0.50	0.82
28	86.19	59.71	1.41	0.83	86.61	61.44	0.50	0.84	85.95	61.21	0.50	0.83
29	85.57	61.73	1.37	0.85	86.53	64.68	0.45	0.86	86.06	63.77	0.47	0.84
30	86.33	65.56	1.25	0.87	89.38	82.60	0.31	1.12	88.90	81.14	0.32	1.10
31	88.89	85.59	0.71	1.21	86.44	87.69	0.13	1.37	86.31	87.88	0.13	1.36

PER TEST	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)
Last Cycle	86.331	49.632	118.672	N/A	89.379	49.925	120.200	1.049	88.897	49.691	120.216	1.034
10 Cycle Avg.	87.43				88.12				87.70			
20 Cycle Avg.	89.76				90.33				90.06			
30 Cycle Avg.	91.83				92.52				92.30			

HX-HPF Ballast: PTC Test Data

	Lamp B, Test 1				Lamp B, Test 2				Lamp B, Test 3			
CYCLES	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)
1	97.80	53.23	1.76	0.85	98.81	54.70	1.77	0.83	97.69	54.03	1.77	0.82
2	98.94	53.65	1.75	0.84	98.08	55.05	1.77	0.83	96.42	54.47	1.78	0.82
3	97.50	53.63	1.76	0.82	99.16	54.94	1.75	0.86	96.17	54.37	1.77	0.83
4	96.89	53.65	1.75	0.85	97.56	54.63	1.75	0.85	97.09	54.56	1.75	0.83
5	97.66	54.36	1.73	0.84	97.37	55.24	1.74	0.84	95.28	54.20	1.77	0.80
6	95.90	54.21	1.71	0.83	97.83	55.30	1.73	0.84	95.11	54.71	1.74	0.83
7	95.59	53.62	1.72	0.83	96.40	55.21	1.72	0.84	95.81	54.82	1.74	0.83
8	96.19	53.98	1.70	0.83	96.32	55.16	1.71	0.84	94.41	54.83	1.72	0.82
9	95.02	54.24	1.70	0.83	97.17	55.45	1.68	0.85	93.61	54.95	1.72	0.83
10	94.39	54.46	1.68	0.85	95.41	55.74	1.68	0.84	93.84	55.24	1.71	0.82
11	93.57	54.65	1.67	0.82	95.30	55.97	1.69	0.84	94.21	55.77	1.69	0.81
12	94.49	54.99	1.67	0.84	94.75	56.12	1.66	0.83	92.72	55.42	1.69	0.81
13	92.98	54.95	1.65	0.84	95.23	56.11	1.64	0.83	92.41	55.64	1.68	0.82
14	92.59	55.04	1.63	0.83	93.86	56.09	1.65	0.85	92.95	55.98	1.66	0.82
15	93.10	55.47	1.61	0.83	93.33	56.11	1.64	0.83	91.45	56.00	1.66	0.82
16	91.35	55.70	1.61	0.83	93.55	56.50	1.61	0.84	90.74	56.39	1.63	0.82
17	91.07	55.88	1.58	0.84	92.25	57.05	1.60	0.82	90.59	56.29	1.63	0.82
18	91.42	56.38	1.57	0.82	91.95	57.00	1.59	0.83	90.90	56.89	1.58	0.81
19	90.18	56.35	1.56	0.83	91.98	57.63	1.56	0.82	89.58	57.11	1.59	0.81
20	89.56	56.65	1.54	0.83	90.69	57.73	1.56	0.83	89.30	57.44	1.56	0.81
21	88.89	57.25	1.50	0.82	90.39	58.02	1.53	0.83	89.35	57.95	1.53	0.81
22	88.91	57.49	1.49	0.83	89.78	58.53	1.50	0.84	88.06	58.17	1.51	0.82
23	87.64	58.03	1.46	0.83	90.65	59.06	1.49	0.83	87.71	58.96	1.48	0.83
24	87.21	58.82	1.44	0.83	88.80	59.59	1.46	0.84	86.82	59.56	1.45	0.81
25	86.50	59.06	1.40	0.83	88.19	60.24	1.44	0.83	86.24	60.26	1.42	0.84
26	86.23	60.44	1.36	0.84	87.85	61.03	1.39	0.84	87.30	61.47	1.37	0.80
27	86.77	61.64	1.31	0.84	87.17	62.04	1.34	0.84	85.56	62.23	1.35	0.84
28	84.79	62.73	1.26	0.85	87.74	63.65	1.28	0.86	85.21	64.53	1.27	0.87
29	84.82	65.48	1.14	0.89	86.34	65.08	1.23	0.89	85.50	67.91	1.15	0.90
30	85.83	76.04	0.90	1.02	86.09	68.92	1.10	0.92	86.43	82.45	0.72	1.19
31	84.77	86.25	0.22	1.31	88.45	84.94	0.58	1.20	83.44	85.21	0.27	1.33

PER TEST	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)
Last Cycle	85.834	51.735	120.083	1.059	86.087	53.187	119.815	1.068	86.434	52.561	118.349	1.067
10 Cycle Avg.	86.76				88.30				86.82			
20 Cycle Avg.	89.40				90.79				89.15			
30 Cycle Avg.	91.79				93.00				91.28			

HX-HPF Ballast: PTC Test Data

	Lamp C, Test 1				Lamp C, Test 2				Lamp C, Test 3			
CYCLES	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)
1	96.68	52.31	1.76	0.82	96.81	52.89	1.77	0.83	96.79	52.84	1.73	0.83
2	97.20	52.59	1.75	0.84	97.59	52.99	1.75	0.85	97.52	52.94	1.70	0.83
3	96.35	52.87	1.75	0.82	96.49	53.02	1.74	0.83	96.00	52.81	1.72	0.82
4	95.35	52.88	1.74	0.82	96.04	53.25	1.75	0.82	95.97	52.55	1.71	0.83
5	96.67	52.98	1.71	0.82	97.39	53.58	1.71	0.82	97.09	53.23	1.69	0.81
6	95.27	53.63	1.72	0.80	95.78	53.64	1.74	0.81	95.50	52.98	1.70	0.82
7	94.70	53.25	1.70	0.82	95.33	53.43	1.71	0.83	94.73	53.05	1.68	0.83
8	95.42	53.60	1.70	0.83	96.11	53.87	1.70	0.81	95.37	53.56	1.66	0.83
9	93.90	53.79	1.70	0.81	94.41	53.83	1.68	0.82	93.65	53.43	1.67	0.81
10	93.43	53.75	1.70	0.81	93.84	53.55	1.69	0.82	93.57	53.37	1.65	0.82
11	93.30	53.94	1.68	0.81	95.22	54.59	1.65	0.84	94.40	54.14	1.64	0.83
12	93.58	54.14	1.65	0.81	93.78	54.34	1.66	0.79	92.93	54.00	1.64	0.81
13	92.28	54.28	1.66	0.81	92.83	54.39	1.65	0.82	92.43	53.98	1.63	0.81
14	92.04	54.28	1.64	0.82	93.86	54.70	1.63	0.82	92.99	54.32	1.61	0.80
15	92.79	54.97	1.62	0.81	92.36	54.83	1.64	0.81	91.65	54.30	1.58	0.81
16	91.05	54.53	1.62	0.81	91.82	54.72	1.62	0.81	91.27	54.92	1.58	0.82
17	90.75	54.84	1.59	0.81	92.42	55.37	1.60	0.81	90.86	55.23	1.57	0.80
18	91.56	55.70	1.58	0.80	90.99	55.97	1.57	0.82	91.03	55.36	1.55	0.82
19	89.56	55.43	1.58	0.81	90.06	55.52	1.57	0.81	89.95	55.46	1.55	0.82
20	89.25	56.16	1.54	0.80	89.98	56.20	1.55	0.82	89.66	56.31	1.52	0.82
21	88.62	56.16	1.55	0.81	89.92	56.49	1.53	0.82	89.66	56.45	1.48	0.81
22	89.48	57.11	1.52	0.82	88.70	56.89	1.51	0.81	88.61	56.55	1.47	0.81
23	87.53	57.72	1.50	0.81	88.32	57.13	1.49	0.82	87.63	57.18	1.45	0.80
24	87.34	58.05	1.46	0.81	88.87	57.91	1.46	0.82	87.34	57.83	1.43	0.82
25	86.65	58.98	1.42	0.80	87.08	58.39	1.45	0.82	87.72	59.11	1.39	0.80
26	87.47	59.88	1.39	0.81	87.09	59.71	1.41	0.81	86.55	59.61	1.37	0.81
27	85.83	60.82	1.37	0.83	86.71	60.17	1.36	0.83	85.83	60.88	1.32	0.82
28	85.49	61.97	1.30	0.83	86.11	62.28	1.31	0.85	86.06	62.84	1.26	0.84
29	86.16	65.36	1.22	0.87	86.50	64.28	1.23	0.86	86.41	66.12	1.17	0.88
30	87.86	81.43	0.78	1.12	87.77	71.30	1.06	0.93	88.56	82.76	0.72	1.14
31	85.81	87.09	0.26	1.37	89.23	90.63	0.35	1.32	85.68	86.75	0.20	1.37

PER TEST	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)
Last Cycle	87.863	50.528	118.471	1.049	87.767	50.812	118.615	1.062	88.564	50.424	118.527	1.053
10 Cycle Avg.	87.24				87.71				87.44			
20 Cycle Avg.	89.43				90.02				89.58			
30 Cycle Avg.	91.45				92.01				91.59			

HX-HPF Ballast: PTC Test Data

	Lamp D, Test 1				Lamp D, Test 2				Lamp D, Test 3			
CYCLES	**Line Voltage (V)**	**Arctube Voltage (V)**	**PV Voltage (V)**	**Current (A)**	**Line Voltage (V)**	**Arctube Voltage (V)**	**PV Voltage (V)**	**Current (A)**	**Line Voltage (V)**	**Arctube Voltage (V)**	**PV Voltage (V)**	**Current (A)**
1	100.63	58.75	1.60	0.91	101.25	59.04	1.61	0.92	100.59	59.75	1.73	0.90
2	99.49	58.96	1.62	0.90	99.90	58.74	1.60	0.90	100.65	59.42	1.74	0.89
3	98.70	58.72	1.61	0.90	99.12	58.80	1.59	0.91	101.47	60.41	1.72	0.91
4	100.20	58.90	1.58	0.90	100.60	58.86	1.58	0.91	99.94	60.30	1.72	0.91
5	98.66	58.64	1.61	0.89	98.74	58.95	1.59	0.90	99.32	60.06	1.70	0.90
6	98.26	58.90	1.59	0.91	99.29	59.29	1.59	0.91	100.74	60.51	1.68	0.91
7	99.62	59.58	1.58	0.90	99.72	59.40	1.55	0.90	99.32	60.04	1.69	0.90
8	97.43	59.16	1.58	0.89	97.93	59.55	1.58	0.87	98.75	60.02	1.67	0.90
9	98.00	59.45	1.55	0.91	97.81	59.42	1.56	0.91	98.69	60.51	1.68	0.90
10	98.50	60.10	1.54	0.89	98.76	60.43	1.54	0.89	99.19	61.21	1.66	0.91
11	97.18	59.74	1.54	0.88	97.62	59.56	1.54	0.91	97.85	60.86	1.66	0.90
12	96.61	59.84	1.54	0.90	96.78	59.67	1.54	0.88	97.84	61.13	1.66	0.90
13	97.38	60.39	1.52	0.89	97.66	60.28	1.52	0.88	98.40	61.28	1.62	0.90
14	96.26	60.19	1.53	0.89	96.30	60.20	1.53	0.89	96.85	61.23	1.61	0.91
15	95.71	60.38	1.51	0.88	96.14	60.71	1.50	0.89	96.08	61.38	1.61	0.88
16	95.27	60.27	1.49	0.89	95.65	60.88	1.49	0.89	97.44	61.79	1.59	0.90
17	96.15	61.03	1.48	0.90	96.40	61.14	1.46	0.89	95.93	61.95	1.59	0.90
18	95.04	61.23	1.47	0.89	94.94	61.56	1.48	0.88	96.05	62.52	1.57	0.90
19	94.35	61.90	1.46	0.88	94.59	61.37	1.44	0.86	96.18	62.49	1.52	0.89
20	95.12	61.91	1.43	0.89	95.06	62.03	1.43	0.89	95.03	63.07	1.53	0.90
21	93.44	61.81	1.42	0.88	93.52	61.97	1.41	0.90	94.47	63.45	1.50	0.90
22	93.41	62.74	1.40	0.89	92.87	63.03	1.39	0.89	93.81	63.61	1.50	0.90
23	93.93	63.00	1.39	0.88	93.93	63.36	1.37	0.89	94.69	64.27	1.47	0.91
24	92.02	63.65	1.38	0.90	92.59	64.04	1.34	0.90	93.00	64.63	1.47	0.89
25	92.13	64.44	1.33	0.88	91.70	64.34	1.34	0.91	92.55	65.40	1.44	0.90
26	91.37	64.85	1.31	0.90	91.74	65.05	1.30	0.90	93.78	66.47	1.37	0.91
27	92.23	66.63	1.26	0.91	91.46	65.87	1.26	0.91	92.59	67.54	1.35	0.93
28	90.75	67.12	1.22	0.92	92.28	67.93	1.19	0.91	91.66	68.64	1.31	0.94
29	91.05	68.76	1.17	0.96	91.06	69.37	1.15	0.93	91.89	70.78	1.24	0.97
30	91.75	73.72	1.06	0.99	91.51	73.68	1.04	0.99	92.96	76.47	1.08	1.02
31	93.83	92.47	0.51	1.32	94.35	92.56	0.47	1.31	95.09	96.83	0.32	1.45

PER TEST	***Line Voltage* (V)**	***SS Arctube* Voltage (V)**	***SS Line* Voltage (V)**	**SS Current (A)**	**Line Voltage (V)**	**SS Arctube Voltage (V)**	**SS Line Voltage (V)**	**SS Current (A)**	**Line Voltage (V)**	**SS Arctube Voltage (V)**	**SS Line Voltage (V)**	**SS Current (A)**
Last Cycle	91.754	56.530	118.503	1.100	91.506	56.609	118.375	1.102	92.957	57.752	118.939	1.090
10 Cycle Avg.	92.21				92.27				93.14			
20 Cycle Avg.	94.06				94.19				94.95			
30 Cycle Avg.	95.69				95.90				96.59			

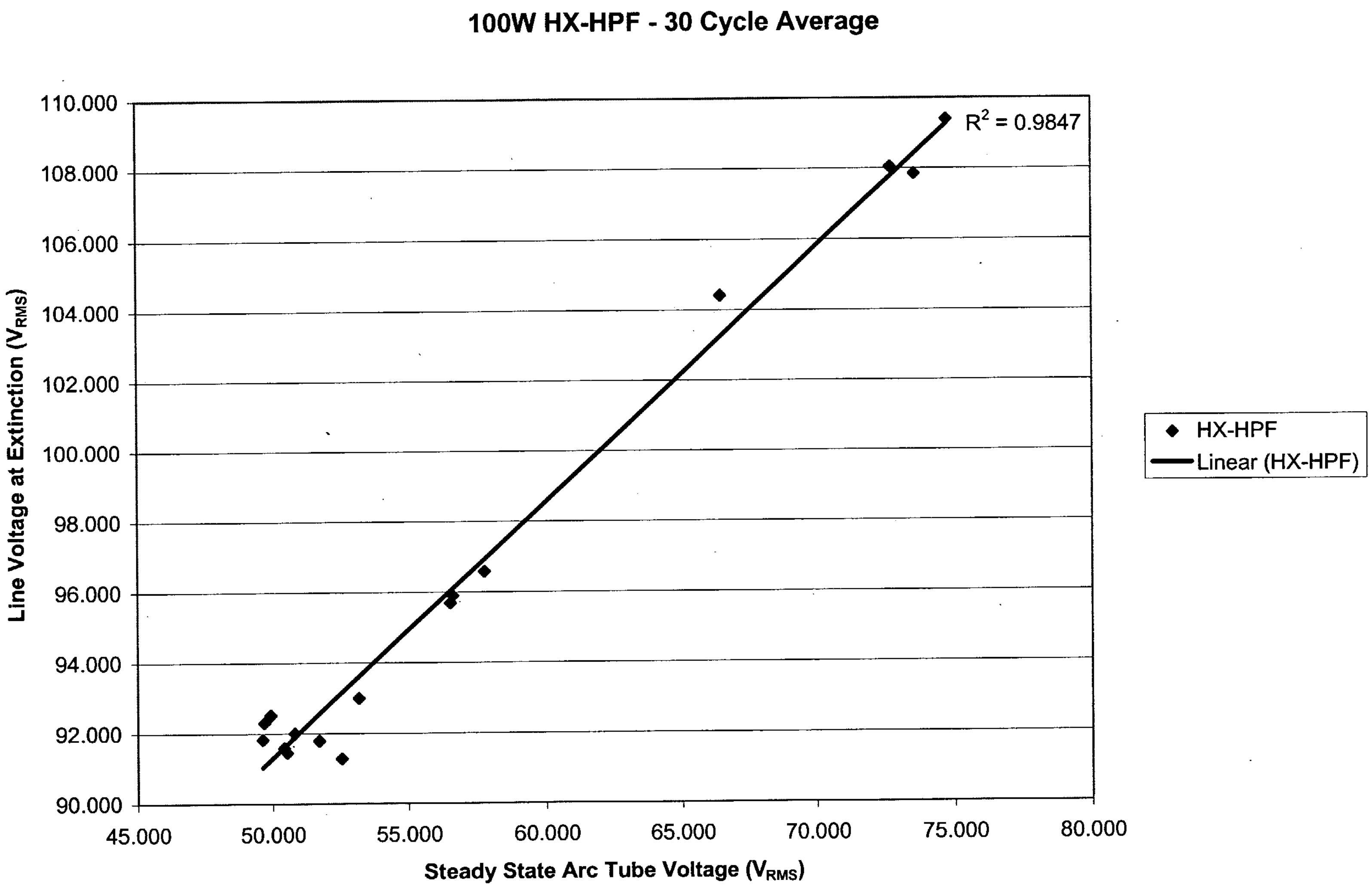
HX-HPF Ballast: PTC Test Data

	Lamp E, Test 1				Lamp E, Test 2				Lamp E, Test 3			
CYCLES	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)
1	109.92	75.73	2.05	1.07	108.20	74.23	2.03	1.07	108.72	74.27	1.94	1.06
2	110.89	76.01	2.05	1.08	108.38	73.92	2.01	1.04	109.48	73.78	1.93	1.07
3	109.29	76.06	2.06	1.09	109.47	74.75	2.01	1.05	108.28	74.23	1.95	1.06
4	109.81	75.80	2.04	1.08	108.04	74.63	2.02	1.06	108.33	74.31	1.95	1.07
5	110.75	76.41	2.03	1.08	108.22	74.56	2.02	1.06	108.06	73.75	1.95	1.07
6	109.33	76.42	2.05	1.07	109.87	74.71	1.99	1.07	109.33	74.62	1.94	1.07
7	109.30	76.42	2.04	1.07	108.34	74.65	2.02	1.07	108.07	74.20	1.92	1.06
8	110.50	76.70	2.02	1.08	108.52	75.00	2.01	1.06	108.12	74.47	1.92	1.08
9	109.28	76.57	2.01	1.09	107.69	74.97	2.01	1.05	109.10	75.29	1.91	1.07
10	109.13	76.40	2.03	1.08	109.24	75.26	1.97	1.06	107.87	74.33	1.93	1.07
11	110.52	77.05	2.02	1.08	107.94	75.30	2.00	1.07	107.16	74.21	1.92	1.08
12	109.23	76.69	2.01	1.07	108.06	74.97	1.98	1.07	109.01	75.41	1.92	1.07
13	109.29	76.98	2.02	1.08	108.64	75.93	1.98	1.07	107.59	75.13	1.91	1.07
14	110.03	77.81	2.00	1.09	108.00	75.74	1.97	1.06	107.39	75.20	1.90	1.08
15	108.96	77.09	2.01	1.10	107.61	75.99	1.99	1.07	108.35	75.64	1.89	1.08
16	108.84	77.45	1.99	1.09	108.90	76.47	1.95	1.06	107.27	75.33	1.89	1.08
17	110.12	78.23	1.98	1.09	107.46	76.19	1.94	1.06	107.61	75.57	1.88	1.09
18	108.50	78.08	1.98	1.08	107.10	76.42	1.94	1.09	108.45	76.73	1.87	1.09
19	108.64	78.11	1.97	1.08	108.48	77.07	1.93	1.07	106.92	76.17	1.87	1.08
20	109.98	79.14	1.96	1.10	107.09	76.97	1.92	1.07	107.00	76.19	1.86	1.09
21	108.73	78.99	1.96	1.09	107.19	77.20	1.91	1.11	108.62	77.67	1.83	1.09
22	108.65	79.39	1.96	1.11	107.20	77.71	1.92	1.08	106.58	76.77	1.84	1.09
23	109.59	80.02	1.92	1.11	108.61	78.46	1.89	1.06	106.86	77.61	1.83	1.10
24	107.88	80.18	1.92	1.12	107.00	78.46	1.89	1.11	106.57	78.26	1.83	1.11
25	108.18	80.65	1.88	1.13	107.30	79.08	1.87	1.10	108.11	78.52	1.78	1.10
26	108.66	81.38	1.88	1.13	108.21	79.81	1.85	1.09	106.60	79.39	1.77	1.10
27	109.59	83.11	1.84	1.12	107.14	80.70	1.82	1.12	107.02	79.88	1.76	1.13
28	108.55	83.75	1.83	1.16	106.99	81.96	1.80	1.13	107.86	81.54	1.73	1.12
29	108.93	86.78	1.77	1.19	108.65	84.20	1.74	1.15	107.66	83.28	1.69	1.15
30	110.91	99.54	1.47	1.39	108.03	87.43	1.67	1.19	107.62	86.41	1.61	1.20
31	112.56	114.08	0.89	1.80	110.16	107.15	1.15	1.59	110.77	104.97	1.18	1.53

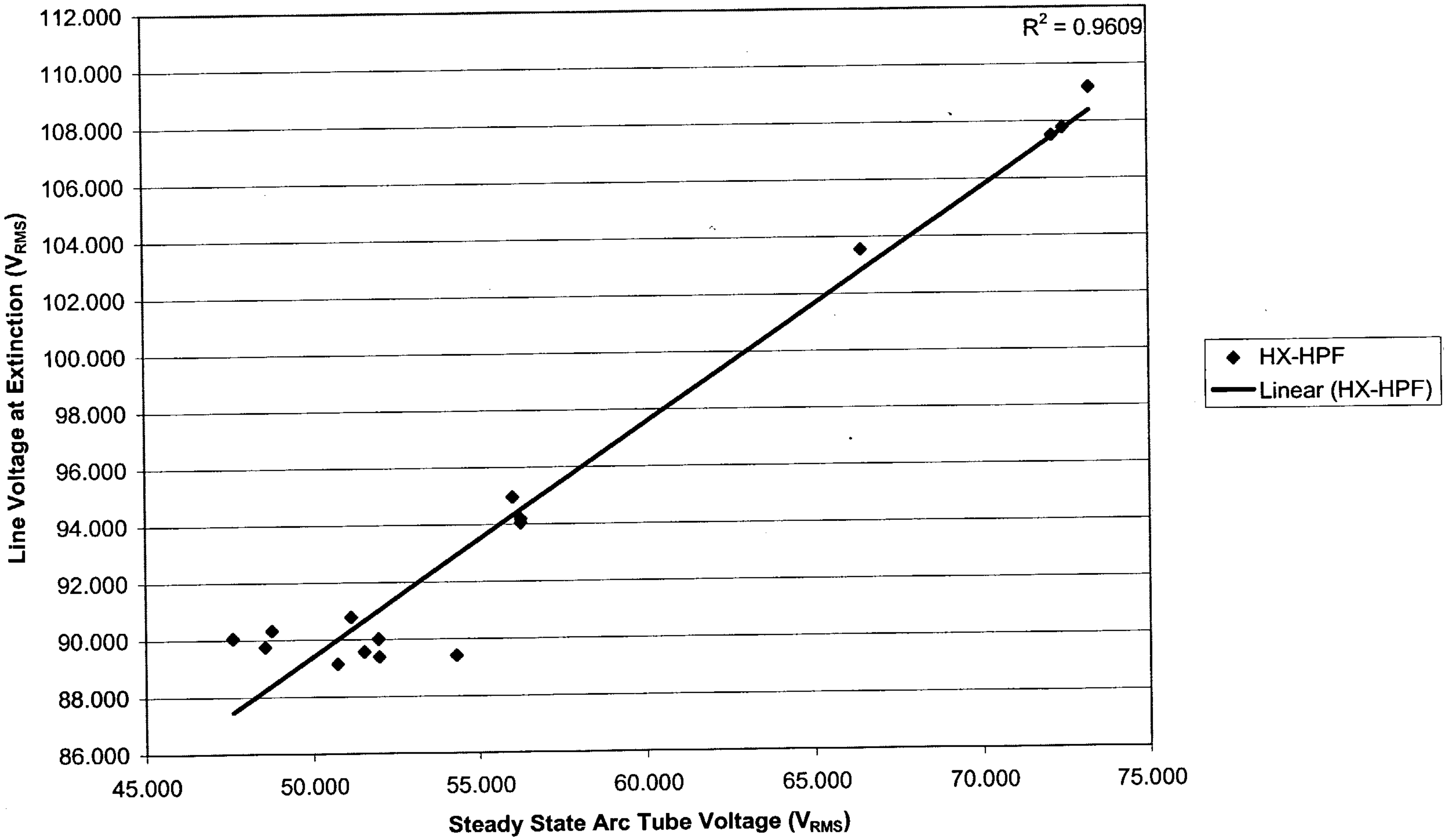
PER TEST	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)
Last Cycle	110.910	74.742	120.151	1.179	108.030	72.698	119.079	1.157	107.620	73.576	119.792	1.163
10 Cycle Avg.	108.97				107.63				107.35			
20 Cycle Avg.	109.19				107.78				107.51			
30 Cycle Avg.	109.40				108.05				107.85			

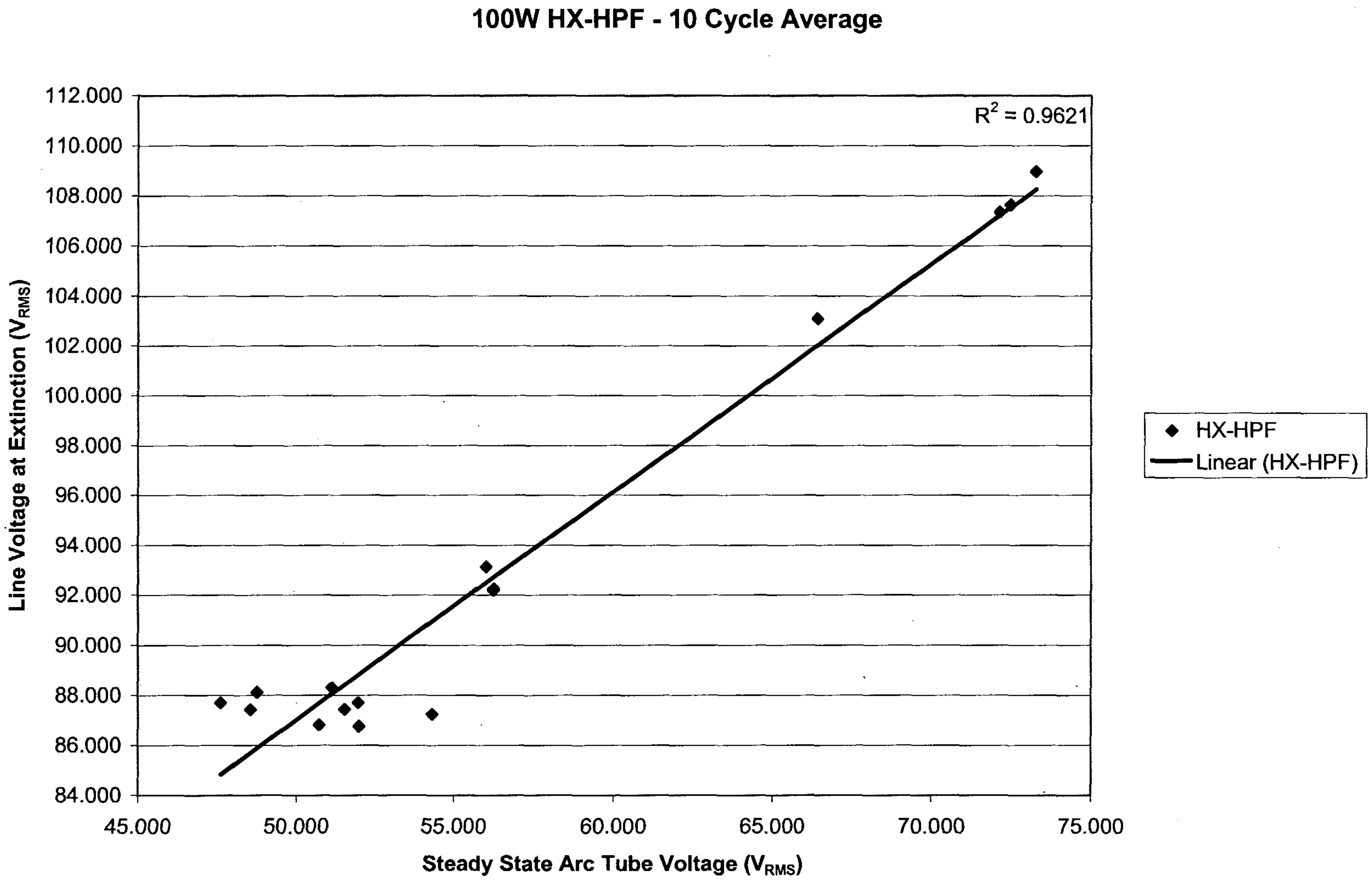
HX-HPF Ballast: PTC Test Data

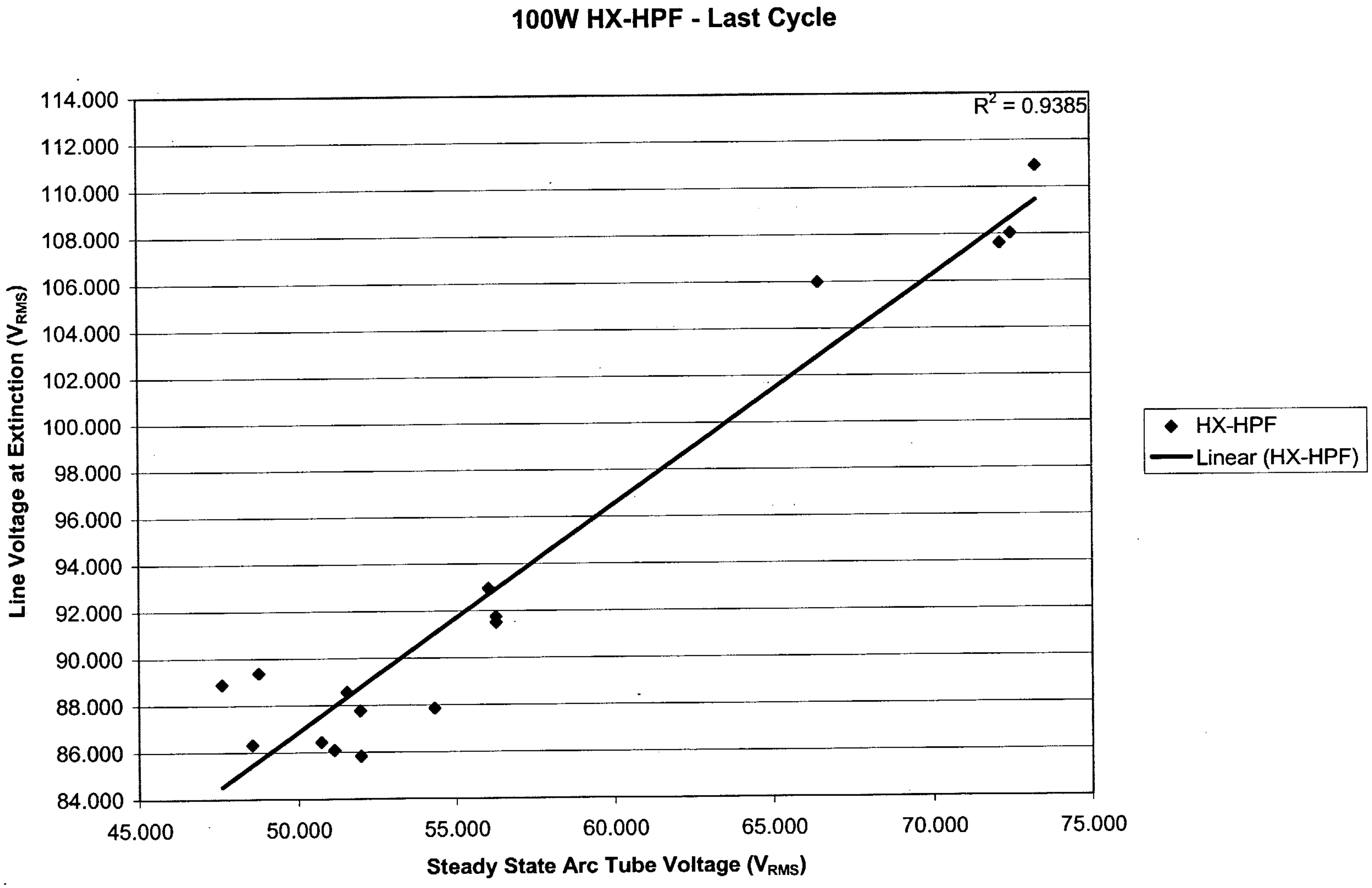
	120204-2, Test 1				120204-2, Test 2				120204-2, Test 3			
CYCLES	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)
1	106.600	66.937	1.793	0.969	106.620	68.542	1.802	0.975	107.660	68.015	1.764	0.989
2	107.630	67.118	1.795	0.970	106.330	68.654	1.805	0.976	106.460	67.947	1.795	0.977
3	106.090	66.614	1.798	0.960	107.540	69.408	1.779	0.987	106.110	67.815	1.779	0.981
4	107.410	67.155	1.781	0.966	105.800	68.309	1.771	0.974	107.180	68.429	1.780	0.988
5	106.430	66.826	1.807	0.964	105.970	68.837	1.797	0.972	105.800	68.806	1.787	0.973
6	106.180	67.252	1.766	0.959	107.420	69.392	1.752	0.980	105.900	68.484	1.781	0.976
7	107.190	67.723	1.780	0.959	105.590	69.128	1.779	0.978	106.830	68.619	1.739	0.974
8	105.020	67.412	1.749	0.951	105.710	69.089	1.758	0.985	105.440	68.629	1.762	0.974
9	104.580	68.263	1.716	0.967	106.790	69.325	1.742	0.976	105.590	68.866	1.745	0.974
10	104.000	68.741	1.705	0.978	105.610	69.967	1.755	0.975	106.550	69.108	1.735	0.984
11	105.490	68.935	1.687	0.962	105.210	69.793	1.747	0.974	105.490	69.225	1.743	0.979
12	104.400	68.685	1.697	0.960	106.070	69.712	1.740	0.985	105.470	69.956	1.715	0.986
13	103.780	69.108	1.699	0.967	104.660	70.141	1.733	0.982	104.990	69.514	1.727	0.973
14	104.820	69.325	1.661	0.979	105.210	70.156	1.720	0.983	105.850	69.870	1.692	0.978
15	103.930	69.660	1.676	0.966	105.980	70.641	1.720	0.987	104.750	69.723	1.701	0.981
16	103.380	69.781	1.667	0.968	104.530	70.650	1.704	0.983	104.590	70.189	1.697	0.988
17	104.130	69.941	1.627	0.980	104.320	70.620	1.683	0.991	106.010	70.760	1.671	0.986
18	103.270	70.369	1.631	0.978	105.930	71.491	1.668	0.985	104.070	70.845	1.675	0.981
19	102.760	70.600	1.626	0.975	104.330	71.610	1.677	0.988	104.400	71.063	1.657	0.986
20	104.240	71.593	1.592	0.983	103.960	71.541	1.653	0.985	105.000	72.148	1.643	0.991
21	102.920	71.806	1.604	0.981	105.210	72.228	1.635	0.992	103.710	71.554	1.641	0.981
22	102.020	71.311	1.580	0.991	103.700	72.682	1.633	0.989	103.810	71.747	1.628	0.993
23	102.770	72.764	1.556	0.983	103.460	73.432	1.619	0.998	104.570	72.955	1.591	1.003
24	103.740	73.445	1.555	0.991	104.900	74.691	1.583	1.006	103.290	73.553	1.576	1.003
25	101.940	73.406	1.530	1.006	103.210	74.273	1.560	1.013	103.090	74.168	1.555	1.013
26	102.210	74.709	1.493	1.009	103.320	75.410	1.532	1.022	104.500	75.073	1.509	1.020
27	103.770	75.758	1.453	1.014	103.160	76.957	1.486	1.033	103.130	76.011	1.479	1.033
28	102.760	76.947	1.401	1.044	104.720	79.455	1.420	1.054	103.560	77.952	1.444	1.046
29	102.750	80.373	1.334	1.070	104.630	83.917	1.292	1.113	103.820	82.270	1.322	1.089
30	105.990	101.300	0.683	1.464	108.260	108.850	0.297	1.619	107.370	108.440	0.303	1.614
31	106.570	107.250	0.147	1.697	106.920	107.990	0.070	1.680	107.780	108.870	0.065	1.643
PER TEST	**Line Voltage (V)**	**SS Arctube Voltage (V)**	**SS Line Voltage (V)**	**SS Current (A)**	**Line Voltage (V)**	**SS Arctube Voltage (V)**	**SS Line Voltage (V)**	**SS Current (A)**	**Line Voltage (V)**	**SS Arctube Voltage (V)**	**SS Line Voltage (V)**	**SS Current (A)**
Last Cycle	105.990	66.444	120.244	1.090	108.260	67.740	119.906	1.093	107.370	67.229	120.177	1.094
10 Cycle Avg.	103.09				104.46				104.09			
20 Cycle Avg.	103.55				104.74				104.57			
30 Cycle Avg.	104.41				105.27				105.17			


100W HX-HPF - 30 Cycle Average
Line Voltage at Extinction (V_{RMS})
Steady State Arc Tube Voltage (V_{RMS})
110.000
108.000
106.000
104.000
102.000
100.000
98.000
96.000
94.000
92.000
90.000
45.000
50.000
55.000
60.000
65.000
70.000
75.000
80.000
$R^2 = 0.9847$
◆ HX-HPF
Linear (HX-HPF)

100W HX-HPF - 20 Cycle Average




100W HX-HPF - 10 Cycle Average
R^2 = 0.9621
112.000
110.000
108.000
106.000
104.000
102.000
100.000
98.000
96.000
94.000
92.000
90.000
88.000
86.000
84.000
Line Voltage at Extinction (V_{RMS})
45.000
50.000
55.000
60.000
65.000
70.000
75.000
Steady State Arc Tube Voltage (V_{RMS})
◆ HX-HPF
Linear (HX-HPF)


100W HX-HPF - Last Cycle
$R^2 = 0.9385$
114.000
112.000
110.000
108.000
106.000
104.000
102.000
100.000
98.000
96.000
94.000
92.000
90.000
88.000
86.000
84.000
Line Voltage at Extinction (V_{RMS})
45.000
50.000
55.000
60.000
65.000
70.000
75.000
Steady State Arc Tube Voltage (V_{RMS})
◆ HX-HPF
— Linear (HX-HPF)

Regulated Lag Ballast: PTC Test Data

	Lamp 3A, Test 1 - August 24, 2004, 15:33				**Lamp 3A, Test 2 - August 24, 2004, 15:58**				**Lamp 3A, Test 3 - August 24, 2004, 16:40**			
CYCLES	**Line Voltage (V)**	**Arctube Voltage (V)**	**PV Voltage (V)**	**Current (A)**	**Line Voltage (V)**	**Arctube Voltage (V)**	**PV Voltage (V)**	**Current (A)**	**Line Voltage (V)**	**Arctube Voltage (V)**	**PV Voltage (V)**	**Current (A)**
1	96.82	46.27	2.73	1.03	97.28	46.32	2.57	1.03	97.34	46.31	2.58	1.02
2	96.41	46.41	2.73	1.03	97.42	46.78	2.57	1.03	96.98	46.53	2.57	1.03
3	96.66	46.62	2.71	1.04	95.93	46.27	2.57	1.03	97.09	46.82	2.57	1.04
4	95.41	46.27	2.72	1.02	95.67	46.64	2.58	1.04	96.06	46.75	2.57	1.04
5	95.02	46.54	2.70	1.03	95.85	46.99	2.54	1.03	95.36	46.36	2.55	1.03
6	94.74	46.98	2.69	1.04	94.56	46.85	2.55	1.03	95.90	47.24	2.55	1.04
7	93.64	46.47	2.70	1.03	94.39	46.29	2.54	1.04	93.57	46.91	2.55	1.03
8	93.11	46.33	2.70	1.03	93.76	46.95	2.53	1.04	93.75	46.62	2.53	1.02
9	93.10	46.91	2.67	1.03	92.79	46.65	2.54	1.04	93.58	47.04	2.52	1.04
10	91.10	46.61	2.68	1.02	92.53	46.88	2.53	1.03	91.84	47.04	2.53	1.04
11	91.11	46.97	2.68	1.03	91.95	47.65	2.52	1.04	91.95	47.06	2.52	1.04
12	90.77	47.21	2.63	1.03	90.63	46.80	2.49	1.04	91.49	47.39	2.49	1.05
13	89.24	47.39	2.65	1.03	89.94	46.94	2.49	1.03	88.81	47.09	2.50	1.04
14	88.52	47.30	2.64	1.03	89.53	47.59	2.47	1.04	88.85	47.38	2.49	1.04
15	87.82	47.49	2.59	1.03	87.96	47.23	2.48	1.03	88.45	47.56	2.46	1.04
16	85.83	47.28	2.60	1.03	86.93	47.37	2.45	1.03	86.29	47.66	2.45	1.04
17	85.35	47.32	2.58	1.03	86.21	47.51	2.42	1.03	85.82	47.79	2.45	1.04
18	84.13	47.89	2.56	1.03	84.13	47.42	2.43	1.04	84.27	47.77	2.43	1.04
19	82.33	47.85	2.56	1.03	83.19	48.11	2.41	1.03	83.49	48.30	2.39	1.04
20	81.35	48.14	2.52	1.03	81.17	48.22	2.39	1.04	82.00	48.21	2.37	1.05
21	78.98	48.69	2.50	1.04	80.97	48.86	2.35	1.04	80.11	48.78	2.36	1.04
22	78.64	48.48	2.46	1.03	78.69	48.46	2.34	1.03	78.95	48.97	2.33	1.05
23	76.04	49.01	2.45	1.04	76.21	49.15	2.30	1.04	77.06	48.97	2.31	1.04
24	73.04	49.60	2.41	1.03	75.77	49.60	2.25	1.05	74.37	49.66	2.27	1.04
25	71.82	49.77	2.37	1.03	73.11	50.26	2.24	1.04	72.12	50.26	2.22	1.04
26	69.54	50.77	2.28	1.04	69.92	50.78	2.17	1.04	70.74	50.94	2.16	1.05
27	66.02	51.60	2.24	1.04	67.58	51.66	2.11	1.05	68.49	51.43	2.09	1.05
28	63.30	53.03	2.15	1.05	64.30	52.90	2.02	1.06	63.70	52.92	2.00	1.06
29	59.77	54.93	2.02	1.08	61.01	54.96	1.89	1.07	60.79	54.93	1.91	1.09
30	53.88	61.99	1.71	1.14	56.53	59.67	1.69	1.12	56.51	60.50	1.66	1.13
31	42.40	78.59	0.47	1.45	46.16	79.77	0.50	1.44	44.49	79.41	0.46	1.45
PER TEST	**Line Voltage (V)**	**SS Arctube Voltage (V)**	**SS Line Voltage (V)**	**SS Current (A)**	**Line Voltage (V)**	**SS Arctube Voltage (V)**	**SS Line Voltage (V)**	**SS Current (A)**	**Line Voltage (V)**	**SS Arctube Voltage (V)**	**SS Line Voltage (V)**	**SS Current (A)**
Last Cycle	53.884	45.604	118.945	0.949	56.532	45.789	118.759	0.954	56.507	45.049	119.077	0.952
10 Cycle Avg.	69.10				70.41				70.29			
20 Cycle Avg.	77.87				78.79				78.71			
30 Cycle Avg.	83.45				84.20				84.19			

Regulated Lag Ballast: PTC Test Data

	Lamp 3B, Test 1				Lamp 3B, Test 2				Lamp 3B, Test 3			
CYCLES	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)
1	100.14	52.97	2.90	1.13	100.70	53.20	3.06	1.12	98.36	52.74	3.05	1.12
2	99.10	52.68	2.91	1.13	98.76	52.57	3.05	1.13	99.04	52.43	3.04	1.13
3	98.58	53.41	2.91	1.14	98.52	52.78	3.06	1.13	98.41	52.49	3.04	1.14
4	98.96	52.78	2.90	1.14	98.15	52.94	3.04	1.13	98.70	52.46	3.02	1.13
5	97.64	52.83	2.91	1.14	98.06	53.16	3.05	1.13	97.56	52.70	3.02	1.13
6	97.42	53.10	2.89	1.14	97.24	53.02	3.06	1.14	97.00	52.97	3.02	1.13
7	97.17	53.16	2.88	1.14	96.35	53.39	3.05	1.13	96.82	52.64	3.00	1.13
8	95.71	52.87	2.88	1.14	96.54	53.17	3.03	1.15	95.82	52.71	3.02	1.13
9	95.59	53.29	2.88	1.15	95.60	52.95	3.05	1.14	95.35	52.83	3.00	1.13
10	95.59	53.15	2.84	1.15	94.75	53.39	3.02	1.14	95.18	53.05	2.98	1.14
11	93.94	52.93	2.86	1.14	94.60	53.46	3.02	1.14	93.42	53.18	2.98	1.13
12	93.46	53.47	2.85	1.14	93.09	53.43	3.01	1.15	93.20	53.10	2.98	1.13
13	92.79	53.49	2.86	1.15	92.50	53.42	2.99	1.14	93.02	53.27	2.98	1.14
14	91.53	53.32	2.83	1.14	91.46	53.74	2.99	1.14	90.76	53.48	2.97	1.14
15	90.69	53.63	2.81	1.14	90.40	53.83	2.98	1.14	90.42	53.72	2.96	1.14
16	90.56	53.81	2.79	1.16	89.84	54.31	2.97	1.14	90.23	53.99	2.94	1.14
17	88.52	53.90	2.79	1.15	88.91	54.22	2.94	1.14	88.24	53.60	2.92	1.14
18	88.02	53.92	2.79	1.15	86.68	54.11	2.94	1.14	86.99	54.07	2.91	1.15
19	86.40	54.59	2.74	1.16	86.18	54.78	2.92	1.14	85.47	54.12	2.92	1.14
20	84.75	54.79	2.74	1.15	84.71	55.05	2.90	1.15	85.21	54.36	2.88	1.15
21	83.05	55.20	2.70	1.15	82.47	54.76	2.89	1.15	82.95	54.46	2.86	1.15
22	81.05	55.13	2.69	1.16	81.41	55.59	2.85	1.15	81.02	55.15	2.84	1.15
23	80.62	55.65	2.63	1.17	78.10	56.02	2.84	1.16	79.88	55.61	2.81	1.15
24	77.52	55.83	2.63	1.16	76.59	55.80	2.79	1.16	77.56	55.43	2.77	1.15
25	74.71	56.83	2.58	1.16	75.50	57.06	2.73	1.17	74.97	56.03	2.73	1.16
26	72.58	57.36	2.52	1.17	71.52	57.82	2.69	1.17	72.49	57.36	2.69	1.16
27	70.35	58.22	2.44	1.18	68.41	58.73	2.63	1.18	70.30	57.83	2.61	1.17
28	66.14	60.11	2.33	1.21	65.42	60.87	2.51	1.20	66.73	60.15	2.53	1.19
29	62.60	63.54	2.16	1.24	60.68	64.80	2.34	1.24	61.78	62.79	2.38	1.22
30	56.95	79.54	1.43	1.35	52.31	81.36	1.58	1.43	57.24	78.70	1.76	1.33
31	39.62	84.11	0.13	1.72	37.34	81.06	0.64	1.68	40.03	83.85	0.63	1.73

PER TEST	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)
Last Cycle	56.947	52.013	120.455	1.017	52.307	52.103	119.701	1.011	57.241	51.834	119.633	1.014
10 Cycle Avg.	72.56				71.24				72.49			
20 Cycle Avg.	81.31				80.54				81.09			
30 Cycle Avg.	86.74				86.18				86.47			

Regulated Lag Ballast: PTC Test Data

	Lamp 3C, Test 1				Lamp 3C, Test 2				Lamp 3C, Test 3			
CYCLES	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)
1	101.04	58.58	2.60	1.22	99.75	58.22	2.63	1.22	99.82	58.46	2.61	1.21
2	100.13	58.39	2.60	1.22	99.97	58.57	2.62	1.22	99.64	58.47	2.60	1.22
3	99.69	58.45	2.61	1.23	100.10	58.66	2.61	1.22	99.78	58.56	2.59	1.22
4	100.11	59.06	2.59	1.24	98.96	58.50	2.61	1.22	98.87	58.63	2.61	1.22
5	98.92	58.89	2.61	1.22	98.42	58.65	2.61	1.22	98.28	58.25	2.61	1.22
6	98.67	58.86	2.59	1.23	98.94	58.75	2.58	1.22	98.64	58.86	2.60	1.23
7	99.03	58.60	2.58	1.23	96.88	58.86	2.60	1.23	97.49	58.75	2.61	1.22
8	97.05	58.91	2.58	1.23	96.96	58.72	2.60	1.23	96.64	58.35	2.59	1.23
9	96.61	58.98	2.58	1.24	97.40	58.56	2.56	1.23	97.12	59.04	2.57	1.22
10	96.95	59.46	2.56	1.24	95.28	59.34	2.59	1.23	95.70	58.96	2.58	1.23
11	94.84	59.33	2.55	1.24	95.55	58.97	2.59	1.23	95.35	58.77	2.57	1.24
12	94.70	59.12	2.57	1.24	95.00	58.93	2.55	1.24	94.99	58.87	2.56	1.24
13	94.79	59.24	2.53	1.25	93.48	59.67	2.56	1.23	93.25	59.43	2.56	1.24
14	92.74	59.33	2.54	1.25	93.08	58.80	2.53	1.24	93.00	59.12	2.55	1.25
15	92.43	59.84	2.54	1.25	92.58	59.30	2.53	1.25	92.18	59.31	2.52	1.25
16	91.18	59.52	2.53	1.25	90.21	59.42	2.53	1.25	91.17	59.62	2.52	1.25
17	90.76	59.99	2.50	1.26	89.73	59.66	2.51	1.25	89.96	60.01	2.51	1.25
18	89.09	60.26	2.48	1.25	88.95	59.75	2.47	1.25	89.08	60.27	2.49	1.25
19	87.59	60.30	2.48	1.26	86.87	60.13	2.47	1.25	87.09	60.08	2.50	1.25
20	87.12	60.30	2.44	1.27	85.84	60.52	2.46	1.26	86.37	60.18	2.46	1.26
21	84.98	61.27	2.43	1.26	83.86	60.56	2.46	1.25	84.37	60.32	2.44	1.26
22	83.07	61.11	2.42	1.27	83.23	61.11	2.41	1.27	83.59	61.34	2.39	1.27
23	81.85	61.49	2.38	1.28	81.15	61.52	2.38	1.27	80.88	61.84	2.38	1.27
24	78.70	61.92	2.34	1.28	78.31	62.06	2.34	1.27	78.34	61.98	2.33	1.27
25	77.87	63.00	2.29	1.29	76.49	62.34	2.30	1.28	75.99	63.07	2.28	1.28
26	73.74	63.33	2.24	1.29	74.27	63.79	2.25	1.29	73.84	63.36	2.24	1.28
27	71.76	65.24	2.17	1.31	71.20	65.38	2.16	1.30	71.52	65.87	2.15	1.30
28	68.12	66.81	2.06	1.33	66.40	66.78	2.09	1.32	65.87	67.13	2.07	1.33
29	63.39	70.81	1.90	1.37	63.45	72.22	1.89	1.38	62.61	72.28	1.86	1.38
30	56.76	86.52	1.36	1.53	54.32	88.28	1.24	1.58	53.42	90.26	1.13	1.63
31	42.08	87.58	0.69	1.82	40.07	86.34	0.69	1.78	38.72	85.22	0.66	1.78

PER TEST	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)
Last Cycle	*56.759*	*58.229*	119.260	1.090	54.324	58.025	119.125	1.090	53.415	58.037	119.092	1.090
10 Cycle Avg.	74.02				73.27				73.04			
20 Cycle Avg.	82.77				82.20				82.14			
30 Cycle Avg.	88.12				87.55				87.49			

Regulated Lag Ballast: PTC Test Data

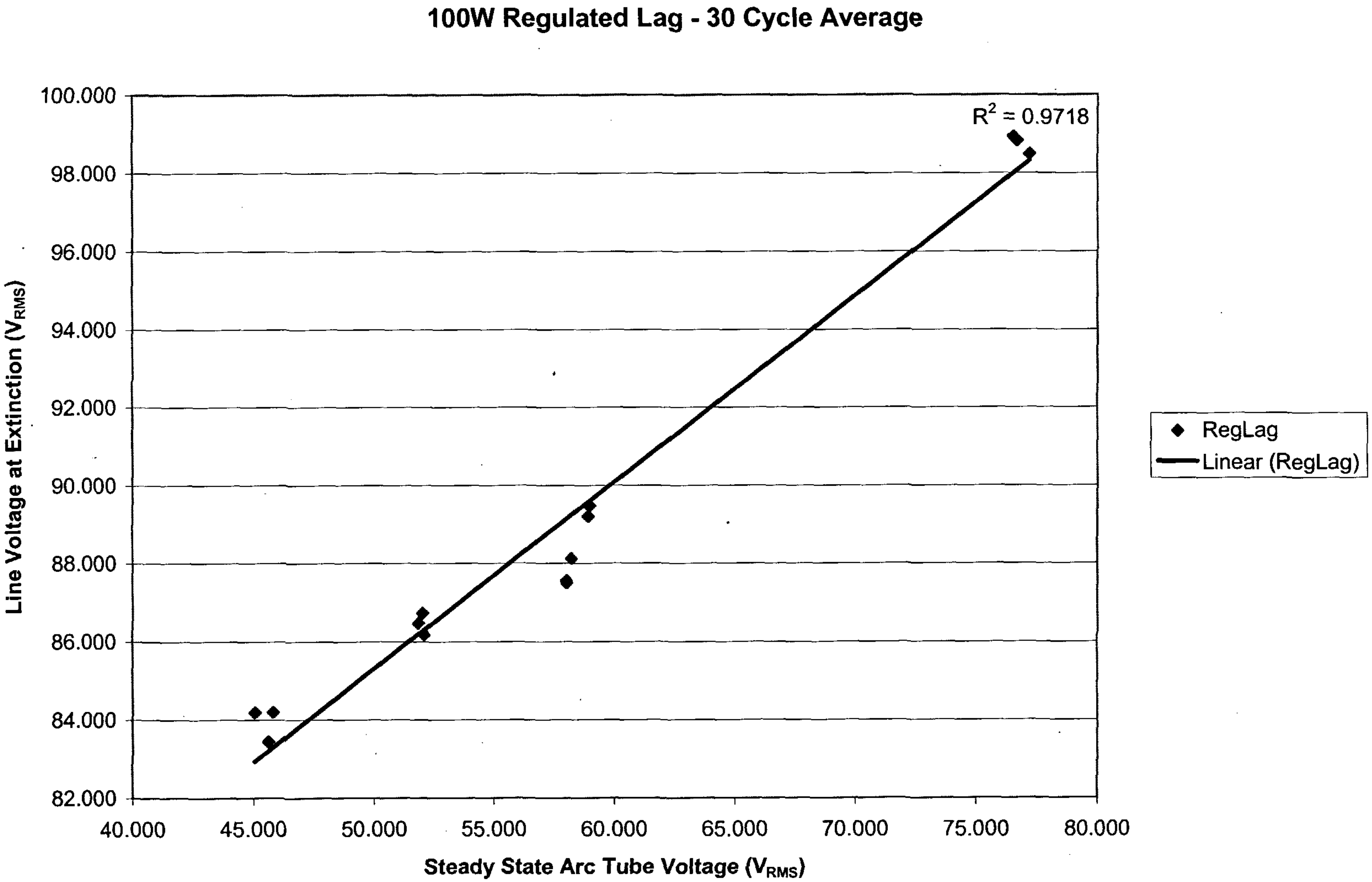
	Lamp 2D, Test 1				Lamp 2D, Test 2				Lamp 2D, Test 3			
CYCLES	**Line Voltage (V)**	**Arctube Voltage (V)**	**PV Voltage (V)**	**Current (A)**	**Line Voltage (V)**	**Arctube Voltage (V)**	**PV Voltage (V)**	**Current (A)**	**Line Voltage (V)**	**Arctube Voltage (V)**	**PV Voltage (V)**	**Current (A)**
1	99.81	59.36	3.07	1.23					100.11	59.31	3.04	1.22
2	100.85	59.59	3.03	1.22					99.89	59.78	3.04	1.23
3	98.62	59.92	3.05	1.22					98.61	59.38	3.06	1.22
4	98.76	59.07	3.04	1.22					98.70	59.21	3.04	1.22
5	99.72	59.80	3.02	1.23					99.08	59.61	3.02	1.23
6	97.57	59.73	3.04	1.23					98.02	59.77	3.04	1.23
7	97.82	59.30	3.02	1.23					97.57	59.30	3.03	1.23
8	97.93	59.60	3.00	1.24					97.57	59.58	3.01	1.24
9	96.43	60.14	3.02	1.23					96.12	60.06	3.02	1.23
10	96.41	59.96	3.01	1.24					95.96	59.29	3.02	1.24
11	96.17	60.00	2.99	1.24					96.26	60.40	2.98	1.24
12	94.58	60.24	3.00	1.24					94.52	59.90	3.01	1.25
13	94.28	60.70	3.00	1.24					94.32	59.88	3.00	1.24
14	92.82	59.80	2.98	1.25					93.61	60.51	2.97	1.25
15	93.25	60.58	2.97	1.25					92.49	60.27	2.97	1.24
16	91.98	60.85	2.96	1.25					91.87	60.33	2.97	1.25
17	91.18	60.61	2.93	1.26	90.80	60.66	2.95	1.25	91.22	60.42	2.94	1.25
18	89.67	61.22	2.94	1.25	90.13	60.48	2.96	1.25	89.96	61.07	2.95	1.26
19	88.93	61.11	2.92	1.26	89.57	60.74	2.90	1.26	89.55	61.00	2.93	1.25
20	88.09	61.36	2.89	1.26	87.70	61.15	2.93	1.26	87.71	61.35	2.89	1.27
21	86.22	61.75	2.88	1.26	86.60	61.79	2.90	1.27	86.47	61.30	2.89	1.26
22	85.20	62.18	2.86	1.27	85.51	61.58	2.86	1.27	85.46	62.17	2.88	1.27
23	83.04	62.23	2.83	1.27	83.88	62.16	2.84	1.27	84.10	62.10	2.84	1.27
24	82.04	63.52	2.77	1.28	82.11	62.39	2.81	1.28	82.02	62.40	2.81	1.28
25	79.67	63.49	2.76	1.28	80.10	63.19	2.78	1.28	80.28	63.27	2.78	1.28
26	76.95	64.65	2.72	1.29	77.79	64.19	2.75	1.29	77.36	63.79	2.73	1.28
27	74.73	65.40	2.65	1.30	76.44	65.28	2.65	1.30	76.15	64.93	2.67	1.31
28	72.11	67.43	2.57	1.33	72.37	66.29	2.59	1.31	73.32	66.64	2.62	1.31
29	68.11	70.37	2.40	1.36	68.46	69.12	2.49	1.35	69.67	68.12	2.49	1.34
30	63.14	87.90	1.71	1.49	65.77	75.61	2.15	1.41	66.15	74.47	2.25	1.40
31	50.81	97.62	0.20	1.93	54.95	98.28	0.60	1.77	57.34	99.50	0.67	1.74

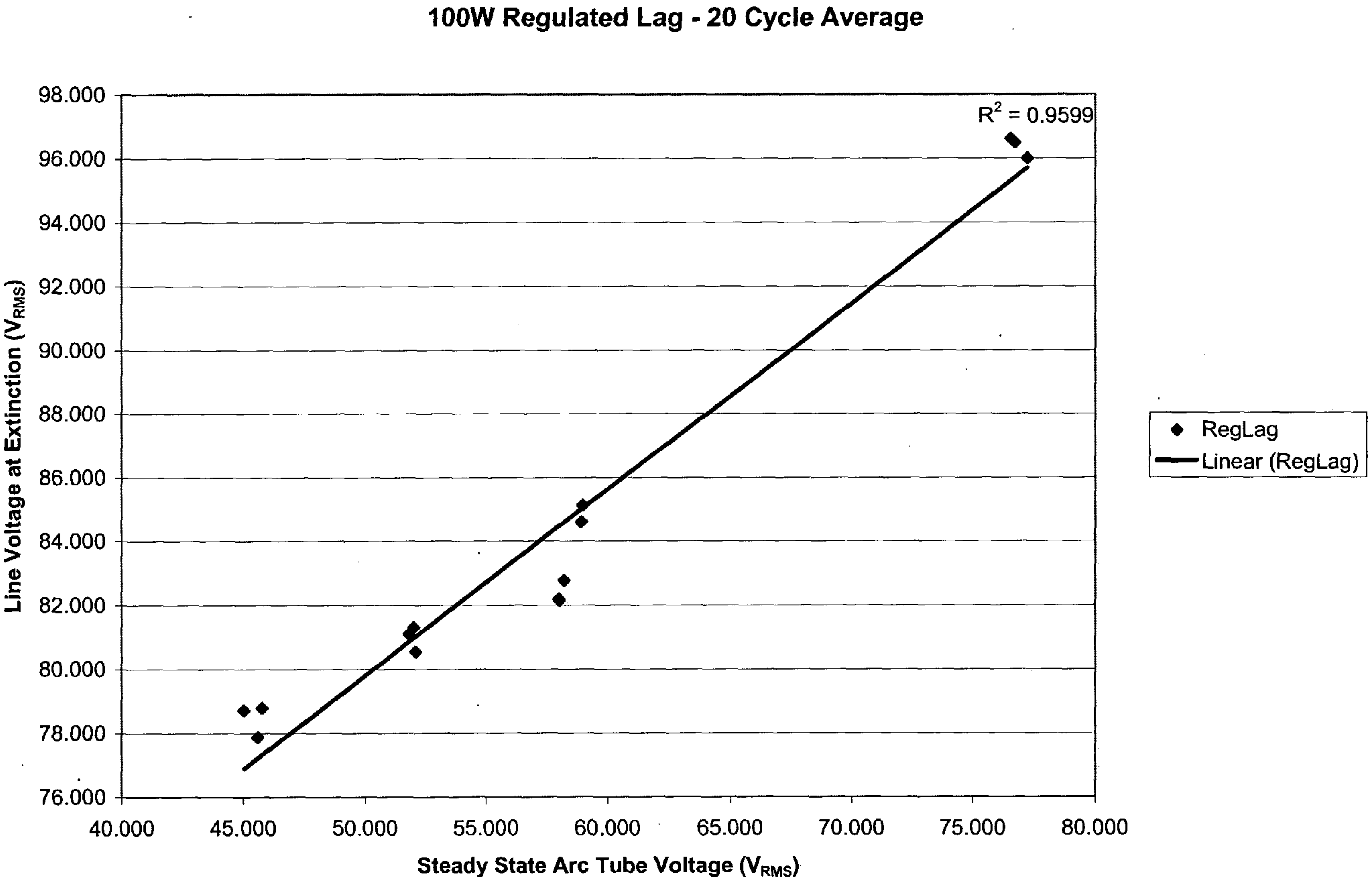
PER TEST	**Line Voltage (V)**	**SS Arctube Voltage (V)**	**SS Line Voltage (V)**	**SS Current (A)**	**Line Voltage (V)**	**SS Arctube Voltage (V)**	**SS Line Voltage (V)**	**SS Current (A)**	**Line Voltage (V)**	**SS Arctube Voltage (V)**	**SS Line Voltage (V)**	**SS Current (A)**
Last Cycle	63.138	58.926	118.530	1.094	65.773	58.838	118.430	1.094	66.151	58.993	118.444	1.094
10 Cycle Avg.	77.12				77.90				78.10			
20 Cycle Avg.	84.61				N/A				85.13			
30 Cycle Avg.	89.20				N/A				89.47			

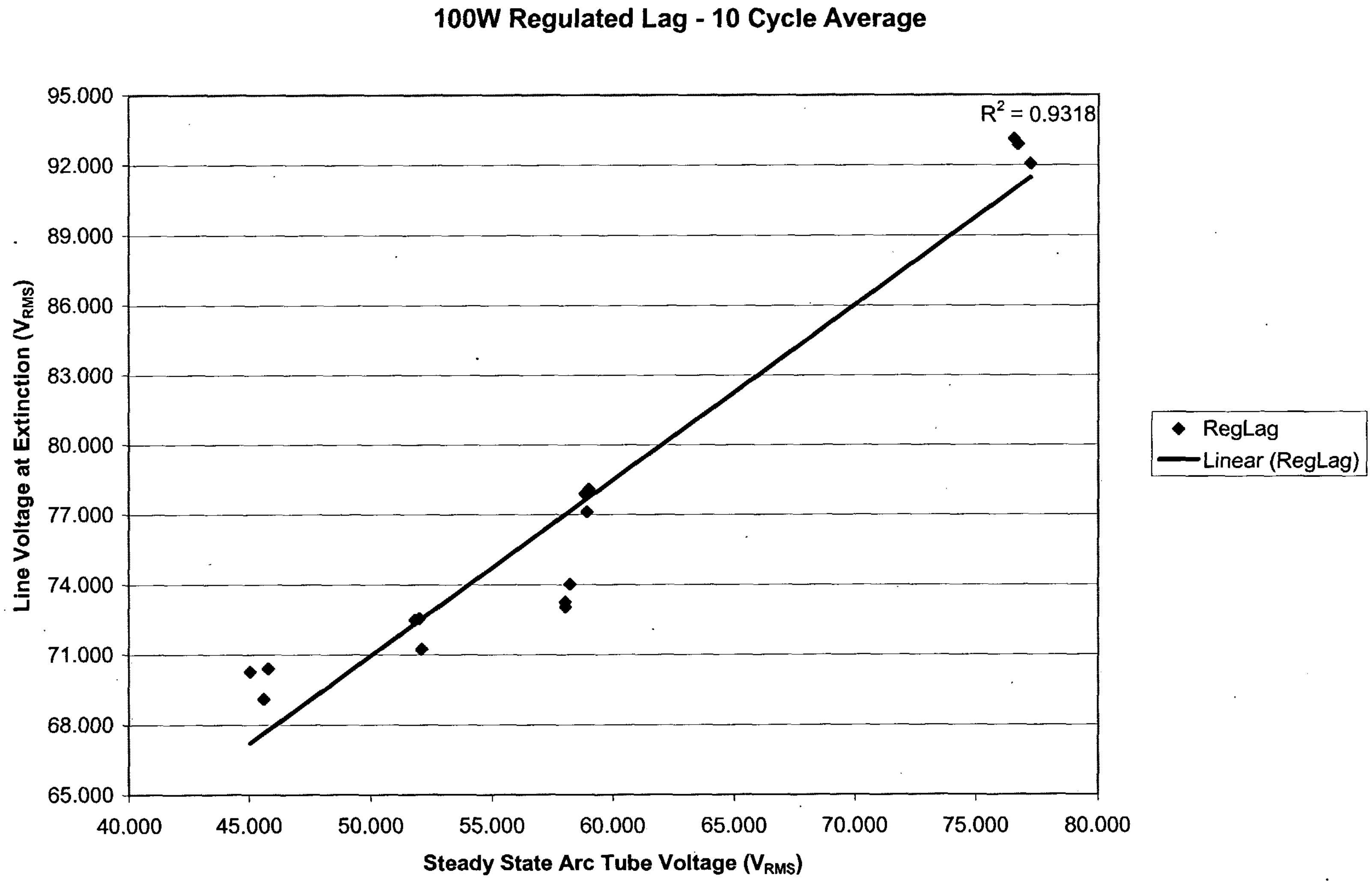
Regulated Lag Ballast: PTC Test Data

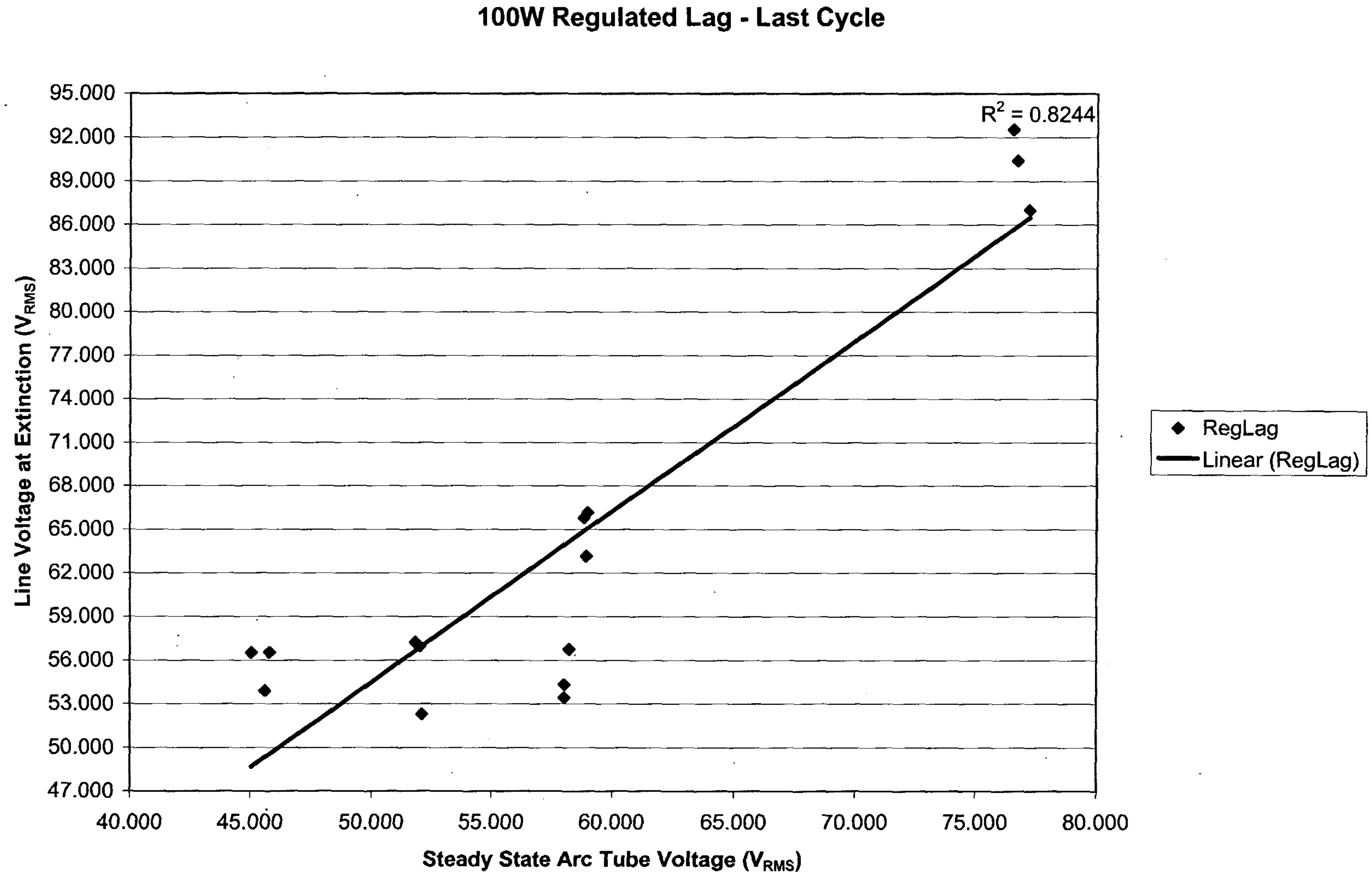
	Lamp 2E, Test 1				Lamp 2E, Test 2				Lamp 2E, Test 3			
CYCLES	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)
1	105.18	77.63	2.74	1.33	104.54	77.55	2.76	1.33	104.19	76.94	2.74	1.34
2	104.40	77.07	2.77	1.34	104.88	78.23	2.73	1.34	104.30	77.28	2.75	1.34
3	103.69	76.93	2.77	1.34	103.16	77.41	2.76	1.34	104.69	77.52	2.72	1.35
4	104.32	77.80	2.73	1.34	103.74	77.21	2.73	1.35	103.71	77.39	2.73	1.34
5	102.75	77.33	2.75	1.35	104.47	78.23	2.72	1.35	103.86	77.55	2.74	1.35
6	103.87	77.13	2.74	1.35	103.12	77.53	2.73	1.35	103.91	78.07	2.72	1.34
7	103.51	78.18	2.72	1.36	103.21	77.54	2.73	1.36	102.80	77.67	2.73	1.35
8	102.55	77.15	2.74	1.35	103.26	78.10	2.70	1.35	102.95	77.74	2.74	1.35
9	102.62	77.44	2.74	1.36	101.97	78.15	2.72	1.36	103.26	78.21	2.71	1.36
10	102.98	78.12	2.71	1.36	102.15	77.82	2.74	1.36	101.42	78.07	2.73	1.36
11	101.29	77.44	2.71	1.36	102.88	78.65	2.69	1.37	102.14	77.94	2.72	1.37
12	101.72	77.51	2.73	1.37	101.12	78.65	2.72	1.37	102.53	78.72	2.69	1.37
13	101.65	78.35	2.70	1.37	100.99	78.69	2.71	1.37	101.08	78.51	2.71	1.37
14	100.40	78.19	2.71	1.38	100.50	78.52	2.68	1.38	100.96	78.10	2.69	1.38
15	100.68	78.31	2.70	1.38	100.41	79.63	2.70	1.39	100.67	79.26	2.68	1.38
16	100.56	78.87	2.68	1.38	99.58	78.97	2.70	1.39	99.59	79.32	2.69	1.39
17	99.38	78.82	2.69	1.39	99.38	79.07	2.68	1.40	98.98	78.61	2.68	1.39
18	98.96	78.67	2.68	1.40	99.47	79.56	2.65	1.40	99.51	79.75	2.64	1.40
19	99.00	79.29	2.67	1.41	97.70	79.95	2.65	1.41	97.79	79.51	2.68	1.41
20	97.42	79.62	2.65	1.41	97.25	79.71	2.65	1.42	97.68	79.78	2.64	1.41
21	97.06	79.39	2.65	1.42	97.42	80.41	2.62	1.42	97.68	80.55	2.62	1.42
22	97.22	81.03	2.60	1.43	95.65	80.70	2.62	1.43	95.77	80.88	2.62	1.42
23	95.22	80.70	2.60	1.44	95.15	81.04	2.60	1.45	95.49	81.22	2.59	1.44
24	94.33	81.55	2.60	1.45	93.18	81.42	2.58	1.46	94.42	82.04	2.57	1.45
25	92.76	82.11	2.55	1.45	93.70	83.40	2.51	1.46	94.03	83.14	2.52	1.46
26	91.58	83.39	2.51	1.47	91.63	83.14	2.52	1.49	92.98	83.81	2.51	1.49
27	92.13	84.92	2.42	1.48	90.33	85.08	2.47	1.50	90.41	85.33	2.46	1.49
28	89.67	87.62	2.37	1.52	88.74	87.00	2.40	1.52	88.87	88.16	2.39	1.52
29	88.70	93.23	2.20	1.55	87.86	89.53	2.30	1.56	88.80	92.98	2.22	1.56
30	92.53	116.14	1.17	1.60	87.00	107.34	1.65	1.64	90.40	113.96	1.28	1.62
31	104.17	120.87	0.18	1.21	99.42	122.14	0.22	1.42	102.84	120.74	0.28	1.25

PER TEST	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)
Last Cycle	92.532	76.552	119.027	1.166	87.004	77.224	119.506	1.165	90.404	76.716	119.883	1.163
10 Cycle Avg.	93.12				92.07				92.88			
20 Cycle Avg.	96.61				96.00				96.49			
30 Cycle Avg.	98.94				98.48				98.83			


100W Regulated Lag - 30 Cycle Average
$R^2 = 0.9718$
100.000
98.000
96.000
94.000
92.000
90.000
88.000
86.000
84.000
82.000
Line Voltage at Extinction (V_{RMS})
40.000
45.000
50.000
55.000
60.000
65.000
70.000
75.000
80.000
Steady State Arc Tube Voltage (V_{RMS})
◆ RegLag
Linear (RegLag)

100W Regulated Lag - 20 Cycle Average
R² = 0.9599
98.000
96.000
94.000
92.000
90.000
88.000
86.000
84.000
82.000
80.000
78.000
76.000
40.000
45.000
50.000
55.000
60.000
65.000
70.000
75.000
80.000
Line Voltage at Extinction (VRMS)
Steady State Arc Tube Voltage (VRMS)
◆ RegLag
Linear (RegLag)


100W Regulated Lag - 10 Cycle Average
R² = 0.9318
95.000
92.000
89.000
86.000
83.000
80.000
77.000
74.000
71.000
68.000
65.000
Line Voltage at Extinction (V_RMS)
40.000
45.000
50.000
55.000
60.000
65.000
70.000
75.000
80.000
Steady State Arc Tube Voltage (V_RMS)
◆ RegLag
Linear (RegLag)


100W Regulated Lag - Last Cycle
Line Voltage at Extinction (V_{RMS})
95.000
92.000
89.000
86.000
83.000
80.000
77.000
74.000
71.000
68.000
65.000
62.000
59.000
56.000
53.000
50.000
47.000
$R^2 = 0.8244$
40.000
45.000
50.000
55.000
60.000
65.000
70.000
75.000
80.000
Steady State Arc Tube Voltage (V_{RMS})
◆ RegLag
Linear (RegLag)

Reactor Ballast: PTC Test Data

	Lamp A2, Test 1 - January 6, 2005, 14:21				Lamp A2, Test 2 - January 6, 2005, 14:40				Lamp A2, Test 3 - January 6, 2005, 15:00			
CYCLES	**Line Voltage (V)**	**Arctube Voltage (V)**	**PV Voltage (V)**	**Current (A)**	**Line Voltage (V)**	**Arctube Voltage (V)**	**PV Voltage (V)**	**Current (A)**	**Line Voltage (V)**	**Arctube Voltage (V)**	**PV Voltage (V)**	**Current (A)**
1	89.61	53.73	2.17	1.06	89.16	53.36	2.17	1.06	88.58	52.98	2.17	1.06
2	87.12	53.54	2.16	1.03	87.71	54.30	2.15	1.03	88.47	53.63	2.13	1.03
3	87.52	54.74	2.13	0.99	87.85	54.18	2.12	0.98	86.16	53.68	2.11	1.00
4	86.05	54.98	2.13	0.96	85.43	54.54	2.10	0.96	86.94	55.12	2.07	0.95
5	85.04	55.18	2.10	0.93	84.66	55.45	2.07	0.92	85.20	55.21	2.06	0.93
6	84.68	55.93	2.05	0.89	85.05	55.97	2.03	0.88	84.64	56.26	2.03	0.89
7	83.86	56.98	2.02	0.86	83.09	56.09	2.02	0.85	83.28	56.13	2.02	0.86
8	83.01	57.60	2.00	0.82	82.44	57.21	1.97	0.82	82.58	57.15	1.98	0.83
9	83.25	58.59	1.96	0.79	82.90	58.04	1.94	0.79	83.37	58.24	1.95	0.78
10	82.51	59.08	1.94	0.76	81.88	59.06	1.93	0.76	81.77	58.70	1.93	0.76
11	82.82	60.61	1.92	0.73	81.73	59.68	1.90	0.72	82.03	59.14	1.90	0.73
12	81.87	61.00	1.89	0.70	82.31	61.01	1.89	0.69	82.29	60.66	1.87	0.71
13	81.95	61.99	1.86	0.66	81.50	61.34	1.86	0.66	81.69	60.94	1.85	0.69
14	82.85	63.36	1.84	0.64	81.46	62.93	1.82	0.64	81.08	62.44	1.82	0.65
15	81.93	63.63	1.81	0.62	82.75	64.11	1.80	0.61	82.55	63.31	1.79	0.62
16	82.37	64.82	1.79	0.60	82.07	64.65	1.77	0.59	81.80	64.22	1.76	0.60
17	83.29	66.42	1.76	0.57	81.79	65.85	1.74	0.56	81.95	65.46	1.74	0.58
18	82.80	66.66	1.76	0.56	83.55	67.17	1.72	0.55	83.15	66.58	1.73	0.56
19	82.66	68.54	1.73	0.53	82.65	67.73	1.72	0.53	82.77	67.25	1.71	0.54
20	83.95	68.90	1.71	0.51	83.25	68.63	1.70	0.51	82.98	68.65	1.68	0.52
21	85.24	71.15	1.67	0.50	85.21	70.87	1.67	0.48	84.75	70.35	1.68	0.49
22	84.49	71.37	1.67	0.48	84.73	71.26	1.65	0.47	84.46	70.81	1.64	0.47
23	85.22	72.62	1.65	0.46	85.23	72.90	1.63	0.46	84.95	71.72	1.63	0.46
24	87.41	74.58	1.64	0.44	86.05	73.88	1.62	0.43	85.29	73.00	1.60	0.44
25	87.31	75.47	1.61	0.42	88.20	75.68	1.61	0.42	87.21	75.21	1.58	0.43
26	88.41	77.01	1.59	0.41	88.04	76.73	1.57	0.40	87.56	76.08	1.57	0.41
27	89.58	78.64	1.57	0.40	89.05	78.29	1.55	0.38	88.39	77.20	1.55	0.39
28	92.27	80.98	1.53	0.37	91.91	81.08	1.53	0.36	89.80	79.25	1.53	0.37
29	93.85	84.30	1.50	0.33	92.82	83.49	1.49	0.34	92.88	82.64	1.50	0.35
30	*107.07*	103.46	1.35	0.17	105.94	102.46	1.34	0.19	95.69	87.90	1.43	0.28
31	121.66	121.39	1.22	0.08	121.29	121.56	1.19	0.05	119.38	119.81	1.19	0.04

PER TEST	**Line Voltage (V)**	**SS Arctube Voltage (V)**	**SS Line Voltage (V)**	**SS Current (A)**	**Line Voltage (V)**	**SS Arctube Voltage (V)**	**SS Line Voltage (V)**	**SS Current (A)**	**Line Voltage (V)**	**SS Arctube Voltage (V)**	**SS Line Voltage (V)**	**SS Current (A)**
Last Cycle	107.070	48.757	120.480	1.975	105.940	48.524	120.578	1.977	95.688	48.477	120.483	1.973
10 Cycle Avg.	90.09				89.72				88.10			
20 Cycle Avg.	86.37				86.01				85.16			
30 Cycle Avg.	86.00				85.68				85.14			

Reactor Ballast: PTC Test Data

	Lamp B2, Test 1 - January 6, 2005, 15:23				**Lamp B2, Test 2 - January 6, 2005, 15:46**				**Lamp B2, Test 3 - January 6, 2005, 16:03**			
CYCLES	**Line Voltage (V)**	**Arctube Voltage (V)**	**PV Voltage (V)**	**Current (A)**	**Line Voltage (V)**	**Arctube Voltage (V)**	**PV Voltage (V)**	**Current (A)**	**Line Voltage (V)**	**Arctube Voltage (V)**	**PV Voltage (V)**	**Current (A)**
1	103.85	57.27	2.51	1.37	103.94	57.83	2.51	1.36	103.78	57.69	2.51	1.36
2	103.35	57.18	2.52	1.35	104.46	57.89	2.51	1.35	104.75	57.33	2.52	1.34
3	103.28	57.51	2.49	1.32	103.22	58.41	2.51	1.32	102.78	57.95	2.51	1.33
4	102.44	57.99	2.49	1.31	103.39	57.65	2.49	1.30	102.48	57.67	2.50	1.31
5	101.44	57.56	2.49	1.30	101.90	58.69	2.47	1.29	103.03	58.14	2.48	1.29
6	102.12	58.69	2.47	1.27	100.84	58.21	2.47	1.27	101.35	58.51	2.46	1.28
7	100.71	58.07	2.46	1.27	102.02	59.08	2.45	1.26	100.39	58.23	2.46	1.25
8	101.05	58.63	2.44	1.23	99.92	58.62	2.46	1.25	101.18	58.80	2.44	1.23
9	99.17	59.15	2.43	1.22	100.66	59.05	2.43	1.21	99.21	59.13	2.44	1.22
10	98.28	59.02	2.43	1.19	98.80	60.20	2.41	1.19	100.18	59.24	2.41	1.19
11	98.92	59.94	2.39	1.17	98.33	59.57	2.40	1.18	98.20	59.76	2.42	1.18
12	96.92	59.47	2.39	1.14	98.53	61.08	2.37	1.14	97.88	59.33	2.39	1.15
13	96.93	59.96	2.37	1.12	96.95	60.46	2.38	1.12	98.05	60.77	2.36	1.12
14	97.25	61.06	2.34	1.10	96.20	61.27	2.34	1.09	95.75	60.42	2.35	1.10
15	95.40	61.12	2.33	1.08	96.40	61.88	2.31	1.07	95.86	61.61	2.35	1.07
16	95.84	61.45	2.30	1.03	95.17	62.26	2.30	1.04	95.79	61.75	2.30	1.04
17	93.91	62.08	2.30	1.01	95.96	63.11	2.28	1.01	94.03	62.04	2.28	1.02
18	93.56	62.70	2.25	0.98	94.38	62.92	2.27	0.99	95.18	63.46	2.26	0.98
19	94.04	63.32	2.23	0.95	93.47	63.97	2.24	0.97	93.60	63.69	2.25	0.96
20	92.48	64.35	2.22	0.93	94.50	64.62	2.21	0.93	93.20	64.82	2.23	0.93
21	92.47	65.36	2.19	0.90	93.04	65.92	2.20	0.89	93.72	64.99	2.19	0.90
22	93.83	66.60	2.16	0.86	92.89	66.48	2.17	0.87	92.82	66.31	2.17	0.87
23	92.29	66.95	2.14	0.83	93.84	67.99	2.12	0.83	92.47	67.15	2.15	0.83
24	92.19	68.45	2.09	0.78	92.75	68.89	2.10	0.80	93.71	69.48	2.10	0.80
25	93.67	70.71	2.06	0.77	93.20	70.36	2.08	0.77	92.89	70.18	2.09	0.77
26	93.09	71.89	2.02	0.73	94.98	72.49	2.02	0.74	93.14	72.25	2.03	0.74
27	94.12	74.29	1.99	0.69	94.25	74.28	1.98	0.69	94.31	73.94	2.00	0.69
28	96.25	77.42	1.93	0.64	95.71	77.08	1.93	0.65	96.57	77.47	1.96	0.66
29	97.74	81.47	1.87	0.59	98.49	80.82	1.87	0.60	97.41	80.76	1.90	0.59
30	108.27	102.42	1.56	0.37	107.99	101.89	1.58	0.39	109.15	102.79	1.59	0.38
31	121.51	121.10	1.19	0.03	120.54	120.03	1.18	0.04	120.22	120.44	1.21	0.04

PER TEST	**Line Voltage (V)**	**SS Arctube Voltage (V)**	**SS Line Voltage (V)**	**SS Current (A)**	**Line Voltage (V)**	**SS Arctube Voltage (V)**	**SS Line Voltage (V)**	**SS Current (A)**	**Line Voltage (V)**	**SS Arctube Voltage (V)**	**SS Line Voltage (V)**	**SS Current (A)**
Last Cycle	108.270	54.415	120.451	1.854	107.990	54.877	120.512	1.847	109.150	54.672	120.555	1.850
10 Cycle Avg.	95.39				95.71				95.62			
20 Cycle Avg.	95.46				95.85				95.69			
30 Cycle Avg.	97.50				97.87				97.76			

Reactor Ballast: PTC Test Data

	Lamp C2, Test 1 - January 6, 2005, 16:28				Lamp C2, Test 2 - January 6, 2005, 16:43				Lamp C2, Test 3 - January 6, 2005, 17:03			
CYCLES	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)
1	101.25	60.84	3.38	1.20	99.98	60.27	3.37	1.22	101.26	60.81	3.35	1.20
2	98.73	60.54	3.36	1.18	100.50	60.65	3.35	1.19	99.48	60.88	3.35	1.19
3	99.53	60.76	3.36	1.15	99.07	61.05	3.35	1.17	100.02	61.41	3.35	1.16
4	97.50	61.40	3.36	1.13	98.30	61.31	3.35	1.16	98.43	61.43	3.33	1.14
5	97.31	61.44	3.33	1.12	98.72	61.52	3.33	1.13	97.78	61.40	3.33	1.13
6	97.89	61.84	3.32	1.09	96.80	61.90	3.34	1.10	98.09	62.20	3.29	1.10
7	96.07	61.81	3.33	1.07	97.68	62.14	3.32	1.08	96.22	62.12	3.30	1.08
8	95.79	62.64	3.30	1.04	95.77	62.45	3.30	1.06	96.26	62.82	3.29	1.05
9	95.91	63.13	3.31	1.01	95.31	62.56	3.29	1.04	96.60	63.55	3.28	1.02
10	94.64	63.37	3.27	1.00	95.67	63.04	3.26	1.01	94.66	63.50	3.27	1.01
11	95.16	64.56	3.26	0.97	94.20	64.08	3.25	0.98	95.41	64.17	3.23	0.97
12	93.37	64.79	3.25	0.94	94.11	64.28	3.23	0.95	93.87	64.33	3.21	0.96
13	93.02	64.79	3.22	0.92	94.35	64.83	3.20	0.93	93.79	65.40	3.19	0.93
14	93.82	65.41	3.18	0.90	93.06	65.69	3.18	0.92	93.98	65.85	3.17	0.91
15	92.33	66.22	3.19	0.86	92.45	65.86	3.17	0.88	92.97	66.29	3.15	0.88
16	92.05	66.58	3.15	0.84	93.29	66.98	3.14	0.86	91.92	67.19	3.14	0.85
17	92.92	68.06	3.11	0.81	91.89	67.46	3.13	0.83	93.67	68.25	3.10	0.83
18	91.81	68.84	3.09	0.79	91.81	68.34	3.09	0.80	92.25	68.53	3.08	0.80
19	91.59	69.42	3.07	0.75	92.90	69.53	3.06	0.77	91.90	69.54	3.06	0.77
20	93.08	70.34	3.04	0.74	91.63	69.75	3.04	0.74	93.30	70.82	3.01	0.74
21	91.68	71.14	3.02	0.71	92.93	70.94	3.00	0.72	91.74	71.18	3.00	0.71
22	91.84	72.87	2.99	0.67	92.52	71.87	2.98	0.70	92.36	72.63	2.97	0.69
23	93.45	74.29	2.94	0.65	92.65	73.42	2.96	0.67	93.77	74.07	2.91	0.67
24	92.79	75.44	2.90	0.63	92.75	74.26	2.91	0.64	93.34	75.12	2.89	0.63
25	93.80	76.83	2.86	0.60	94.65	76.60	2.85	0.61	94.22	77.12	2.83	0.61
26	95.27	78.90	2.80	0.57	94.49	78.17	2.82	0.59	95.46	78.78	2.80	0.58
27	95.47	80.68	2.80	0.54	95.44	79.77	2.80	0.56	95.67	80.22	2.77	0.55
28	96.99	82.93	2.71	0.50	96.47	81.56	2.73	0.52	97.04	82.09	2.71	0.52
29	99.54	86.88	2.62	0.46	99.31	85.21	2.66	0.48	99.09	85.44	2.63	0.47
30	110.08	105.81	2.02	0.27	102.39	91.28	2.51	0.41	104.54	94.87	2.42	0.36
31	119.80	119.35	1.05	0.01	118.17	118.55	1.28	0.04	119.48	119.88	1.19	0.03
PER TEST	**Line Voltage (V)**	***SS Arctube* Voltage (V)**	***SS Line* Voltage (V)**	***SS Current* (A)**	**Line Voltage (V)**	**SS Arctube Voltage (V)**	**SS Line Voltage (V)**	**SS Current (A)**	**Line Voltage (V)**	**SS Arctube Voltage (V)**	**SS Line Voltage (V)**	**SS Current (A)**
Last Cycle	110.080	56.989	120.115	1.794	102.390	56.904	120.445	1.805	104.540	57.297	120.369	1.796
10 Cycle Avg.	96.11				95.36				95.72			
20 Cycle Avg.	94.51				94.16				94.51			
30 Cycle Avg.	95.50				95.37				95.64			

Reactor Ballast: PTC Test Data

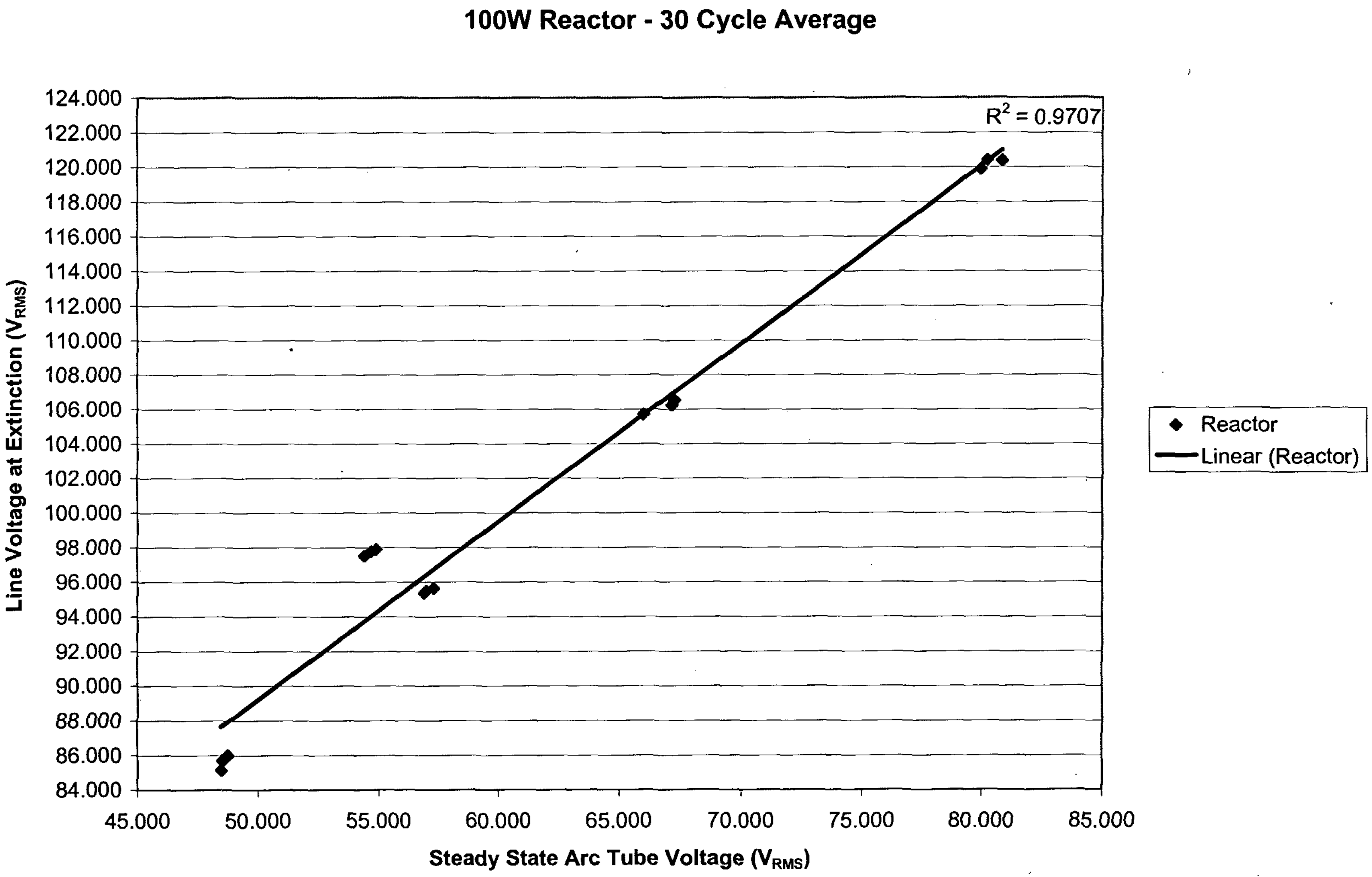
	Lamp D2, Test 1 - January 6, 2005, 19:17				Lamp D2, Test 2 - January 6, 2005, 19:34				Lamp D2, Test 3 - January 6, 2005, 19:50			
CYCLES	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)
1	108.76	69.15	3.35	1.21	108.34	70.26	3.35	1.21	109.13	69.44	3.32	1.21
2	107.38	68.86	3.35	1.21	108.64	70.36	3.33	1.20	108.02	68.82	3.33	1.22
3	107.17	69.52	3.34	1.20	107.85	70.29	3.33	1.20	107.40	69.38	3.32	1.21
4	106.74	69.92	3.35	1.19	107.77	70.85	3.33	1.18	108.34	70.20	3.33	1.19
5	108.11	70.09	3.32	1.18	108.86	70.47	3.33	1.18	107.30	69.53	3.32	1.19
6	106.72	69.58	3.34	1.18	107.46	70.89	3.32	1.17	107.04	70.23	3.32	1.18
7	106.27	70.13	3.32	1.16	107.20	71.57	3.31	1.15	107.83	70.30	3.31	1.16
8	107.55	70.51	3.32	1.15	107.88	71.14	3.29	1.14	106.47	70.24	3.31	1.16
9	105.94	70.54	3.32	1.14	106.34	71.63	3.32	1.14	106.03	70.48	3.31	1.15
10	105.35	70.95	3.32	1.13	106.59	71.31	3.30	1.13	107.67	71.12	3.30	1.13
11	106.69	71.19	3.30	1.12	107.71	72.55	3.28	1.11	105.93	71.03	3.28	1.12
12	105.12	71.02	3.30	1.11	105.83	72.15	3.29	1.10	105.72	71.25	3.28	1.11
13	105.98	71.51	3.28	1.09	107.33	72.37	3.27	1.08	106.65	71.62	3.25	1.10
14	105.08	71.61	3.27	1.08	105.76	72.92	3.27	1.08	104.89	71.90	3.25	1.08
15	104.39	72.33	3.26	1.06	105.66	73.04	3.26	1.06	105.19	71.91	3.27	1.06
16	104.64	71.79	3.27	1.05	106.76	73.45	3.25	1.05	106.02	72.73	3.23	1.05
17	105.73	73.23	3.23	1.03	105.32	73.89	3.24	1.03	104.50	73.00	3.24	1.03
18	103.98	73.55	3.23	1.02	104.97	74.06	3.23	1.01	105.57	73.59	3.21	1.02
19	104.53	73.84	3.22	1.01	106.04	75.44	3.22	1.00	104.38	74.25	3.19	1.01
20	104.76	74.57	3.20	0.98	105.25	75.25	3.21	0.98	104.46	74.19	3.19	0.99
21	103.88	74.89	3.19	0.96	104.71	75.46	3.20	0.97	105.14	75.72	3.16	0.96
22	103.56	75.59	3.17	0.93	105.96	76.36	3.16	0.95	104.22	75.90	3.17	0.94
23	104.67	77.00	3.16	0.92	105.06	77.24	3.15	0.93	104.09	76.41	3.14	0.92
24	103.98	77.01	3.15	0.89	104.67	77.93	3.14	0.91	105.25	77.95	3.10	0.90
25	103.69	79.35	3.11	0.86	105.77	79.34	3.10	0.88	104.30	77.87	3.08	0.88
26	104.78	80.32	3.08	0.83	105.16	79.14	3.09	0.86	103.97	79.40	3.06	0.84
27	106.05	81.89	3.02	0.80	105.09	81.19	3.05	0.84	104.53	80.93	3.03	0.81
28	105.53	83.33	2.98	0.77	106.91	82.93	3.01	0.80	106.97	83.43	2.98	0.77
29	105.67	85.99	2.95	0.71	106.65	85.22	2.98	0.75	106.79	85.97	2.92	0.72
30	108.10	91.08	2.84	0.62	108.02	89.41	2.86	0.66	113.45	105.96	2.27	0.43
31	119.23	117.98	1.64	0.10	119.12	118.81	1.60	0.10	122.26	122.12	0.97	0.02

PER TEST	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)
Last Cycle	108.100	65.999	120.824	1.634	108.020	67.275	120.805	1.604	113.450	67.168	120.992	1.611
10 Cycle Avg.	104.99				105.80				105.87			
20 Cycle Avg.	105.04				105.93				105.60			
30 Cycle Avg.	105.69				106.52				106.24			

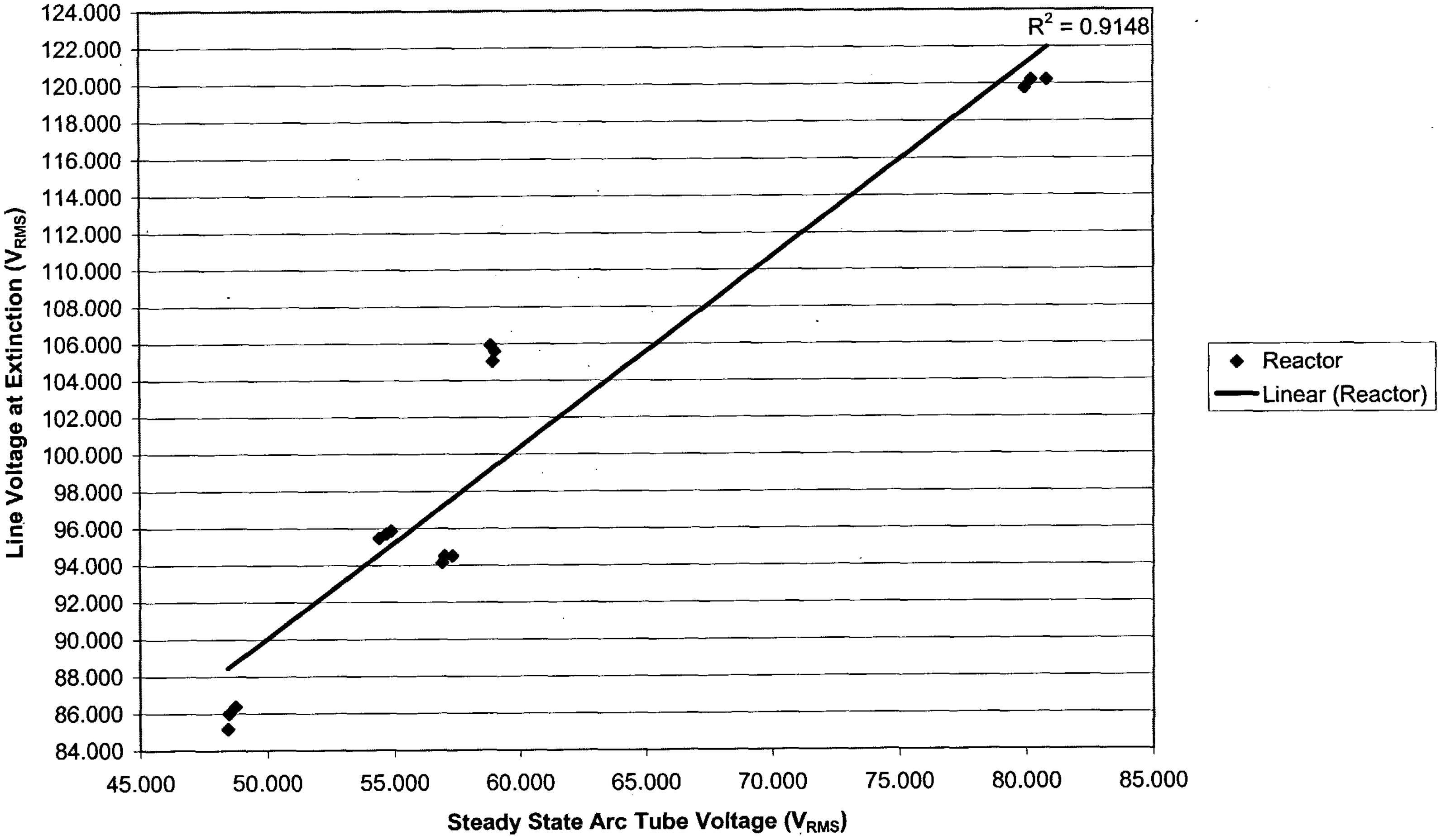
Reactor Ballast: PTC Test Data

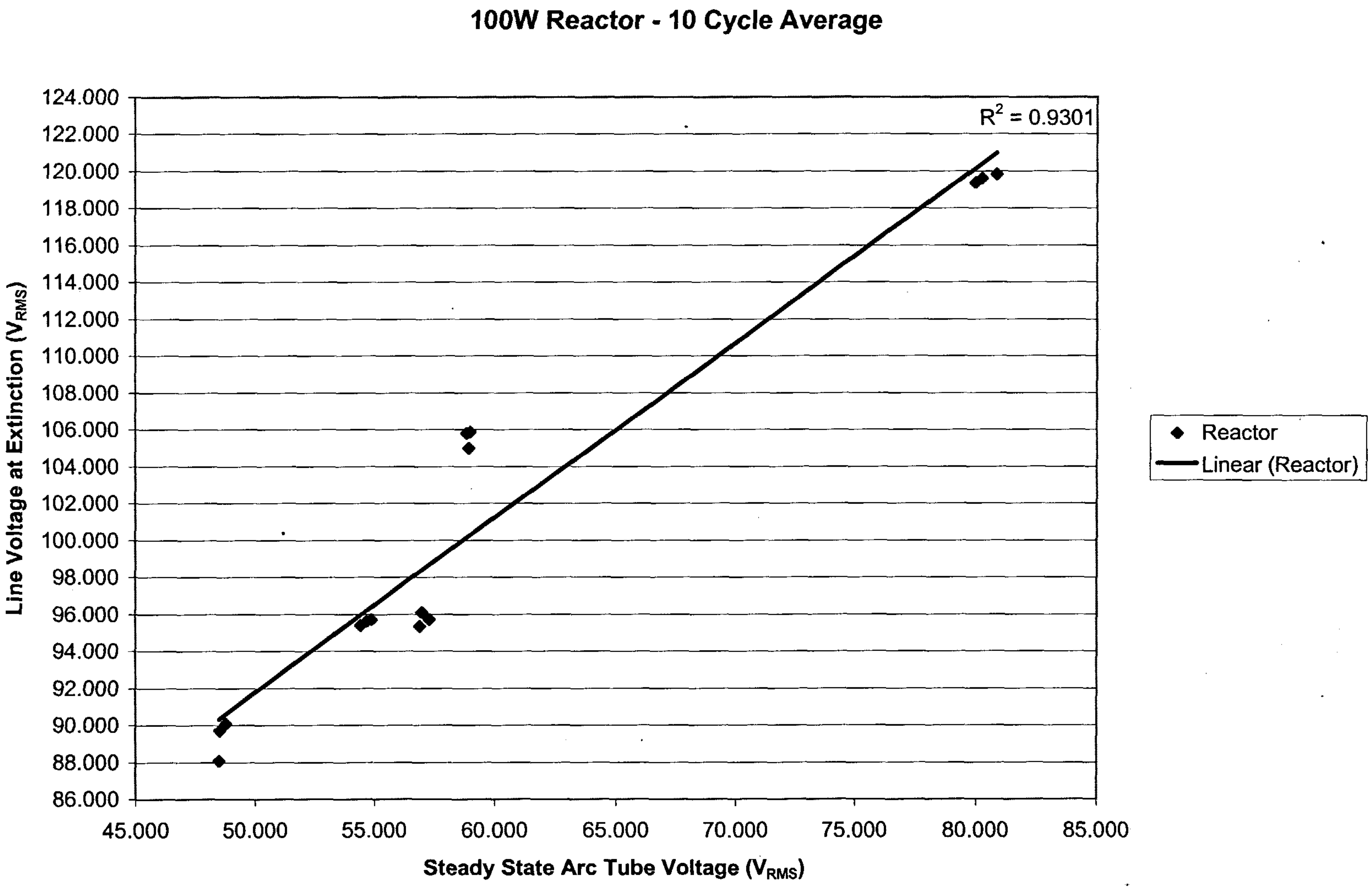
	Lamp E2, Test 1 - January 6, 2005, 18:03				Lamp E2, Test 2 - January 6, 2005, 18:19				Lamp E2, Test 3 - January 6, 2005, 18:36			
CYCLES	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)	Line Voltage (V)	Arctube Voltage (V)	PV Voltage (V)	Current (A)
1	119.64	80.18	3.45	1.29	121.76	80.36	3.45	1.29	120.67	80.65	3.46	1.29
2	119.52	80.30	3.46	1.29	120.54	79.88	3.47	1.30	120.50	80.76	3.44	1.28
3	121.18	79.79	3.45	1.28	120.20	80.22	3.47	1.30	121.49	80.66	3.44	1.28
4	119.84	79.92	3.47	1.29	121.51	80.02	3.46	1.29	119.87	80.48	3.45	1.29
5	119.93	80.81	3.47	1.30	120.07	80.36	3.45	1.29	120.19	80.65	3.44	1.28
6	121.26	80.28	3.46	1.28	120.33	80.76	3.47	1.30	121.69	80.86	3.43	1.28
7	119.54	80.03	3.45	1.29	121.41	79.91	3.45	1.30	120.33	80.85	3.44	1.29
8	119.79	80.75	3.47	1.28	120.05	80.09	3.46	1.29	120.01	80.40	3.43	1.29
9	120.79	80.26	3.44	1.28	120.40	80.70	3.45	1.31	121.65	80.40	3.43	1.29
10	119.80	80.36	3.47	1.30	121.18	80.49	3.46	1.29	120.27	80.37	3.44	1.28
11	119.61	80.50	3.45	1.29	120.60	80.17	3.44	1.30	120.18	80.81	3.43	1.27
12	121.20	80.15	3.46	1.29	120.33	81.03	3.45	1.30	121.86	80.76	3.43	1.29
13	119.53	79.79	3.46	1.29	121.75	80.51	3.45	1.29	120.29	80.72	3.43	1.29
14	120.08	80.24	3.45	1.29	120.31	79.87	3.46	1.30	120.27	80.70	3.44	1.28
15	120.71	80.11	3.45	1.28	120.57	80.27	3.45	1.30	121.16	80.52	3.43	1.28
16	119.58	79.95	3.46	1.29	122.09	80.22	3.45	1.29	120.46	80.63	3.43	1.28
17	119.88	80.43	3.45	1.28	120.12	79.69	3.46	1.29	120.10	80.86	3.43	1.29
18	121.03	80.09	3.46	1.27	120.42	80.41	3.46	1.30	121.57	80.35	3.44	1.28
19	119.94	80.28	3.45	1.28	121.61	80.34	3.46	1.29	120.32	80.73	3.43	1.28
20	120.05	80.03	3.47	1.29	120.55	80.04	3.45	1.30	119.70	80.32	3.43	1.28
21	121.53	80.09	3.45	1.28	120.31	80.06	3.45	1.30	121.54	80.77	3.43	1.29
22	119.60	80.22	3.45	1.29	121.46	80.18	3.44	1.29	120.36	80.77	3.45	1.29
23	119.61	80.14	3.46	1.29	120.40	80.17	3.45	1.30	120.07	80.82	3.44	1.29
24	121.15	80.18	3.46	1.28	120.21	80.37	3.46	1.29	121.77	80.52	3.43	1.28
25	119.49	80.47	3.44	1.28	122.14	80.09	3.46	1.29	120.04	80.62	3.44	1.29
26	119.99	79.80	3.45	1.29	118.78	81.10	3.43	1.23	119.98	80.69	3.43	1.28
27	119.14	80.87	3.42	1.21	117.24	85.14	3.33	1.06	118.45	83.42	3.36	1.12
28	116.54	85.71	3.30	1.04	118.87	88.43	3.27	1.00	117.89	87.54	3.28	1.01
29	118.17	90.79	3.22	0.91	117.50	91.93	3.20	0.90	119.14	92.16	3.19	0.91
30	118.70	113.86	2.33	0.35	119.25	111.44	2.43	0.45	119.03	110.55	2.46	0.48
31	119.96	119.72	1.02	0.06	120.39	120.57	1.02	0.03	120.47	120.08	0.99	0.05

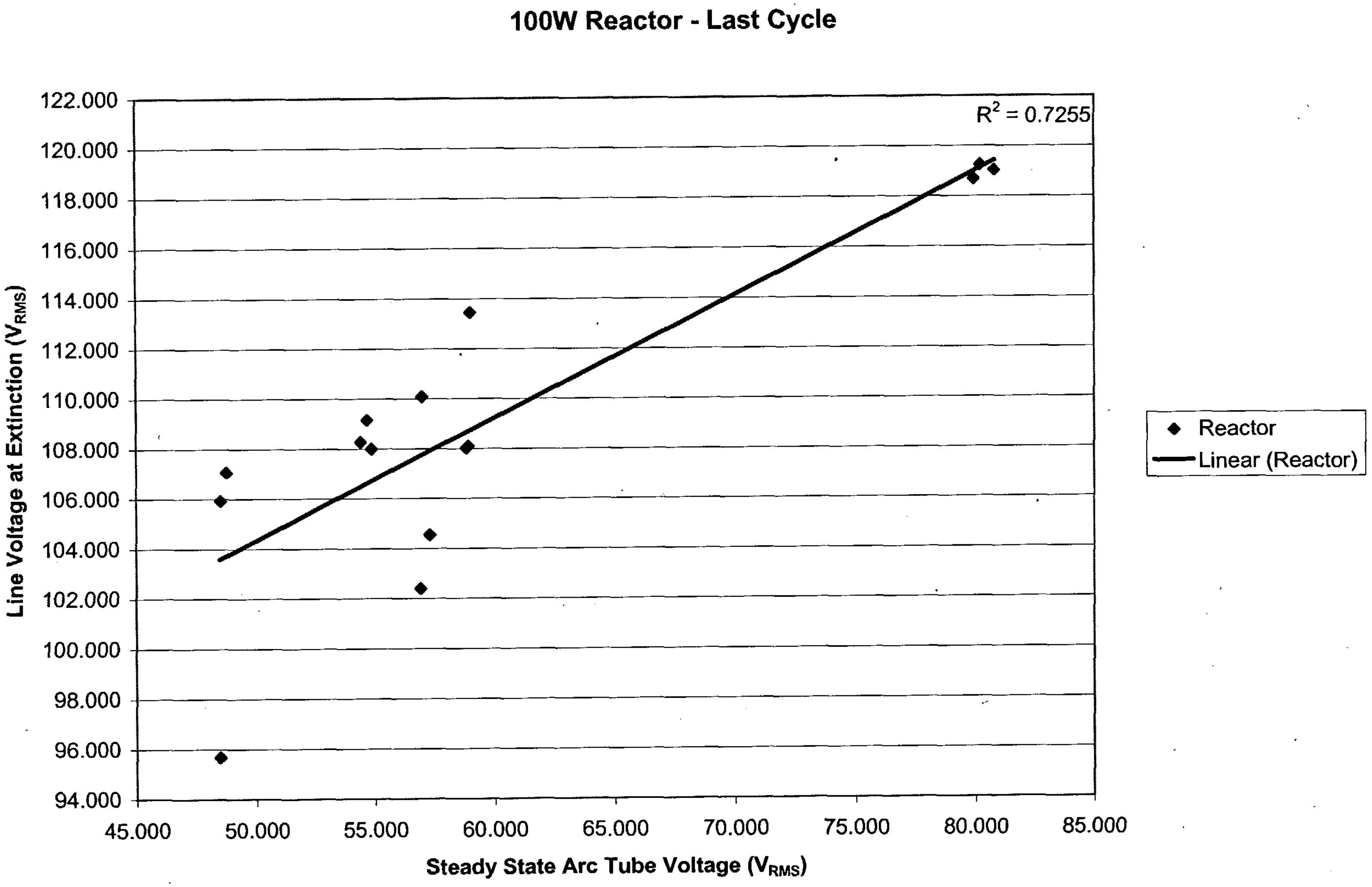
PER TEST	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)	Line Voltage (V)	SS Arctube Voltage (V)	SS Line Voltage (V)	SS Current (A)
Last Cycle	118.700	79.976	120.127	1.285	119.250	80.244	120.841	1.299	119.030	80.853	120.865	1.280
10 Cycle Avg.	119.39				119.62				119.83			
20 Cycle Avg.	119.78				120.23				120.21			
30 Cycle Avg.	119.89				120.40				120.36			


100W Reactor - 30 Cycle Average
R² = 0.9707
Line Voltage at Extinction (VRMS)
124.000
122.000
120.000
118.000
116.000
114.000
112.000
110.000
108.000
106.000
104.000
102.000
100.000
98.000
96.000
94.000
92.000
90.000
88.000
86.000
84.000
45.000
50.000
55.000
60.000
65.000
70.000
75.000
80.000
85.000
Steady State Arc Tube Voltage (VRMS)
Reactor
Linear (Reactor)

100W Reactor - 20 Cycle Average




100W Reactor - 10 Cycle Average
$R^2 = 0.9301$
124.000
122.000
120.000
118.000
116.000
114.000
112.000
110.000
108.000
106.000
104.000
102.000
100.000
98.000
96.000
94.000
92.000
90.000
88.000
86.000
Line Voltage at Extinction (V_{RMS})
45.000
50.000
55.000
60.000
65.000
70.000
75.000
80.000
85.000
Steady State Arc Tube Voltage (V_{RMS})
◆ Reactor
— Linear (Reactor)

100W Reactor - Last Cycle
R² = 0.7255
Line Voltage at Extinction (V_RMS)
122.000
120.000
118.000
116.000
114.000
112.000
110.000
108.000
106.000
104.000
102.000
100.000
98.000
96.000
94.000
45.000
50.000
55.000
60.000
65.000
70.000
75.000
80.000
85.000
Steady State Arc Tube Voltage (V_RMS)
◆ Reactor
Linear (Reactor)

Appendix F: Smart Photocontrol Cost Analysis

Cost Benefit Analysis of Using Lamp Life Monitor

Case 1: Utility is urban, rural and uses a relamp cycle

1. Lamp failure rates

Based on failure rate data and a base of 100 lamps:

Lamp Years of Service for Group Relamped System

Year	Cum. Failures	Annual Failures		# of lamp yrs of service		**For lamps used to end of life**	**Group Relamp every 4 years**	**Group Relamp every 5 years**	**Group Relamp every 6 years**
Year 1	1	1	1	100			100	100	100
Year 2	3	2	2	99			99	97	97
Year 3	6	3	3	97			97	94	94
Year 4	11	5	4	94			94	89	89
Year 5	20	9	5	89				80	80
Year 6	35	15	6	80					65
Year 7	43	8	7	65		Lamp burn years per			
Year 8	50	7	8	57		100 original lamps =	390	460	525
Year 9	61	11	9	50					
Year 10	75	14	10	39		Average			
Year 11	90	15	11	25		Lamp Life			
Year 12	100	10	12	10					
				805	burn yrs				

2. Relamp Cycle		**Avg Lamp Life:**	8.05 yrs	3.9 yrs	4.6 yrs	5.25 yrs
4 Year	4		**Spot Replacement**	**Spot Replacement**	**Spot Replacement**	**Spot Replacement**
5 Year	5					
6 Year	6		0.5 % per yr	2.75 % per yr	4 % per yr	5.8 % per yr
none	city		(estimate)			

3. Spot Replacement Cost per Lamp — plus any vandalism caused failures

1 lamp at a time	varies

4. Disposal Cost

$0.60 per lamp

5. Vandalism (broken lens on those in relamp area)

3.0% per year

6. Fixture Failure (on those in relamp area)

1.5% per year

7. Costs of Group Relamp Contractor

Relamp (labor)	$8.30	
Lamp (avg)	$9.00	Same for contractor or company personnell
Photcntrl (std)	$6.90	"
Photcntrl (elec)	$10.00	"
Lens	$24.00	"
Fixture Swap (labor)	$25.00	
Avg Fixture	$100.00	"

8. Costs of Spot Complaint Repair -- (2 Full time company personnel & a contractor for one city/urban area)

Based on an avg of *27.5 compaints/day handled, the labor for each is about $20/each* (Loaded cost = $21/visit) (Annually -- $125,000 {labor & truck} handling about 5,940 complaints

Breakdown:			Typical # in a day, 220 days/yr)	
Relamp (labor)	$21.00		13	47.3%
Replace P.C.	$21.00		7	25.5%
No Voltage	$170.00	(Requires 2nd visit by a crew)	3	10.9%
Chg Starter	$21.00		0.5	1.8%
Starter	$8.00			
Repl Fixture	$170.00	(Requires 2nd visit by a crew)	2	7.3%
Remve Animal	$21.00		2	7.3%
Replac Lens	$21.00		*negl*	

9. Costs of Spot Complaint Repair -- (contractor *for one city/urban area, includes material)*

12,000 fixtures

1800 Complaints per year

	Avg Cost	avg annual	cause of problem by %
Replace lamp	$40.00	90	5.0%
Replace PC	$35.00	180	10.0%
Re Lmp & PC	$75.00	1296	72.0%
Fixture Swap	$225.00	180	10.0%
No Voltage	$50.00	18	1.0%
Starter	$55.00	36	2.0%
Inspection/mo	$1,000.00	12	

NOTE: Replace fixture includes animal, PC replaced when lamp replaced if not new, fixture cost varies but is similar to utilities' cost

Lamp replacment cost includes lamp, visit, usually PC replacement *too and disposal @ .90/lamp*

In cold months, complaints (spot problems) run about 200/mo and in warm months about 100/mo

Case 1: Utility with 100,000 fixtures, urban/rural, group relamp on 5 year cycle

Relamp/yr	**Photocontrol**
20000	every other cycle (elec)

Costs	**Group**		**Spot (internal)**	**Spot (contactor)**		
Relamp (labor)	$166,000		$120,120.00	$55,440.00		
Lamp & Disp	$192,000		$54,912.00	included		
Lens	$14,400			neglible		
Photocontrol	$100,000		$83,160.00	*$51,660.00*	*B96: why is this cost = elec PC*20000*0.5*	
Fixture Swap	$7,500		$149,600.00	$40,500.00	D96: why is this cost = G66*220*2*(B66+6)	ans: $21 is the labor and truck cost, $6 is the photocontrol material cost
Fixtures	$30,000		*$88,000.00*	*included*	D100: why is cost = G71*220*2*B72	
No Voltage			$224,400.00	$900.00	This should be B71 instead. Where does the "2" come from anyway	
Animal			$18,480.00			
Starter			$6,380.00	$1,980.00		
Inspection				$12,000.00		
Total	$509,900		$745,052	$162,480		
		Per fixture	$8.47	$13.54		

Use Lamp Life Monitor Photocontrol with electronic on/off						**Relamp/yr**		**Photocontrol**	**Spot Relamp**
		Work from		Work from		12500		20 yr	0.5%
		two		City					
Costs		attendants		Contractor		Monitoring Control		$35.00	(may be considered capital)
Relamp (labor)	*$103,750*						install	$3.00	
Lamp & Disp	$120,000								
Lens	$14,400								
Photocontrol	$190,000	$25,000				Figure on 1/2% going bad per year, replacment = $15/stop			
Fixture Swap	$7,500	$22,000.00		$40,500.00		Bad Fixtures replaced by system relamp contractor			
Fixtures	$30,000	$88,000.00		incl					
Spot Repl Lamp	$4,150					(On all 100,000 -- only a few will not be changed out before failure and need to be spot replaced)			
Spot Lamps	$4,800								
No Voltage		$224,400.00		$900.00					
Animal		$18,480.00							
Starter		$6,380.00		$1,980.00					
Drive System	$41,000					(Drive past 100,000 lamps, approx 40,000 miles with GPS based receiver at 30mph			
Routing Sys	$50,000					*labor=1,333 hrs + ovhd = 1,600hrs x $16/hr + $.32/mile x 40,000 mi)*			
						** Or drive by may be done by meter reader vehicle and downloaded to database			
Total	*$565,600*	$384,260		$43,380		Routing Sys is database with fixture history and creates printouts for servicing			
Other Advantages:			**Other**						
			Benefits						
Complete system checked each year			$20,000.00		(record of what is operational and not -- can tell townships, legal, regulatory, etc.)				
Database Establsihed for Reference			$10,000.00						
Higher level of Customer Service			$20,000.00						
Longer lamp life with non-bounce start			$24,702.00		(possibly add 1 yr of life to lamp or more = 1,380 less lamps needed/yr ~for a 100,000 lamp system)				
Longer lamp and ballast life with anti-cycle			$5,000.00		(will be more for utilities with lower quality ballasts)				
Database trend will identify bad ballasts			$5,000.00		(will be more for utilities with lower quality ballasts)				
High Accuracy Switching (energy savings)									
Less Photocontrol problems									
		Total	$84,702.00						
Summary:									
	Monitored Sys	**Group Sys**							
Annual Cost:	**$993,240**	**$1,417,432**							
Potential									
Annual									
Savings	**$424,192**	29.9%	saving						
W/benefits	**$508,894**	35.9%	total benefit						

How the system works:

Person drives the system with a car and a transceiver that is equipped with GPS. *(Data is transferred similarly to how ITRON drive by meter read system works).*

The SMART Photocontrol sends the following info: Serial #, Last Deterioration Reading (Delta V), Deterioration Rate (%/yr), Remaining Life (days to lamp failure, 0 if bad), fixture condition (0=OK, 1=Fixture Bad). *The receiver in the vehicle will record:*

Serial #		(used by servicemen to insure they are servicing correct fixture when more than 1 at a location or close proximity)
Date of read	(yyyy,dd,mm)	
GPS Location	(Coordinates)	(used for setting up routes)
Last Deterioration Reading	(Delta V)	
Deterioration Rate	(%/yr)	
Remaining Life	(days or 0 for bad lamp)	
Fixture Cond	(0=OK, 1=BAD)	

NOTES:

Other data such as on hours, max volt, min volt, burn hours, power consumption, # of outages, etc. could potentially be gathered for incremental added cost.

Photocontrols will be assumed to be bad if they do not report or if hours are counted, if they are outside norms. Partially bad ballasts can be detected if lamps fail in a short time and if these lamps are sent for testing, and show a lot of life left. If lamps aren't sent for testing then after several cycles of short lamp life, the ballast can be suspected. Fixtures that have leakage problems and won't start during moist weather will be flagged as bad fixture since it doesn't come on some times -- if run hours were captured, this situation could probably be predicted by central analysis algorithyms.

Appendix G: Schematics and Bill of Materials for Smart Photocontrol Prototype

Parts Summary for Street Lamp Life Photocontrol Prototype Rev.0 (9/13/2004)

RefDes	Name	Description	Package	Manufacturer	Manufacturer Part #	Supplier	Catalog Part #	Qty	Unit Price	Price
C1, C16, C19, C22	Tantalum Capacitor	100nF, 50V, 10%	SMD-3216-8	AVX	TAJA104K050R	Digikey	478-1648-1-ND	4	$0.65	$2.60
C14, C20-C21, C24	Ceramic Chip Cap.	33nF, 50V, 10%	SMD-0805	Panasonic	ECJ-2VB1H333K	Digikey	PCC1834CT-ND	6	$0.06	$0.36
C15, C23	Electrolytic Cap.	10uF, 10V, 10%	SMD-3216-18	Nichicon	UWT1C100MCL1GB	Digikey	493-2173-1-ND	3	$0.16	$0.48
C17-C18	Ceramic Chip Cap.	22pF, 50V, 5%	SMD-0805	Panasonic	ECJ-2VC1H220J	Digikey	PCC220CNCT-ND	2	$0.04	$0.08
C2, C4, C8, C11-C12	Electrolytic Cap.	1uF, 50V, 20%	SMD	Nichicon	UWT1H010MCL2GB	Digikey	493-2215-1-ND	5	$0.19	$0.95
C3	Electrolytic Cap.	330uF, 35V, 20%	SMD	Nichicon	UWT1V331MNL1GS	Digikey	493-2206-1-ND	1	$0.55	$0.55
C5-C7	Electrolytic Cap.	0.1uF, 50V, 20%	SMD	Nichicon	UWT1H0R1MCL1GB	Digikey	493-2208-1-ND	3	$0.19	$0.57
C9-C10	Ceramic Chip Cap.	0.01uF, 50V, 10%	SMD-0805	Panasonic	ECJ-2VB1H103K	Digikey	PCC103BNCT-ND	2	$0.05	$0.10
MOV	*Metal Oxide Varistor*	*2750 VRMS*	*Axial*	*Littelfuse*	V14E275	Mouser	576-V14E275	1	$0.38	$0.38
PTC	Pos. Temp. Coef. Thermistor	260Vmax, 920mA Trip	Axial	Stetron	CB1-3R7-261SLB	N/A	N/A	1		$0.00
R1	Carbon Film	510, 1/4W, 5%	Axial	N/A	N/A	N/A	N/A	1	$0.02	$0.02
R2, R6, R8, R11	Metal Film	1k, 1/4W, 0.1%	Axial	Vishay-Dale	PTF65-B-1K	Mouser	71-PTF65-B-1K	4	$1.41	$5.64
R3	Carbon Film	60, 1/4W, 5%	Axial	N/A	N/A	N/A	N/A	1	$0.02	$0.02
R4-R5	Carbon Film	1.8k, 1/4W, 5%	Axial	N/A	N/A	N/A	N/A	2	$0.02	$0.04
R7	Chip	10k, 1/4W, 5%	1206	Panasonic	ERJ-8GEYJ103V	Digikey	P10KECT-ND	1	$0.09	$0.09
R9-R10	Metal Film	499k, 1/4W, 0.1%	Axial	Vishay-Dale	RN60C-B-499K	Mouser	71-RN60C-B-499K	2	$0.64	$1.28
CT	Current Transformer	0.1-30A, 50-400Hz, 110mV/A	PCB	Triad Magnetics	CSE187-L	Digikey	237-1103-ND	1	$2.89	$2.89
D1	LED	green, diffused, dome		N/A	N/A	N/A	N/A	1	$0.10	$0.10
D2-D6	Diode	150mA, 75V	DO-35	Micro Commercial Co.	1N4148	Digikey	1N4148MSCT-ND	5	$0.05	$0.27
DC1	DC-Jack		PCB	CUI Inc.	PJ-102B	Digikey	CP-102B-ND	1	$0.38	$0.38
L1-L3	Ferrite bead core	100MHz, 110ohms	Axial	Panasonic	EXC-ELSA39	Digikey	P9818BK-ND	3	$0.13	$0.39
MOD	*RJ-11 Jack*	*modular, 6-contact*	*PCB*	*FCI Electronics*	68898-001	Newark	89F4576	1	$0.95	$0.95
POD	Header	20-pin, gold, 2mm vertical	PCB	Molex	87331-2020	Digikey	WM18066-ND	1	$2.21	$2.21
RELAY1-RELAY2	Power Relay	16A, SPST-NO, 6VDC coil	PCB	Aromat Corporation	JR1AF-DC5V	Digikey	255-1109-ND	2	$3.92	$7.84
SW1	Switch	Tactile pushbutton switch	SMD	E-Switch Inc.	TL3301AF160QG/TR	Digikey	EG2526CT-ND	1	$0.45	$0.45
Term1	Terminal Block	Green, 2-pin, 90° orientation	PCB	Pheonix Contacts	1711026	Digikey	277-1022-ND	1	$1.42	$1.42
TX1	Power Transformer	115V primary, 10VCT, 150mA	PCB	Hammond	164-E20	Mouser	546-164E20	1	$8.49	$8.49
XTAL1	Resonator	30MHz	PCB	ZTT	ZTT-30.00MX	N/A	N/A	1	$0.54	$0.54
XTAL2	Crystal	3.570545MHz, 17pF	SMD	ECS Inc.	ECS-35-17-5P-TR	Digikey	XC560CT-ND	1	$0.73	$0.73
U1	RS232 Transceiver	5V, 10mA, 2DVR/2RCVR	SOIC-16	Maxim Semiconductor	MAX232CWE	Digikey	MAX232CWE-ND	1	$3.31	$3.31
U2	5 volt regulator	DMOS, LDO, 250mA	SOIC-8	Burr-Brown/TI	Reg102UA-5	Digikey	Reg102UA-5-ND	1	$2.36	$2.36
U3	3 volt regulator	DMOS, LDO, 500mA	SOIC-8	Burr-Brown/TI	Reg103UA-3	Digikey	Reg103UA-3-ND	1	$4.50	$4.50
U4	Microcontroller	Flash, 40 MHz max, 23 I/O	SOIC	Microchip	PIC18F252-I/SO	Digikey	PIC18F252-I/SO-ND	1	$8.48	$8.48
U5	EEPROM	64k (8kx8), SPI Bus	SSOIC	Microchip	25LC640-I/SN	Digikey	25LC640-I/SN-ND	1	$1.10	$1.10
U6	*5V-3V level converter*	*8-channel, 35Mbps, 1.2-5.5V*	*TSSOP-20*	*Maxim Semiconductor*	MAX3001E	Maxim	Samples (Price at 1k)	1	$1.60	$1.60
U7	Energy metering IC	N/A	SSOP	Analog Devices	ADE7753ARS	Digikey	ADE7753ARS-ND	1	$5.58	$5.58
U8-U9	BJT	40V, 1A, NPN	TO-92	Fairchild Semiconductor	PN2222ATFR	Digikey	PN2222AD26ZCT-ND	2	$0.20	$0.40
Z1	Bridge Rectifier	1A, 100V	DIP	Micro Commercial Co.	DB102	Digikey	DB102MS-ND	1	$0.52	$0.52
U10	Transceiver Module	902-928 MHz	DIP Header	Xemics	XM1203	Future-Active	XM1203-C915XEM-1	1	$52.00	$52.00
Manufacturing Cost								1	$101.02	$101.02
							Totals	**71**		**$220.69**

Parts Summary and Price Estimation when Manufactured in Quantities of 1,000

RefDes	Name	Description	Package	Manufacturer	Manufacturer Part #	Supplier	Catalog Part #	Qty	Unit Price	Price
C1, C16, C19, C22	Tantalum Capacitor	100nF, 50V, 10%	SMD-3216-8	AVX	TAJA104K050R	Digikey	478-1648-1-ND	4	$0.560	$2.240
C14, C20-C21, C24	*Ceramic Chip Cap.*	33nF, 50V, 10%	SMD-0805	Panasonic	ECJ-2VB1H333K	Digikey	PCC1834CT-ND	6	$0.021	$0.126
C15, C23	Electrolytic Cap.	10uF, 10V, 10%	SMD-3216-18	Nichicon	UWT1C100MCL1GB	Digikey	493-2173-1-ND	3	$0.080	$0.240
C17-C18	Ceramic Chip Cap.	22pF, 50V, 5%	SMD-0805	Panasonic	ECJ-2VC1H220J	Digikey	PCC220CNCT-ND	2	$0.024	$0.048
C2, C4, C8, C11-C12	Electrolytic Cap.	1uF, 50V, 20%	SMD	Nichicon	UWT1H010MCL2GB	Digikey	493-2215-1-ND	5	*$0.080*	*$0.400*
C3	Electrolytic Cap.	330uF, 35V, 20%	SMD	Nichicon	UWT1V331MNL1GS	Digikey	493-2206-1-ND	1	$0.181	$0.181
C5-C7	Electrolytic Cap.	0.1uF, 50V, 20%	SMD	Nichicon	UWT1H0R1MCL1GB	Digikey	493-2208-1-ND	3	$0.075	$0.225
C9-C10	Ceramic Chip Cap.	0.01uF, 50V, 10%	SMD-0805	Panasonic	ECJ-2VB1H103K	Digikey	PCC103BNCT-ND	2	$0.019	$0.038
MOV	Metal Oxide Varistor	2750 VRMS	Axial	Littelfuse	V14E275	Mouser	576-V14E275	1	$0.210	$0.210
PTC	Pos. Temp. Coef. Thermistor	260Vmax, 920mA Trip	Axial	Stetron	CB1-3R7-261SLB	N/A	N/A	1	$0.500	$0.500
R1	Carbon Film	*510, 1/4W, 5%*	*Axial*	N/A	N/A	N/A	N/A	1	$0.016	$0.016
R2, R6, R8, R11*	Carbon Film	1k, 1/4W, 0.1%	Axial	N/A	N/A	Digikey	N/A	4	$0.016	$0.063
R3	Carbon Film	60, 1/4W, 5%	Axial	N/A	N/A	N/A	N/A	1	$0.016	$0.016
R4-R5	Carbon Film	1.8k, 1/4W, 5%	Axial	N/A	N/A	N/A	N/A	2	$0.016	$0.032
R7	Chip	10k, 1/4W, 5%	1206	Panasonic	ERJ-8GEYJ103V	Digikey	P10KECT-ND	1	$0.020	$0.020
R9-R10*	Carbon Film	499k, 1/4W, 0.1%	Axial	N/A	N/A	Digikey	N/A	2	$0.016	$0.032
CT	Current Transformer	0.1-30A, 50-400Hz, 110mV/A	PCB	*Triad Magnetics*	*CSE187-L*	*Digikey*	237-1103-ND	1	$1.590	$1.590
D1	LED	green, diffused, dome		N/A	N/A	N/A	N/A	1	$0.058	$0.058
D2-D6	Diode	150mA, 75V	DO-35	Micro Commercial Co.	1N4148	Digikey	1N4148MSCT-ND	5	$0.035	$0.175
DC1**	DC-Jack		PCB	CUI Inc.	PJ-102B	Digikey	CP-102B-ND	0	$0.000	$0.000
L1-L3	Ferrite bead core	100MHz, 110ohms	Axial	Panasonic	EXC-ELSA39	Digikey	P9818BK-ND	3	$0.058	$0.174
MOD	RJ-11 Jack	modular, 6-contact	PCB	FCI Electronics	68898-001	Newark	89F4576	1	$0.000	$0.000
POD	Header	20-pin, gold, 2mm vertical	PCB	Molex	87331-2020	Digikey	WM18066-ND	1	$1.283	$1.283
RELAY1-RELAY2	Power Relay	16A, SPST-NO, 6VDC coil	PCB	Aromat Corporation	JR1AF-DC5V	Digikey	255-1109-ND	2	$2.320	$4.640
SW1**	Switch	Tactile pushbutton switch	SMD	E-Switch Inc.	TL3301AF160QG/TR	Digikey	EG2526CT-ND	0	$0.000	$0.000
Term1**	Terminal Block	Green, 2-pin, 90° orientation	PCB	Pheonix Contacts	1711026	Digikey	277-1022-ND	0	$0.000	$0.000
TX1	Power Transformer	115V primary, 10VCT, 150mA	PCB	Hammond	164-E20	Mouser	546-164E20	1	$6.800	$6.800
XTAL1	Resonator	30MHz	PCB	ZTT	ZTT-30.00MX	N/A	N/A	1	$0.270	$0.270
XTAL2	Crystal	3.570545MHz, 17pF	SMD	ECS Inc.	ECS-35-17-5P-TR	Digikey	XC560CT-ND	1	$0.365	$0.365
U1**	RS232 Transceiver	5V, 10mA, 2DVR/2RCVR	SOIC-16	Maxim Semiconductor	MAX232CWE	Digikey	*MAX232CWE-ND*	*0*	*$0.000*	*$0.000*
U2	5 volt regulator	DMOS, LDO, 250mA	SOIC-8	Burr-Brown/TI	Reg102UA-5	Digikey	Reg102UA-5-ND	1	$1.338	$1.338
U3	3 volt regulator	DMOS, LDO, 500mA	SOIC-8	Burr-Brown/TI	Reg103UA-3	Digikey	Reg103UA-3-ND	1	$1.338	$1.338
U4	*Microcontroller*	Flash, 40 MHz max, 23 I/O	SOIC	Microchip	PIC18F252-I/SO	Digikey	PIC18F252-I/SO-ND	1	$5.150	$5.150
U5	EEPROM	64k (8kx8), SPI Bus	SSOIC	Microchip	25LC640-I/SN	Digikey	25LC640-I/SN-ND	1	$0.690	$0.690
U6	5V-3V level converter	8-channel, 35Mbps, 1.2-5.5V	TSSOP-20	Maxim Semiconductor	MAX3001E	Maxim	Samples (Price at 1k)	1	$1.600	$1.600
U7	Energy metering IC	N/A	SSOP	Analog Devices	ADE7753ARS	Digikey	ADE7753ARS-ND	1	$3.488	$3.488
U8-U9	BJT	40V, 1A, NPN	TO-92	Fairchild Semiconductor	PN2222ATFR	Digikey	*PN2222AD26ZCT-ND*	2	$0.046	*$0.092*
Z1	Bridge Rectifier	1A, 100V	DIP	Micro Commercial Co.	DB102	Digikey	DB102MS-ND	1	$0.260	$0.260
U10	Transceiver Module	902-928 MHz	DIP Header	Xemics	XM1203	Future-Active	XM1203-C915XEM-1	1	$17.830	$17.830
				Manufacturing Cost				1	$7.09	$7.09
							Totals	**67**		**$58.61**

*** Carbon film resistors will be used in the field version of the prototype.**

**** Parts will not be needed in field version of the prototype**

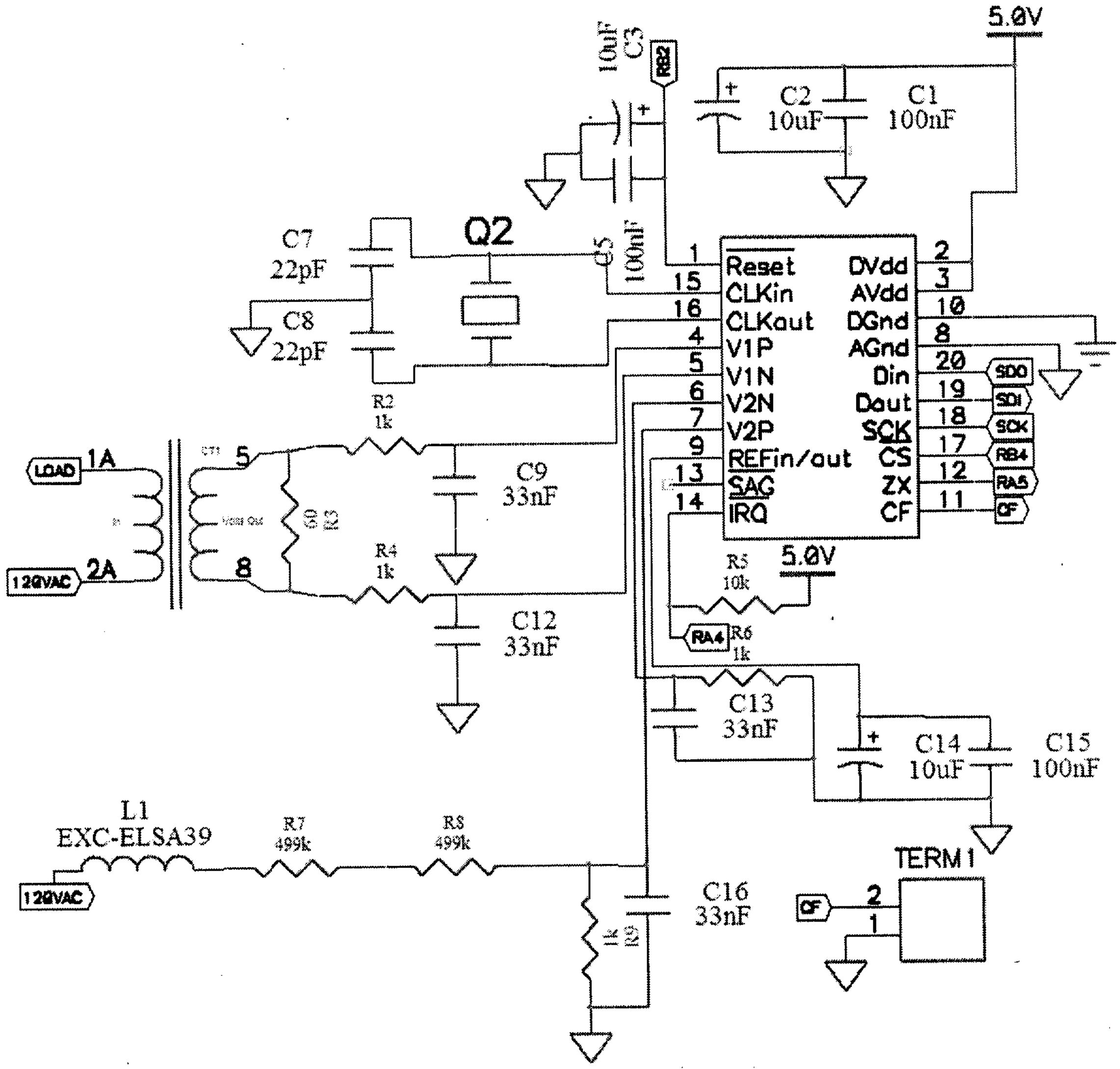
Parts Summary and Price Estimation when Manufactured in Quantities of 10,000

RefDes	Name	Description	Package	Manufacturer	Manufacturer Part #	Supplier	Catalog Part #	Qty	Unit Price	Price
C1, C16, C19, C22	Tantalum Capacitor	100nF, 50V, 10%	SMD-3216-8	AVX	TAJA104K050R	Digikey	478-1648-1-ND	4	$0.240	$0.960
C14, C20-C21, C24	Ceramic Chip Cap.	33nF, 50V, 10%	SMD-0805	Panasonic	ECJ-2VB1H333K	Digikey	PCC1834CT-ND	6	$0.017	$0.102
C15, C23	Electrolytic Cap.	10uF, 10V, 10%	SMD-3216-18	Nichicon	UWT1C100MCL1GB	Digikey	493-2173-1-ND	3	$0.059	$0.176
C17-C18	Ceramic Chip Cap.	22pF, 50V, 5%	SMD-0805	Panasonic	ECJ-2VC1H220J	Digikey	PCC220CNCT-ND	2	$0.019	$0.038
C2, C4, C8, C11-C12	Electrolytic Cap.	1uF, 50V, 20%	SMD	Nichicon	UWT1H010MCL2GB	Digikey	493-2215-1-ND	5	$0.059	$0.293
C3	Electrolytic Cap.	330uF, 35V, 20%	SMD	Nichicon	UWT1V331MNL1GS	Digikey	493-2206-1-ND	1	$0.168	$0.168
C5-C7	Electrolytic Cap.	0.1uF, 50V, 20%	SMD	Nichicon	UWT1H0R1MCL1GB	Digikey	493-2208-1-ND	3	$0.059	$0.176
C9-C10	Ceramic Chip Cap.	0.01uF, 50V, 10%	SMD-0805	Panasonic	ECJ-2VB1H103K	Digikey	PCC103BNCT-ND	2	$0.015	$0.030
MOV	Metal Oxide Varistor	2750 VRMS	Axial	Littelfuse	V14E275	Mouser	576-V14E275	1	$0.203	$0.203
PTC	Pos. Temp. Coef. Thermistor	260Vmax, 920mA Trip	Axial	Stetron	CB1-3R7-261SLB	N/A	N/A	1	$0.300	$0.300
R1	Carbon Film	510, 1/4W, 5%	Axial	N/A	N/A	N/A	N/A	1	$0.006	$0.006
R2, R6, R8, R11*	Carbon Film	1k, 1/4W, 0.1%	Axial	N/A	N/A	Digikey	N/A	4	$0.006	$0.025
R3	Carbon Film	60, 1/4W, 5%	Axial	N/A	N/A	N/A	N/A	1	$0.006	$0.006
R4-R5	Carbon Film	1.8k, 1/4W, 5%	Axial	N/A	N/A	N/A	N/A	2	$0.006	$0.013
R7	Chip	10k, 1/4W, 5%	1206	Panasonic	ERJ-8GEYJ103V	Digikey	P10KECT-ND	1	$0.008	$0.008
R9-R10*	Carbon Film	499k, 1/4W, 0.1%	Axial	N/A	N/A	Digikey	N/A	2	$0.006	$0.013
CT	Current Transformer	0.1-30A, 50-400Hz, 110mV/A	PCB	Triad Magnetics	CSE187-L	Digikey	237-1103-ND	1	$0.880	$0.880
D1	LED	green, diffused, dome		N/A	N/A	N/A	N/A	1	$0.044	$0.044
D2-D6	Diode	150mA, 75V	DO-35	Micro Commercial Co.	1N4148	Digikey	1N4148MSCT-ND	5	$0.010	$0.051
DC1**	DC-Jack		PCB	CUI Inc.	PJ-102B	Digikey	CP-102B-ND	0	$0.000	$0.000
L1-L3	Ferrite bead core	100MHz, 110ohms	Axial	Panasonic	EXC-ELSA39	Digikey	P9818BK-ND	3	$0.051	$0.153
MOD	RJ-11 Jack	modular, 6-contact	PCB	FCI Electronics	68898-001	Newark	89F4576	1	$0.000	$0.000
POD	Header	20-pin, gold, 2mm vertical	PCB	Molex	87331-2020	Digikey	WM18066-ND	1	$1.125	$1.125
RELAY1-RELAY2	Power Relay	16A, SPST-NO, 6VDC coil	PCB	Aromat Corporation	JR1AF-DC5V	Digikey	255-1109-ND	2	$2.128	$4.256
SW1**	Switch	Tactile pushbutton switch	SMD	E-Switch Inc.	TL3301AF160QG/TR	Digikey	EG2526CT-ND	0	$0.000	$0.000
Term1**	Terminal Block	Green, 2-pin, 90° orientation	PCB	Pheonix Contacts	1711026	Digikey	277-1022-ND	0	$0.000	$0.000
TX1	Power Transformer	115V primary, 10VCT, 150mA	PCB	Hammond	164-E20	Mouser	546-164E20	1	$4.000	$4.000
XTAL1	Resonator	30MHz	PCB	ZTT	ZTT-30.00MX	N/A	N/A	1	$0.200	$0.200
XTAL2	Crystal	3.570545MHz, 17pF	SMD	ECS Inc.	ECS-35-17-5P-TR	Digikey	XC560CT-ND	1	$0.338	$0.338
U1**	RS232 Transceiver	5V, 10mA, 2DVR/2RCVR	SOIC-16	Maxim Semiconductor	MAX232CWE	Digikey	MAX232CWE-ND	0	$0.000	$0.000
U2	5 volt regulator	DMOS, LDO, 250mA	SOIC-8	Burr-Brown/TI	Reg102UA-5	Digikey	Reg102UA-5-ND	1	$1.310	$1.310
U3	3 volt regulator	DMOS, LDO, 500mA	SOIC-8	Burr-Brown/TI	Reg103UA-3	Digikey	Reg103UA-3-ND	1	$1.310	$1.310
U4	Microcontroller	Flash, 40 MHz max, 23 I/O	SOIC	Microchip	PIC18F252-I/SO	Digikey	PIC18F252-I/SO-ND	1	$4.240	$4.240
U5	EEPROM	64k (8kx8), SPI Bus	SSOIC	Microchip	25LC640-I/SN	Digikey	25LC640-I/SN-ND	1	$0.690	$0.690
U6	5V-3V level converter	8-channel, 35Mbps, 1.2-5.5V	TSSOP-20	Maxim Semiconductor	MAX3001E	Maxim	Samples (Price at 1k)	1	$1.250	$1.250
U7	Energy metering IC	N/A	SSOP	Analog Devices	ADE7753ARS	Digikey	ADE7753ARS-ND	1	$3.400	$3.400
U8-U9	BJT	40V, 1A, NPN	TO-92	Fairchild Semiconductor	PN2222ATFR	Digikey	PN2222AD26ZCT-ND	2	$0.029	$0.058
Z1	Bridge Rectifier	1A, 100V	DIP	Micro Commercial Co.	DB102	Digikey	DB102MS-ND	1	$0.195	$0.195
U10	Transceiver Module	902-928 MHz	DIP Header	Xemics	XM1203	Future-Active	XM1203-C915XEM-1	1	$15.000	$15.000
Manufacturing Cost								1	$6.670	$6.670
							Totals	**67**		**$47.68**

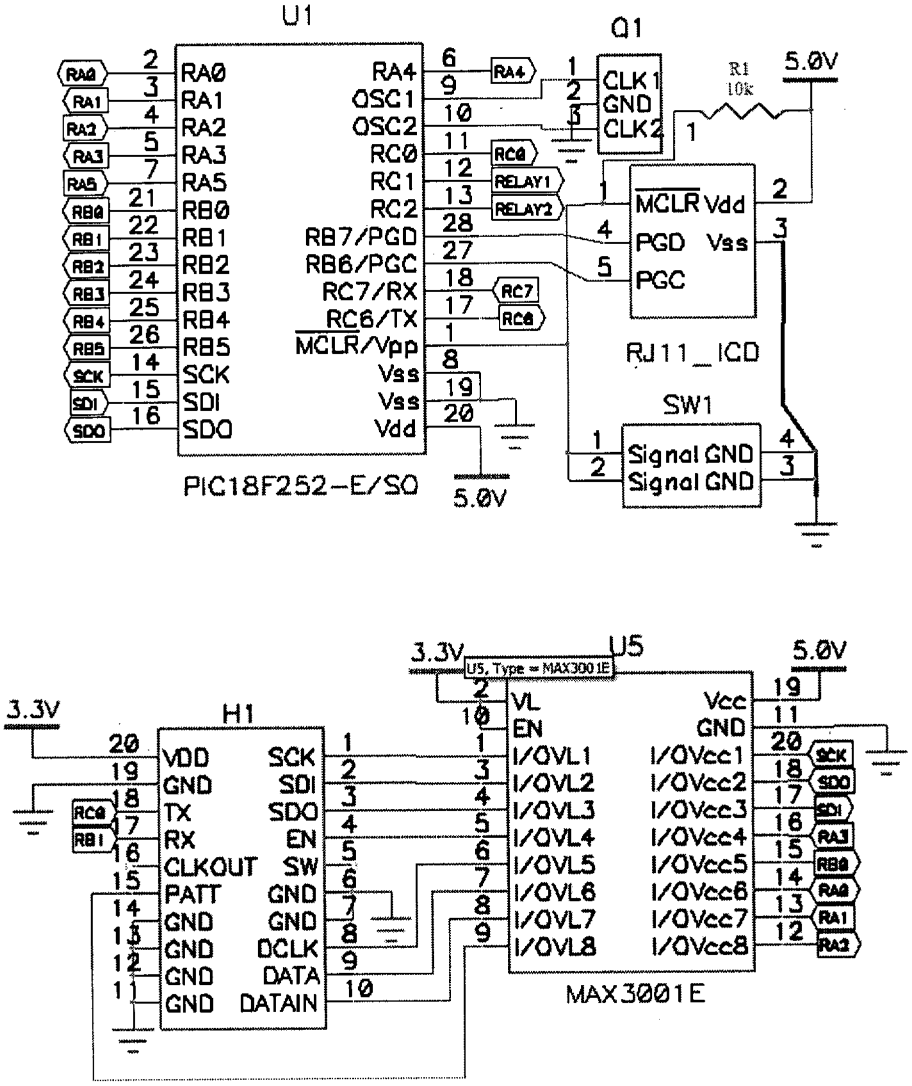
*** Carbon film resistors will be used in the field version of the prototype.**

**** Parts will not be needed in field version of the prototype**

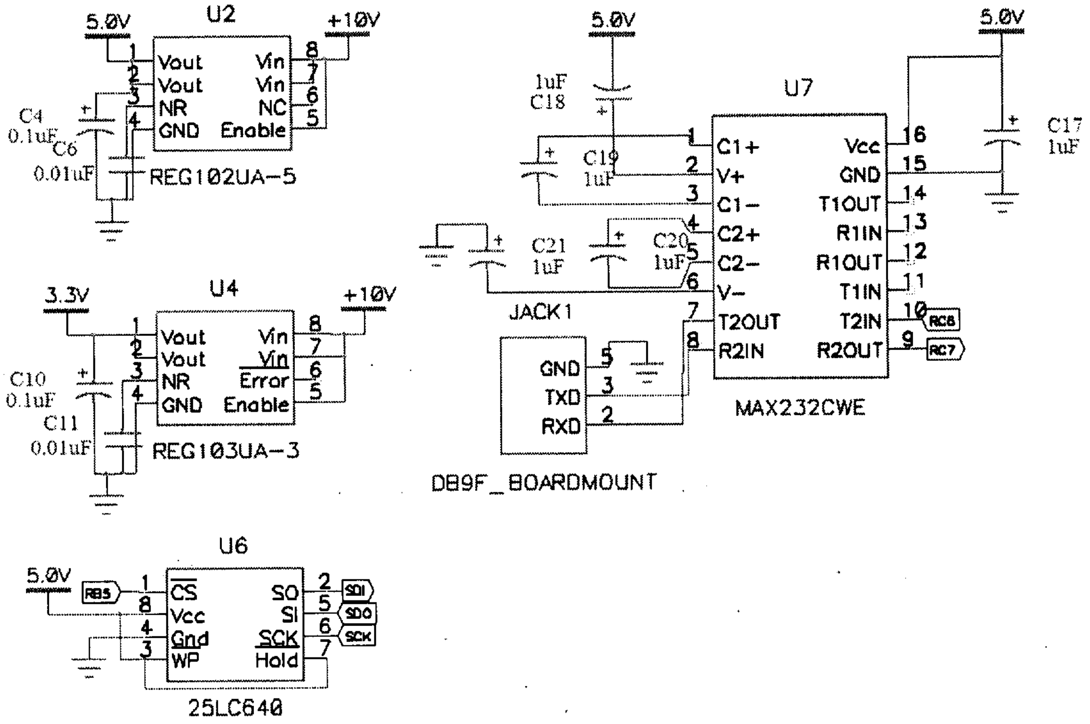
ADE7753 Power IC Circuit



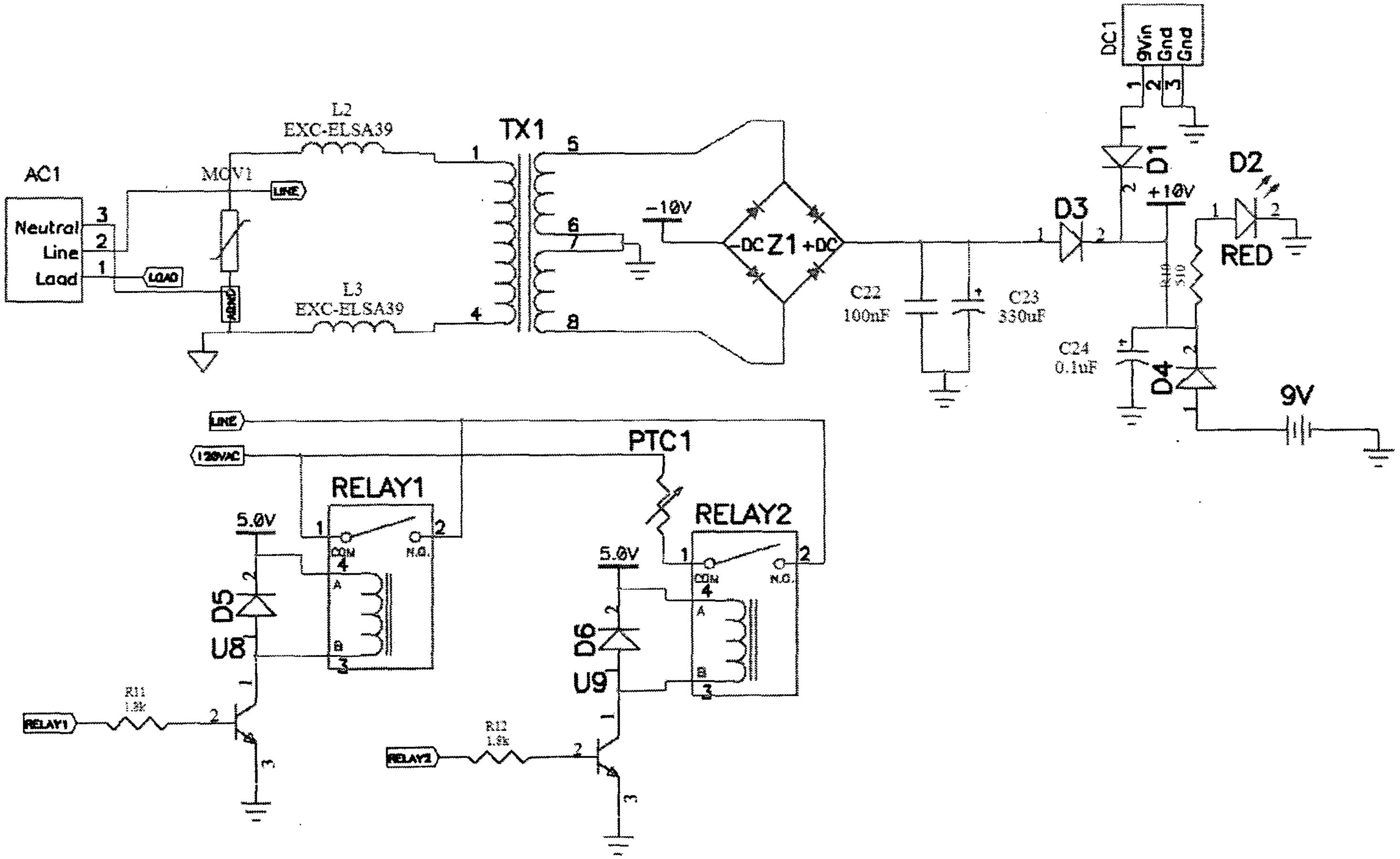
(TOP) PIC Microcontroller Schematic
(BOTTOM) MAX3001E Logic Level Converter and Header for Transceiver Connection



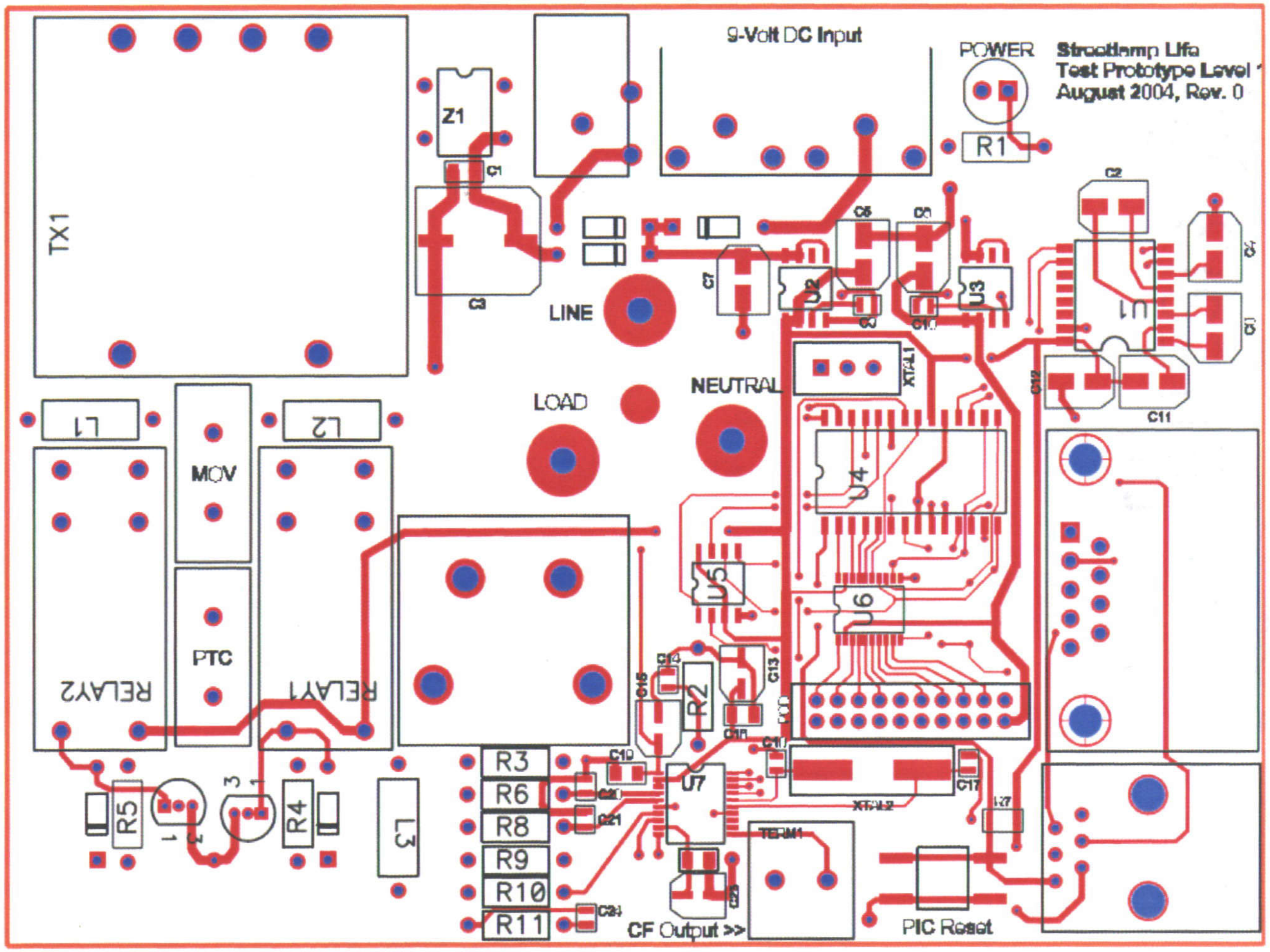
(LEFT) Voltage Regulators and EEPROM
(RIGHT) RS232 Transceiver and DB9 Connector



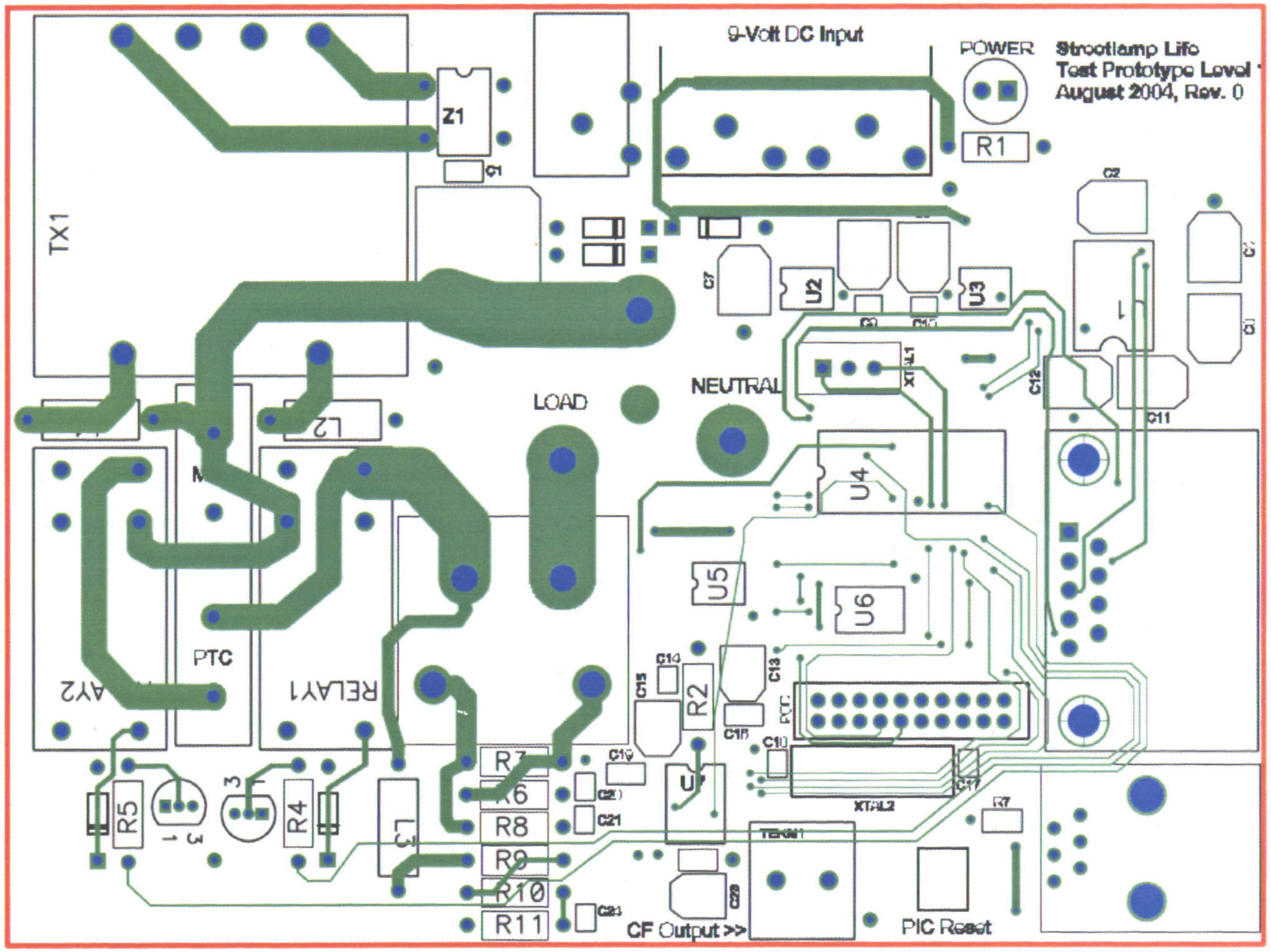
(TOP) Power Supply
(BOTTOM) PTC Relay Control Circuit



CAMtasticDXP (TM): Prototype Circuit - Top Signal Layer



CAMtasticDXP (TM): Prototype Circuit - Bottom Signal Layer



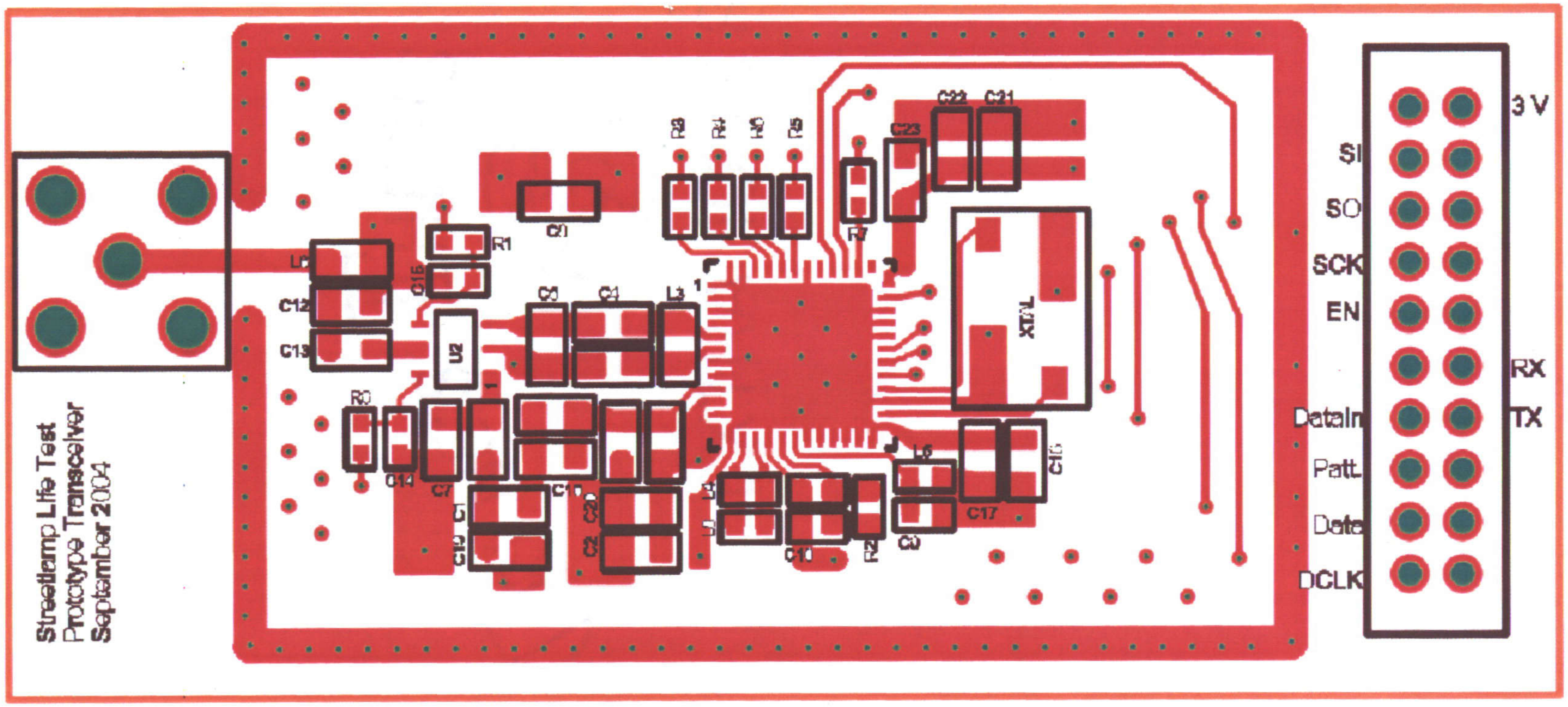
Parts Summary for Photocontrol Transceiver Prototype Rev.0 (9/21/2004)

RefDes	Name	Description	Package	Function	Comments	Manufacturer	Manufacturer Part #	Catalog	Proto Cost	1KU Price
U1	XE1203F063		VQFN 48	900 MHz Transceiver		XEMICS	XE1203	Samples	$6.400	$4.000
U2	UPG152TA		SMD		RF-Switch GaAs SPDT	NEC	UPG152TA	Mouser	$1.320	$1.070
XTAL	39MHz		SMD	XTAL	Crystal 39MHz, 10pF	N/A	C3XC1-1G5-39M000	C3 Electronics	??	??
R1	1k	Resistor (+/-1%)	402			Xicon	304-1k	Mouser	$0.100	$0.009
R2	1k	Resistor (+/-1%)	402	f Synthesizer Loop		Xicon	304-1k	Mouser	$0.100	$0.009
R3	1k	Resistor (+/-1%)	402			Xicon	304-1k	Mouser	$0.100	$0.009
R4	1k	Resistor (+/-1%)	402			Xicon	304-1k	Mouser	$0.100	$0.009
R5	1k	Resistor (+/-1%)	402			Xicon	304-1k	Mouser	$0.100	$0.009
R6	1k	Resistor (+/-1%)	402			Xicon	304-1k	Mouser	$0.100	$0.009
R7	1k	Resistor (+/-1%)	402			Xicon	304-1k	Mouser	$0.100	$0.009
R8	1k	Resistor (+/-1%)	402			Xicon	304-1k	Mouser	$0.100	$0.009
C1	33pF	Capacitor COG (+/-5%)	603			AVX	06035A330JAT2A	Mouser	$0.190	$0.030
C2	1uF	Capacitor X7R (+/-10%)	603	TX Matching Network	Change to X5R	AVX	0603ZD105KAT2A	Mouser	$0.600	$0.200
C3	1.8pF	Capacitor COG (+/-5%)	603	TX Matching Network		AVX	06035J1R8BBTTR	Mouser	$0.630	$0.400
C4	1pF	Capacitor COG (+/-5%)	603	RX Matching Network		AVX	06035J1R0AAWTR	Samples	$0.000	$1.350
C5	1pF	Capacitor COG (+/-5%)	603	RX Matching Network		AVX	06035J1R0AAWTR	Samples	$0.000	$1.350
C6	NC		603							
C7	2.2pF	Capacitor COG (+/-5%)	603			AVX	06035J2R2BBTTR	Mouser	$0.630	$0.400
C8	1uF	Capacitor X7R (+/-10%)	603		Change to X5R	AVX	0603ZD105KAT2A	Mouser	$0.600	$0.200
C9	1.5pF	Capacitor COG (+/-5%)	402	Input Supply Filter		AVX	04023J1R5BBWTR	Mouser	$0.500	$0.320
C10	4.7nF	Capacitor COG (+/-5%)	402	f Synthesizer Loop		Kemet	C0402C472J3RAC7867	Mouser	$0.520	$0.135
C11	330pF	Capacitor COG (+/-5%)	402	f Synthesizer Loop		Kemet	C0402C331J5RAC7867	Mouser	$0.520	$0.135
C12	1.2pF	Capacitor COG (+/-5%)	603		Tolerance = 0.02pF	AVX	06035J1R2YBTTR	Mouser	$0.950	$0.610
C13	33pF	Capacitor COG (+/-5%)	603			Murata	06035A330JAT2A	Mouser	$0.190	$0.030
C14	1nF	Capacitor COG (+/-5%)	402			AVX	04025C102JAT2A	Mouser	$0.420	$0.130
C15	1nF	Capacitor COG (+/-5%)	402			AVX	04025C102JAT2A	Mouser	$0.420	$0.130
C16	NC		603							
C17	3.3nF	Capacitor COG (+/-5%)	603	Input Supply Filter		AVX		Samples	$0.000	$0.000
C18	1uF	Capacitor X7R (+/-10%)	603	Input Supply Filter	Change to X5R	AVX	0603ZD105KAT2A	Mouser	$0.600	$0.200
C19	3.3pF	Capacitor COG (+/-5%)	603			Murata	GRM1885C1H3R3BZ01D	Mouser	$0.120	$0.027
C20	33pF	Capacitor COG (+/-5%)	603	TX Matching Network		Murata	06035A330JAT2A	Mouser	$0.190	$0.030
C21	3.3nF	Capacitor COG (+/-5%)	603	Input Supply Filter		AVX		Samples	$0.000	$0.000
C22	1uF	Capacitor X7R (+/-10%)	603	Input Supply Filter	Change to X5R	AVX	0603ZD105KAT2A	Mouser	$0.600	$0.200
C23	1uF	Capacitor X7R (+/-10%)	603	Input Supply Filter	Change to X5R	AVX	0603ZD105KAT2A	Mouser	$0.600	$0.200
L1	10nH	LQW18AN10NG10D	603		Multilayer	Murata	LQW18AN10NG10D	Samples	$0.000	$0.180
L2	47nH	LQG18HN47NJ00D	603	TX Matching Network	Multilayer	Murata	LQG18HN47NJ00D	Samples	$0.000	$0.080
L3	27nH	LQG18HN27NJ00D	603	RX Matching Network	Wire Wound	Murata	LQG18HN27NJ00D	Samples	$0.000	$0.110
L4	NC		402	VCO Tank						
L5	18nH	LQG15HN18NJ02D	402	Input Supply Filter	Multilayer	Murata	LQG15HN18NJ02D	Samples	$0.000	$0.030
L6	18nH	LQG18HN18NJ00D	603		Multilayer	Murata	LQG18HN18NJ00D	Samples	$0.000	$0.120
L7	8.2nH	LQG18HN8N2J00D	603		Multilayer	Murata	LQG18HN8N2J00D	Digikey	$0.220	$0.060
L8	6.8nH	LQG15HN6N8J02D	402	VCO Tank		Murata	LQG15HN6N8J02D	Samples	$0.000	$0.030
POD1			PCB	Board connector	20-pin, female header	Molex	873802001	Samples	$0.000	N/A
RF_I/O			PCB	SMA	50 Ohm	Johnson Components	142-0701-301	Mouser	$7.310	$3.000

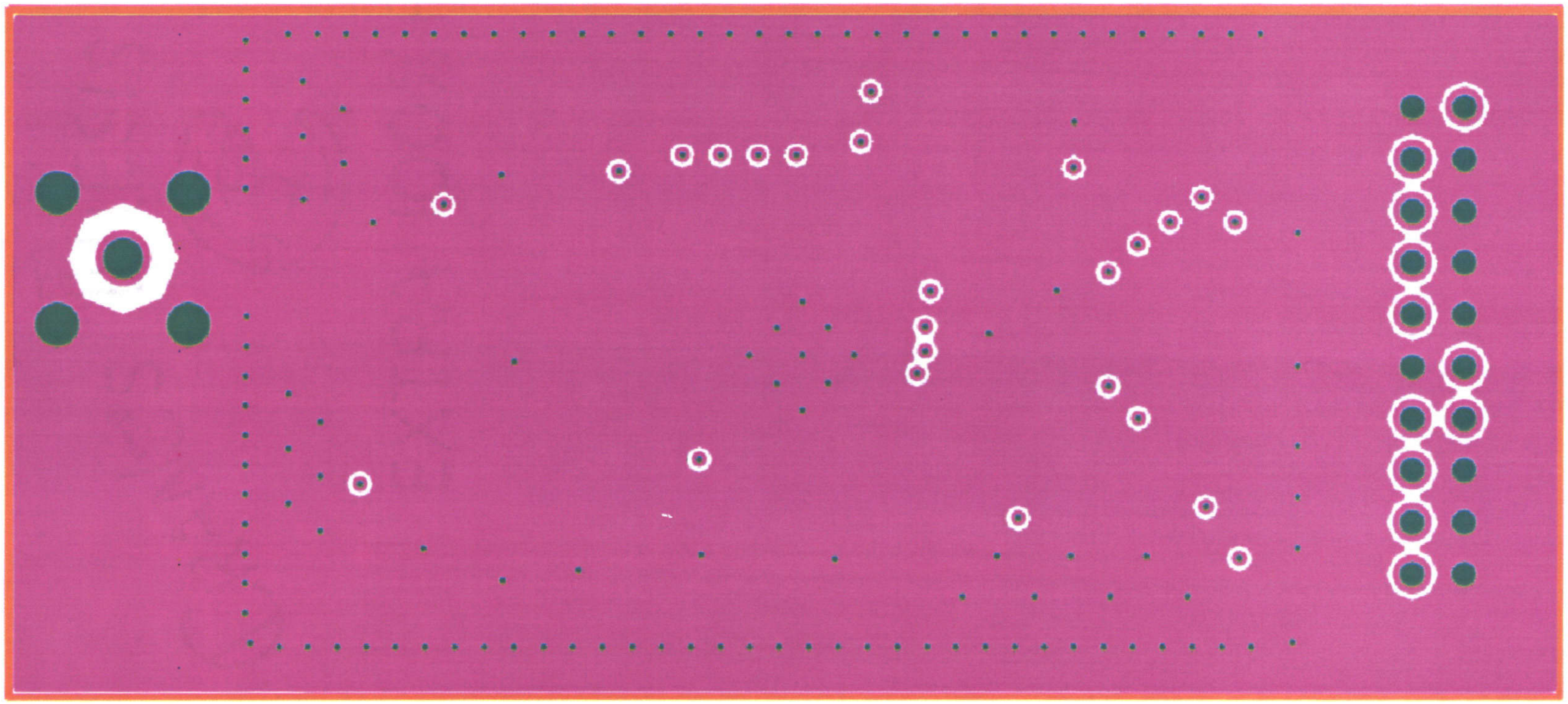
TOTALS

Price for One Unit	$24.33
Price for 1,000 Units	$14.83
No. of Parts	41

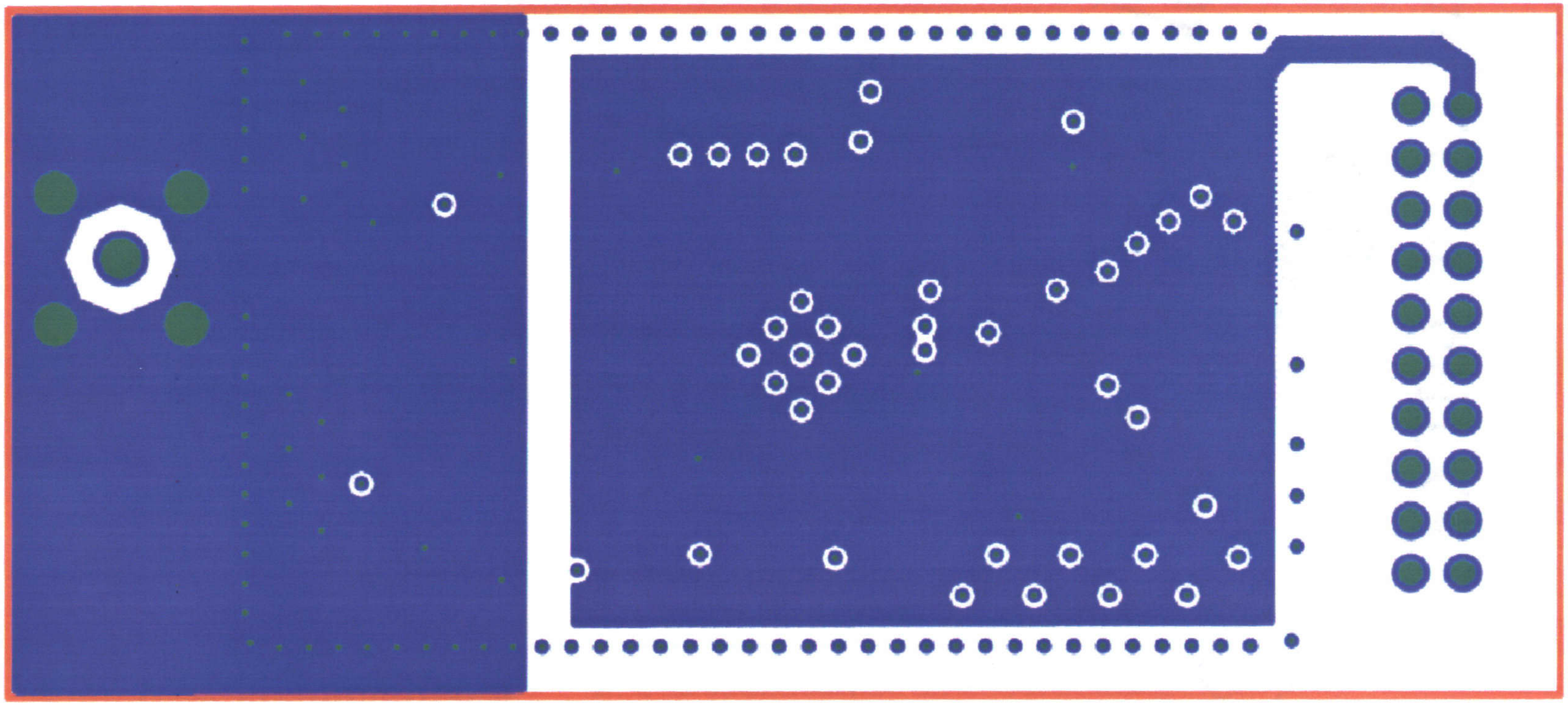
CAMtasticDXP (TM): Transceiver Prototype - Top Signal Layer



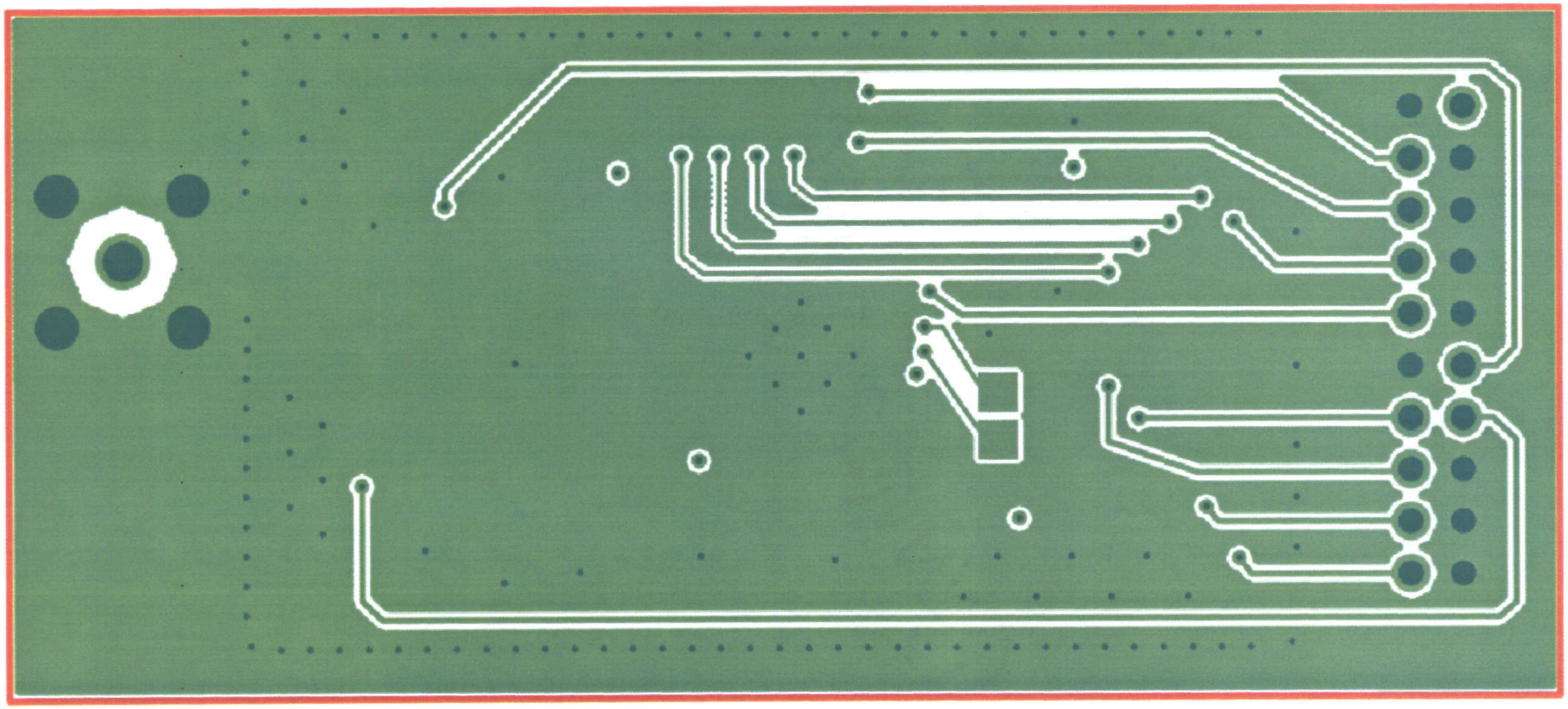
CAMtasticDXP (TM): Transceiver Prototype - Inner Signal Layer 1 (Ground Plane)



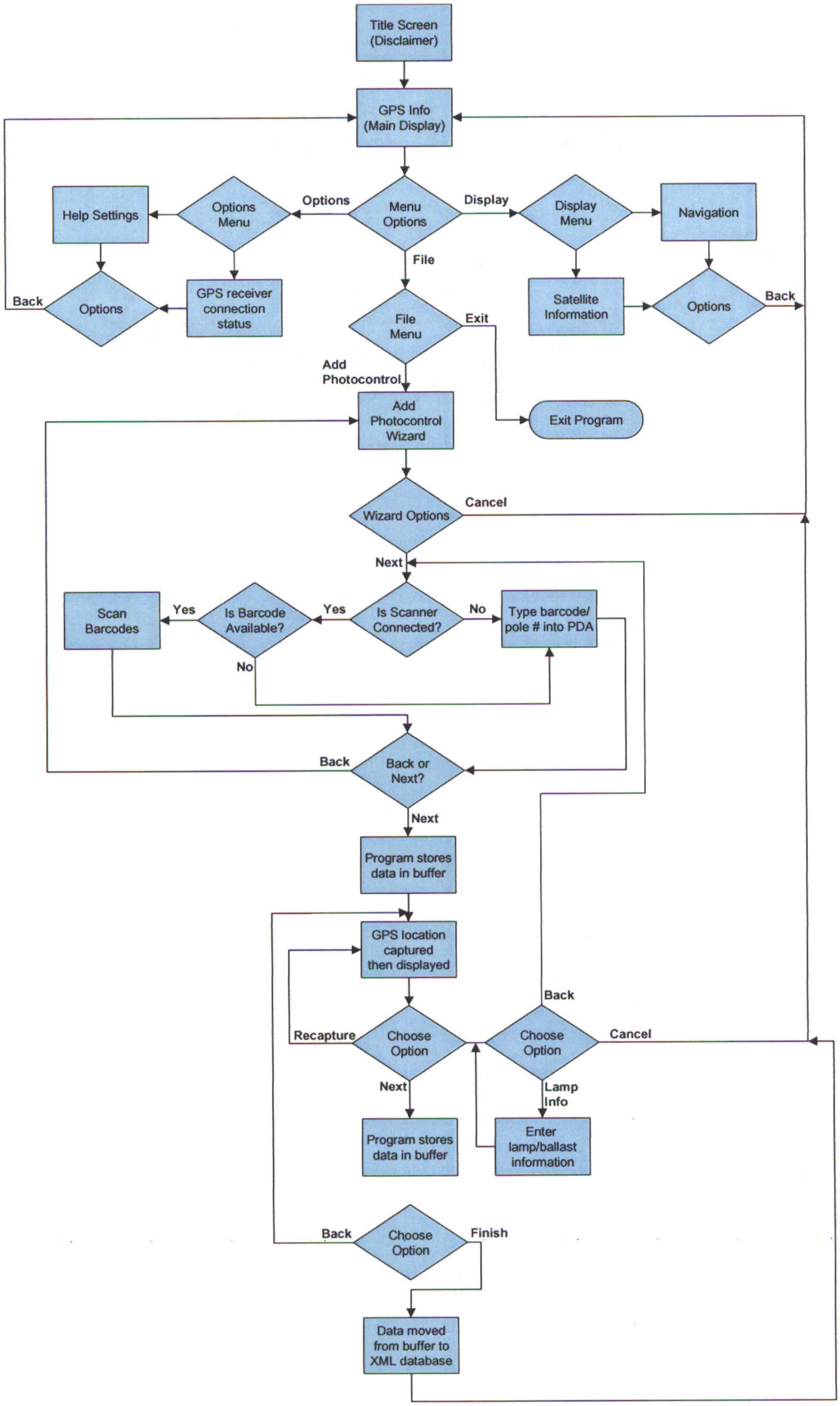
CAMtasticDXP (TM): Transceiver Prototype - Inner Signal Layer 2 (Ground/Power)



CAMtasticDXP (TM): Transceiver Prototype - Bottom Signal Layer



Appendix H: PDA Flow Chart and embedded Visual Basic Code Module


Title Screen (Disclaimer)
GPS Info (Main Display)
Help Settings
Options Menu
Options
Menu Options
Display
Display Menu
Navigation
File
Back
Options
GPS receiver connection status
Satellite Information
Options
Back
File Menu
Exit
Add Photocontrol
Add Photocontrol Wizard
Exit Program
Wizard Options
Cancel
Next
Scan Barcodes
Yes
Is Barcode Available?
Yes
Is Scanner Connected?
No
Type barcode/ pole # into PDA
No
Back
Back or Next?
Next
Program stores data in buffer
GPS location captured then displayed
Back
Recapture
Choose Option
Choose Option
Cancel
Next
Lamp Info
Program stores data in buffer
Enter lamp/ballast information
Back
Choose Option
Finish
Data moved from buffer to XML database

Summary of PDA/Bluetooth GPS Asset Management Program

Module/Object Name	Function	Lines of Code
"frmMain.ebf"	Intefaces directly to the user	414
"modAddNewWizard.bas"	Controls "Add New Equipment Wizard" through frmMain	239
"modBuffer.bas"	Recieves and stores raw data from gps module until it is ready to be parsed. Filters out "garbage" from incoming signal.	87
"modDeclares.bas"	Declares various variables	60
"modDisplayEngine.bas"	Controls compass and heading marker on the on the PDA display through frmMain when GPS screen is active.	572
"modFunctions.bas"	Custom functions created to perform various tasks not included eVB.	47
"modHelpEngine.bas"	Controls slidebars that alert user of errors. If the slidebars are clicked, a separate form is triggered that attempts to help the user solve the problem.	54
"modNMEAParser.bas"	Separates filtered sentence from modBuffer into separate NMEA sentences. Scales and calculates all data for use by NavEngine and DisplayEngine.	309
"modScanner.bas"	Uses Symbol SPS3000 drivers to control scanner based on user input.	69
"modSearchWizard.bas"	Allows user to search through and recall data from the XML database	404
"modWatchdog.bas"	Keeps track of port status (open/closed), timers, and communication status.	38
"modXMLWrapper.bas"	Creates XML data base and stores information entered by user.	225

Total Size of Program (lines of code)

2518

```
Option Explicit
'private flags to frmmain
Private m_blnSimulate As Boolean
Private m_blnStream As Boolean
'private ID counter
Private m_IDCounter As Integer
Public m_objMain As MenuBarMenu
Private Sub cmdAgree_Click()
Dim strBannerText As String
frmMain.lblBanner.Caption = "Initializing..."
Call MakeMenu
Call MakeImageList
m_CurrentFrame = "GPSINFO"
Call Arrange
strBannerText = lblBanner.Caption
frmMain.lblBanner.Caption = "Please Wait... " & strBannerText
Call OpenComms
frmMain.lblBanner.Caption = strBannerText
End Sub
Private Sub MakeImageList()
frmMain.imlMain.Add App.Path & "\Bad16x16.bmp"
frmMain.imlMain.Add App.Path & "\Error16x16.bmp"
frmMain.imlMain.Add App.Path & "\Good16x16.bmp"
frmMain.imlMain.Add App.Path & "\Help16x16.bmp"
frmMain.imlMain.Add App.Path & "\Info16x16.bmp"
frmMain.imlMain.Add App.Path & "\New16x16.bmp"
frmMain.imlMain.Add App.Path & "\Times16x16.bmp"
frmMain.imlMain.Add App.Path & "\Warning16x16.bmp"
frmMain.imlMain.Add App.Path & "\Prop16x16.bmp"
End Sub
Private Sub cmdHlpOK_Click()
m_CurrentHelpCode = 0
m_CurrentHelpMessage = ""
m_CurrentHelpTitle = ""
m_QuickMessage = ""
If m_LastFrame = "HELP" Then
m_CurrentFrame = "GPSINFO"
Else
m_CurrentFrame = m_LastFrame
End If
Call Arrange
End Sub
Private Sub cmdSWBack_Click()
m_SWOrder = m_SWOrder - 1
Call ArrangeFromOrder
If m_SWOrder = SW_DATA Then
frmMain.cmdSWNext.Enabled = True
frmMain.cmdSWCancel.Caption = "Cancel"
frmMain.txtSWChange.Text = ""
End If
frmMain - 2
End Sub
Private Sub cmdSWCancel_Click()
m_CurrentFrame = "GPSINFO"
Call Arrange
End Sub
```

```
Private Sub cmdSWNext_Click()
Dim intSI As Integer
Dim strCaption As String
Dim lvItem As ListItem
m_SWOrder = m_SWOrder + 1
Call ArrangeFromOrder
If m_SWOrder = SW_DATA Then
strCaption = frmMain.lblBanner.Caption
frmMain.lblBanner.Caption = "Please Wait... " & strCaption
intSI = GetSearchIdentifier
Select Case intSI
Case 2
frmMain.lblSWStatus.Caption = "Applying Date Filter..."
End Select
Call DoSearch(intSI)
frmMain.lblBanner.Caption = strCaption
frmMain.lblSWStatus.Caption = ""
frmMain.cmdSWCancel.Caption = "Cancel"
frmMain.cmdSWNext.Enabled = True
ElseIf m_SWOrder = SW_DETAILS Then
frmMain.lblBanner.Caption = "Please Wait... " & strCaption
Set lvItem = lstSWData.SelectedItem
Call ShowDetails(lvItem.Text, lvItem.SubItems(1))
frmMain.lblBanner.Caption = strCaption
frmMain.cmdSWNext.Enabled = False
frmMain.cmdSWCancel.Caption = "Finish"
End If
End Sub
Private Function GetSearchIdentifier()
Dim intTemp As Integer
If (frmMain.optSWPCCode.Value = True) Then
intTemp = 1
ElseIf (frmMain.optSWDate.Value = True) Then
intTemp = 2
ElseIf (frmMain.optSWLightType.Value = True) Then
intTemp = 3
ElseIf (frmMain.optSWWattage.Value = True) Then
intTemp = 4
End If
GetSearchIdentifier = intTemp
End Function
Private Sub cmdWZDBack_Click()
m_WizardSequence = m_WizardSequence - 1
Call ShowSequence(m_WizardSequence)
End Sub
Private Sub cmdWZDCanFin_Click()
frmMain - 3
If cmdWZDCanFin.Caption = "Cancel" Then
Call ScannerDetected
m_CurrentFrame = "GPSINFO"
Call Arrange
Else
Call SavePC
End If
End Sub
Private Sub cmdWZDGPSRecapture_Click()
m_WaitCount = 0
```

```
m_GoodLocation = False
Call WaitForGPS
End Sub
Private Sub cmdWZDLPScan_Click()
'Clear data on screen
scnScan.Text = ""
If Scanning = False Then
scnScan.SetSoftTrigger True 'Start Soft trigger scan
Scanning = True
Else
scnScan.SetSoftTrigger False 'Stop soft trigger scan
Scanning = False
End If
m_CurrentScan = "LP"
End Sub
Private Sub cmdWZDNext_Click()
If m_WizardSequence = 2 Then
If (txtWZDPCNumber.Text = "") And (txtWZDLPNumber.Text = "") Then
Call ShowStatus(HLP_FILLOUT, ICN_WARNING, 3000)
Else
m_WizardSequence = m_WizardSequence + 1
Call ShowSequence(m_WizardSequence)
End If
Else
m_WizardSequence = m_WizardSequence + 1
Call ShowSequence(m_WizardSequence)
End If
End Sub
Private Sub cmdWZDPCScan_Click()
'Clear data on screen
scnScan.Text = ""
If Scanning = False Then
scnScan.SetSoftTrigger True 'Start Soft trigger scan
Scanning = True
Else
scnScan.SetSoftTrigger False 'Stop soft trigger scan
Scanning = False
End If
frmMain - 4
m_CurrentScan = "PC"
End Sub
Private Sub comMain_OnComm()
Select Case comMain.CommEvent
Case comEvReceive
m_intNoComms = 0
Call BufferRawData(comMain.Input)
tmrWatchDog.Enabled = True
End Select
End Sub
Private Sub fmeSearchWizard_MouseDown(ByVal Button As Integer, ByVal
Shift As Integer, ByVal X As Sing
le, ByVal Y As Single)
End Sub
Private Sub fmeStatus_MouseDown(ByVal Button As Integer, ByVal Shift As
Integer, ByVal X As Single, By
Val Y As Single)
Call ShowHelp(m_CurrentHelpCode, 1)
```

```
End Sub
Private Sub Form_Load()
Call Arrange
Call SetTags
tmrBuffer.Enabled = True
tmrDisplay.Enabled = True
End Sub
Private Sub SetTags()
lblUTC.Tag = "1"
lblCurDate.Tag = "9"
lblCurDir.Tag = "8"
lblCurSpeed.Tag = "7"
lblLatitude.Tag = "3"
lblLongitude.Tag = "5"
lblTotSats.Tag = "3"
lblGoodSats.Tag = "7"
lblHeight.Tag = "9"
lblWZDLat.Tag = "3"
lblWZDLong.Tag = "5"
lblWZDSats.Tag = "7"
lblWZDFix.Tag = "2"
End Sub
Private Sub Form_OKClick()
App.End
End Sub
'Makes the menu at the bottom of the screen
Private Sub MakeMenu()
Set m_objMain = mnuMain.Controls.AddMenu("File", "FILE")
Call m_objMain.Items.Add(, "ADDNEW", "New")
Call m_objMain.Items.Add(, "SEARCH", "Search")
Set m_objMain = mnuMain.Controls.AddMenu("Display", "DISPLAY")
frmMain - 5
Call m_objMain.Items.Add(, "GPSINFO", "GPS Info")
Call m_objMain.Items.Add(, "SAT", "Satellites")
Call m_objMain.Items.Add(, "NAV", "Navigation")
Set m_objMain = mnuMain.Controls.AddMenu("Options", "OPTIONS")
Call m_objMain.Items.Add(, "OPTCOMMS", "Communications")
Call m_objMain.Items.Item("OPTCOMMS").SubItems.Add(, "OPENCOM", "Open
Port")
Call m_objMain.Items.Item("OPTCOMMS").SubItems.Add(, "CLOSECOM", "Close
Port")
Call m_objMain.Items.Add(, "COMPOPT", "Compass Display")
Call m_objMain.Items.Item("COMPOPT").SubItems.Add(, "HEADINGUP",
"Heading Up")
Call m_objMain.Items.Item("COMPOPT").SubItems.Add(, "NORTHUP", "North
Up")
Call m_objMain.Items.Add(, "SCAN", "Barcode Scanner")
Call m_objMain.Items.Item("SCAN").SubItems.Add(, "AUTODETECTSCN", "Auto
Detect")
End Sub
Private Sub lblCurDate_Click()
Call ShowStatus("Shows the current date", ICN_HELP, 2000)
End Sub
Private Sub lblLatitude_Click()
Call ShowStatus(HLP_LAT, ICN_HELP, 3000)
End Sub
Private Sub lblStatus_Click()
```

```
Call ShowHelp(m_CurrentHelpCode, 1)
End Sub
Private Sub lstSWData_BeforeLabelEdit(Cancel As Boolean)
Dim lvItem As ListItem
Set lvItem = lstSWData.SelectedItem
Call ShowDetails(lvItem.Text, lvItem.SubItems(1))
Cancel = True
End Sub
Private Sub lstSWData_ItemClick(ByVal Index As Long)
Call ValidateNext
End Sub
Private Sub lstSWDetails_BeforeLabelEdit(Cancel As Boolean)
Cancel = True
End Sub
Private Sub lstSWDetails_ItemClick(ByVal Index As Long)
Dim lvItem As ListItem
Set lvItem = frmMain.lstSWDetails.ListItems.Item(Index)
Select Case lvItem.Key
Case "PCS"
txtSWChange.Text = m_strSWPCS
Case "PCB"
frmMain - 6
txtSWChange.Text = m_strSWPCB
Case "LPS"
txtSWChange.Text = m_strSWLPS
Case "LPB"
txtSWChange.Text = m_strSWLPB
Case "LPE"
txtSWChange.Text = m_strSWLPE
Case "LAT"
txtSWChange.Text = m_strSWLAT
Case "LON"
txtSWChange.Text = m_strSWLON
Case "FIX"
txtSWChange.Text = m_strSWFIX
Case "LTP"
txtSWChange.Text = m_strSWLTP
Case "WAT"
txtSWChange.Text = m_strSWWAT
Case "DAT"
txtSWChange.Text = m_strSWDAT
End Select
Set lvItem = Nothing
End Sub
Private Sub mnuMain_MenuClick(ByVal Item As MenuBarLib.Item)
Select Case Item.Key
Case "GPSINFO"
m_CurrentFrame = "GPSINFO"
Call Arrange
Case "ADDNEW"
m_CurrentFrame = "ADDNEW"
Call Arrange
Case "SEARCH"
m_CurrentFrame = "SEARCH"
Call Arrange
Case "OPENCOM"
Call OpenComms
```

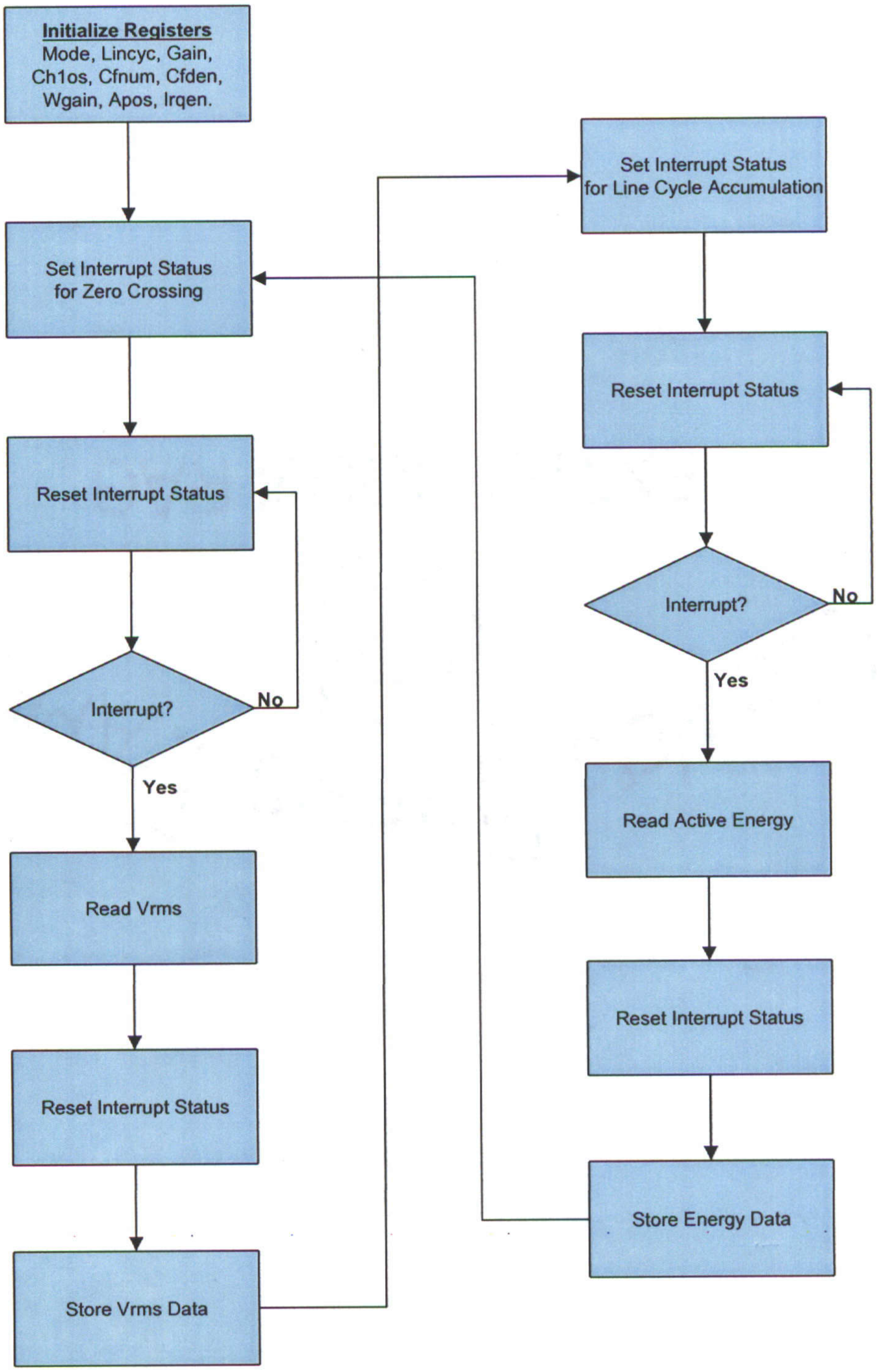
```
Case "CLOSECOM"
Call CloseComms
Case "HEADINGUP"
m_blnHeadingUp = True
Call Arrange
Case "NORTHUP"
m_blnHeadingUp = False
Call Arrange
Case "AUTODETECTSCN"
Call ScannerDetected
End Select
End Sub
Private Sub optPCBar_Click()
If optPCBar.Value = False Then
lblWZDPCCodeLabel.Caption = "Serial Num:"
txtWZDPCNumber.Enabled = True
Else
lblWZDPCCodeLabel.Caption = "Bar Code:"
txtWZDPCNumber.Enabled = False
End If
txtWZDPCNumber.Left = lblWZDPCCodeLabel.Left + lblWZDPCCodeLabel.Width
+ 4
txtWZDPCNumber.Width = fmePCScanInfo.Width - (txtWZDPCNumber.Left + 4)
cmdWZDPCScan.Visible = (optPCBar.Value = True)
End Sub
frmMain - 7
Private Sub optPCMan_Click()
If optPCMan.Value = False Then
lblWZDPCCodeLabel.Caption = "Bar Code:"
txtWZDPCNumber.Enabled = False
Else
lblWZDPCCodeLabel.Caption = "Serial Num:"
txtWZDPCNumber.Enabled = True
End If
txtWZDPCNumber.Left = lblWZDPCCodeLabel.Left + lblWZDPCCodeLabel.Width
+ 4
txtWZDPCNumber.Width = fmePCScanInfo.Width - (txtWZDPCNumber.Left + 4)
cmdWZDPCScan.Visible = (optPCBar.Value = True)
End Sub
Private Sub optLPBar_Click()
If optLPBar.Value = False Then
lblWZDLPCodeLabel.Caption = "Serial Num:"
txtWZDLPNumber.Enabled = True
Else
lblWZDLPCodeLabel.Caption = "Bar Code:"
txtWZDLPNumber.Enabled = False
End If
txtWZDLPNumber.Left = lblWZDLPCodeLabel.Left + lblWZDLPCodeLabel.Width
+ 4
txtWZDLPNumber.Width = fmePCScanInfo.Width - (txtWZDLPNumber.Left + 4)
cmdWZDLPScan.Visible = (optLPBar.Value = True)
End Sub
Private Sub optLPMan_Click()
If optLPMan.Value = False Then
lblWZDLPCodeLabel.Caption = "Bar Code:"
txtWZDLPNumber.Enabled = False
Else
```

```
lblWZDLPCodeLabel.Caption = "Serial Num:"
txtWZDLPNumber.Enabled = True
End If
txtWZDLPNumber.Left = lblWZDLPCodeLabel.Left + lblWZDLPCodeLabel.Width
+ 4
txtWZDLPNumber.Width = fmePCScanInfo.Width - (txtWZDLPNumber.Left + 4)
cmdWZDLPScan.Visible = (optLPBar.Value = True)
End Sub
Private Sub optSWDate_Click()
fmeSWPC.Visible = (optSWPCCode.Value = True)
End Sub
Private Sub optSWLightType_Click()
fmeSWPC.Visible = (optSWPCCode.Value = True)
End Sub
Private Sub optSWPCCode_Click()
fmeSWPC.Visible = (optSWPCCode.Value = True)
End Sub
Private Sub optSWWattage_Click()
fmeSWPC.Visible = (optSWPCCode.Value = True)
End Sub
frmMain - 8
Private Sub scnScan_ScanEvent(ByVal lEventCode As Long, ByVal lParam As
Long)
Dim Response As Integer
If lEventCode = SCAN_EVENT_STATE_CHANGE Then
If lParam <> SCAN_STATUS_SCANNING And lParam <> SCAN_STATUS_AIMING Then
scnScan.SetSoftTrigger False 'Stop soft trigger scan
Scanning = False
End If
End If
End Sub
Private Sub scnScan_ScanComplete(ByVal bstrBarCode As String, ByVal
bstrSource As String, ByVal lStatu
s As Long, ByVal lLabelType As Long, ByVal lDataLength As Long)
Dim intResponse As Integer
Scanning = False
' Error from scanner?
If lStatus <> 0 Then
scnScan.EnableScanning False 'Disable scanning
scnScan.CloseScanner 'Close the scanner
intResponse = MsgBox("Error=" & Hex(lStatus) & ". Do you want to Retry
Scan?", vbYesNo, "Scan E
rror")
If intResponse = vbYes Then
scnScan.OpenScanner 'Re-Open the scanner
scnScan.EnableScanning True 'Re-Enable Scanning
Else
Call CloseScan
m_CurrentFrame = "GPSINFO"
Call Arrange
End If
End If
If m_CurrentScan = "PC" Then
txtWZDPCNumber.Text = scnScan.Text
Else
txtWZDLPNumber.Text = scnScan.Text
End If
```

```
End Sub
Private Sub tmrBuffer_Timer()
If (Not m_intNoComms > 1) Then
Call Create4SentenceBuffer
End If
End Sub
Private Sub tmrDisplay_Timer()
If (Not m_intNoComms > 1) Then
Call UpdateDisplay
End If
End Sub
frmMain - 9
Private Sub tmrNMEA_Timer()
If (Not m_intNoComms > 1) Then
Call ShowNMEA
End If
End Sub
Private Sub tmrStatus_Timer()
Call MoveStatus
End Sub
Private Sub tmrWatchDog_Timer()
Call ToggleComms
End Sub
Private Sub tmrWZDWait_Timer()
If lblWZDFix.Caption = "3D" Then
m_GoodLocation = True
Else
m_GoodLocation = False
End If
m_WaitCount = m_WaitCount + 1
Call WaitForGPS
End Sub
Private Sub txtSWSearch_Change()
If txtSWSearch.Text <> "" Then
Call AutoSelect(txtSWSearch.Text)
End If
End Sub
Private Sub txtSWSearch_Click()
Screen.ActiveForm.SIPVisible = True
End Sub
```

Appendix I: Smart Photocontrol Programming Flow Charts and C Code

ADE7753 Program Flow Chart



```
#include "C:\Program Files\PICC\Work\rms.h"
#include <string.h>
#include <math.h>
#include <stdlib.h>
#include <input.c>
#include <25640.c>
#include <floatee.c>

void Write_Mode_Register();
void Read_MODE_Register();
void Read_AENERGY_Register();
void Read_LINCYC_Register();
void Write_LINCYC_Register();
void Read_PERIOD_Register();
void Write_GAIN_Register();
void Read_GAIN_Register();
void Read_RSTSTATUS_Register();
void Read_LAENERGY_Register();
void Read_RAENERGY_Register();
void Read_CH1OS_Register();
void Write_CH1OS_Register();
void Read_VRMS_Register();
void Read_IRMS_Register();
void Write_CFNUM_Register();
void Read_CFNUM_Register();
void Write_CFDEN_Register();
void Read_CFDEN_Register();
void Write_WGAIN_Register();
void Write_APOS_Register();
void Write_IRQEN_Register();
void Write_IRQEN1_Register();
void Read_IRQEN_Register();


void main()
{
   long int address=0, long_value, j=0;
   byte cmd, hex_value=0;

   setup_adc_ports(NO_ANALOGS);
   setup_adc(ADC_CLOCK_DIV_2);
   setup_spi(SPI_MASTER|SPI_L_TO_H|SPI_CLK_DIV_4|SPI_SS_DISABLED);
   setup_wdt(WDT_OFF);
   setup_timer_0(RTCC_INTERNAL);
   setup_timer_3(T3_DISABLED|T3_DIV_BY_1);

   output_high(PIN_B0);    //LED HIGH
   output_high(EEPROM_SELECT); // DISABLE COM TO EEPROM

   init_ext_eeprom();   // NEED TO INITIALIZE EEPROM

   output_high(PIN_C2);  // CS PIN for ADE7753 to disable when start  up.

   output_high(PIN_C1);  // RESET PIN (1) to  ADE7753
   output_low(PIN_C1);   // A logic 'low' will reset.
   delay_ms(1);          // logic 'low' for 1ms.
   output_high(PIN_C1);  // back to logic 'high' to get out of reset  mode.

   printf("\f\n\rADE7753  TEST\n\rROWAN UNIVERSITY");

   Write_Mode_Register();  //write to MODE  Register of ADE7753.
     delay_us(100);
   Write_LINCYC_Register();
     delay_us(100);
   Write_CH1OS_Register();  // disable integrator
     delay_us(100);
   Write_CFNUM_Register();
      delay_us(100);
   Write_CFDEN_Register();
      delay_us(100);
   Write_WGAIN_Register();
    delay_us(100);
```

```
   Write_GAIN_Register();
     delay_us(100);
   Write_IRQEN_Register();
     delay_us(100);

      Read_IRQEN_Register();
      binString0(data0); binString1(data1); //binString2(data2);
      //*************************************************************************
      //*** BINARY TO DECIMAL ***************************************************
      //*************************************************************************
      //strcat(bin1,bin2);// appends two strings  from binaryString2(data_2) to  binaryString1(data1).
      //strcat(bin0,bin1);// appends two strings  from binaryString1(data_1) to  binaryString0(data_0).
      //printf("\n\rBinary String: %s", bin0); //  Output combined 16 bits.
      printf("\n\rIRQEN Data 0: %X, Data1: %X" , data0, data1);
      delay_ms(100);

      Read_RSTSTATUS_Register();
      binString0(data0); binString1(data1);
      printf("\n\rRSTSTATUS  Data0: %X, Data1: %X" , data0, data1);
      delay_ms(100);

   i=0;  //initialize address counter to be 0; will  increment by two.
   while(1)
   {

      if ( !input(PIN_B2) )  //IF ENERGY COMPLETES ACCUMULATION
    {
         OUTPUT_HIGH(PIN_B3); // OUTPUT TO TEST FREQ.
            Read_AENERGY_Register(); // THEN TAKE ENERGY READING
            //printf("\n\rE %X %X", data0, data1);  // IF PRINTF IS USED, THEN DATA COLLECTION WILL
REDUCE TO 50 HZ.
               //write_ext_eeprom(address, data0); // WRITE TO EEPROM
               //write_ext_eeprom(address, data1); // WRITE
            write_ext_eeprom(i, data0); // WRITE TO EEPROM. Start at address i, which is address 0
here.
            write_ext_eeprom(i+1, data1); // WRITE.  Start at address i+2, which is address 2 here.
         OUTPUT_LOW(PIN_B3);
         Read_RSTSTATUS_Register();    // Read Status  following FlowChart

         OUTPUT_HIGH(PIN_B4);  // OUTPUT TO TEST FREQ.
            Read_VRMS_Register();  // ALSO TAKE VRMS READING
           //printf("\n\rV %X %X", data0, data1);  // View on HyperTerminal
               //write_ext_eeprom(address, data0); // WRITE TO EEPROM.
               //write_ext_eeprom(address, data1); // WRITE
            write_ext_eeprom(4000+i, data0); // WRITE TO EEPROM. Start at address i, which is
address 4000 here.
            write_ext_eeprom(4000+i+1, data1); // WRITE. Start  at address i+2, which is address 4002
here.
         OUTPUT_LOW(PIN_B4);
         i = i+2; // And ALWAYS increment address counter, 'i', by 2 b/c we are storing two bytes
for Vrms and two for Energy
         //if (i>=1000)
         //{
         //   i =0;
         //}

         //**************************************************************************
         //******** GO TO THIS INFINITE TEST STATE WHEN FINISHED *********************
         //**************************************************************************
         if (i>=1000)  // If, say, i >=1000, then do this
         {
             j=0;
             for  (;;)
             {
               printf("\n\rE%X %X" , read_ext_eeprom(j), read_ext_eeprom(j+1));
               printf("\n\rV%X %X" , read_ext_eeprom(4000+j), read_ext_eeprom(4000+j+1));  // View on
HyperTerminal
               j=j+2;
               if (j==1000)
                  goto infinite;
             }
             for(;;)
```

```
             { infinite:
               output_high(PIN_B0);
               DELAY_MS(500);
               output_low(PIN_B0);
               DELAY_MS(500);
             }
         }// end if
         //************* *************************** **************************
         //************* *************************** **************************

      }// end if
   } // end infinite while

} // end main

void Write_Mode_Register()
{
   output_low(PIN_C2);  // enable comm to ADE7753
   //delay_us(1);
   setup_spi(SPI_MASTER|SPI_SAMPLE_AT_END|SPI_CLK_DIV_4|SPI_SS_DISABLED);
   spi_write(0x89);   // write '1000 1001'. MSB of '1' allows write.  See Communications Reg.   Page44.
                      // the 'x000 1001' bits address the Mode Register.  Page 42 of ADE7753
datasheet.
   spi_write(0x18);   // write '0001 1000' MSB of '1' enables 'Positive-only Acc. mode. Page 32 & 44.
                      // 'waveform reg', '3.5 kSps', 'Swap', 'no short'.
   spi_write(0x88);   // write '1000 1000' default Mode Register values. page 42.

   output_high(PIN_C2); // disable comm to ADE7753.
}

void Read_MODE_Register()
{
   output_low(PIN_C2);  // enable comm to ADE7753
   delay_us(1);
   setup_spi(SPI_MASTER|SPI_SAMPLE_AT_END|SPI_CLK_DIV_4|SPI_SS_DISABLED);
   spi_write(0x09);   // write '0000 1001'. MSB of '0' allows read.
                      // the 'x000 1001' bits address the MODE Register.  Page 42 of ADE7753
datasheet.
   setup_spi(SPI_MASTER|SPI_L_TO_H|SPI_CLK_DIV_4|SPI_SS_DISABLED);
   delay_us(5);       // delay 4 us.  t9 on page 5.
   data0=spi_read(data);
   data1=spi_read(data);

   output_high(PIN_C2); // disable comm to ADE7753.
}

void Read_AENERGY_Register()
{
   output_low(PIN_C2);  // enable comm to ADE7753

   setup_spi(SPI_MASTER|SPI_SAMPLE_AT_END|SPI_CLK_DIV_4|SPI_SS_DISABLED);
   spi_write(0x02);   // write '0000 0010'. MSB of '0' allows read.
                      // the 'x000 0010' bits address the AENERGY Register.  Page 42 of ADE7753
datasheet.
   delay_us(5);       // delay 4 us.  t9 on page 5.
   setup_spi(SPI_MASTER|SPI_L_TO_H|SPI_CLK_DIV_4|SPI_SS_DISABLED);
   data0=spi_read(data);
   data1=spi_read(data);
   data2=spi_read(data);

   output_high(PIN_C2); // disable comm to ADE7753.
}
void Read_LINCYC_Register()
{
   output_low(PIN_C2);  // enable comm to ADE7753

   setup_spi(SPI_MASTER|SPI_SAMPLE_AT_END|SPI_CLK_DIV_4|SPI_SS_DISABLED);
   spi_write(0x1C);   // write '0001 0110'. MSB of '0' allows read.
                      // the 'x000 0110' bits address the IRMS Register.  Page 43 of ADE7753
datasheet.
   delay_us(5);       // delay 4 us.  t9 on page 5.
   setup_spi(SPI_MASTER|SPI_L_TO_H|SPI_CLK_DIV_4|SPI_SS_DISABLED);
```

```
   data0=spi_read(data);
   data1=spi_read(data);
   //data2=spi_read(data);

   output_high(PIN_C2); // disable comm to ADE7753.
}

void Write_LINCYC_Register()
{
   output_low(PIN_C2);  // enable comm to ADE7753
   //delay_us(1);
   setup_spi(SPI_MASTER|SPI_SAMPLE_AT_END|SPI_CLK_DIV_4|SPI_SS_DISABLED);
   spi_write(0x9C);  // write '1000 1001'. MSB of '1' allows write.  See Communications Reg.   Page44.
                     // the 'x000 1001' bits address the Mode Register.  Page 42 of ADE7753
datasheet.
   spi_write(0x00);  // write '0000 0000'
   spi_write(0x02);  // write '0000 0010' 2 VALUE. [(2)/60]/2 =  .016667 seconds

   output_high(PIN_C2); // disable comm to ADE7753.
}

void Read_PERIOD_Register()
{
   output_low(PIN_C2);  // enable comm to ADE7753

   setup_spi(SPI_MASTER|SPI_SAMPLE_AT_END|SPI_CLK_DIV_4|SPI_SS_DISABLED);
   spi_write(0x27);  // write '0001 0110'. MSB of '0' allows read.
                     // the 'x000 0110' bits address the IRMS Register.  Page 43 of ADE7753
datasheet.
   delay_us(5);      // delay 4 us.  t9 on page 5.
   setup_spi(SPI_MASTER|SPI_L_TO_H|SPI_CLK_DIV_4|SPI_SS_DISABLED);
   data0=spi_read(data);
   data1=spi_read(data);
   //data2=spi_read(data);

   output_high(PIN_C2); // disable comm to ADE7753.
}


void Write_GAIN_Register()
{
   output_low(PIN_C2);  // enable comm to ADE7753
   //delay_us(1);
   setup_spi(SPI_MASTER|SPI_SAMPLE_AT_END|SPI_CLK_DIV_4|SPI_SS_DISABLED);
   spi_write(0x8F);  // write '1000 1111'. MSB of '1' allows write.  See Communications Reg.   Page44.
                     // the 'x000 1111' bits address the GAIN Register.  Page 42 of ADE7753
datasheet.
   spi_write(0x01);  // write '0000 0001' Channel 1: GAIN=2.

   output_high(PIN_C2); // disable comm to ADE7753.
}

void Read_GAIN_Register()
{
   output_low(PIN_C2);  // enable comm to ADE7753

   setup_spi(SPI_MASTER|SPI_SAMPLE_AT_END|SPI_CLK_DIV_4|SPI_SS_DISABLED);
   spi_write(0x0F);  // write '0001 0111'. MSB of '0' allows read.
                     // the 'x000 0111' bits address the VRMS Register.  Page 43 of ADE7753
datasheet.
   delay_us(5);      // delay 4 us.  t9 on page 5.
   setup_spi(SPI_MASTER|SPI_L_TO_H|SPI_CLK_DIV_4|SPI_SS_DISABLED);
   data0=spi_read(data);

   output_high(PIN_C2); // disable comm to ADE7753.
}
void Read_RSTSTATUS_Register()
{
   output_low(PIN_C2);  // enable comm to ADE7753

   setup_spi(SPI_MASTER|SPI_SAMPLE_AT_END|SPI_CLK_DIV_4|SPI_SS_DISABLED);
   spi_write(0x0C);  // write '0001 0110'. MSB of '0' allows read.
```

```
                     // the 'x000 0110' bits address the IRMS Register.  Page 43 of ADE7753
datasheet.
   delay_us(5);      // delay 4 us.  t9 on page 5.
   setup_spi(SPI_MASTER |SPI_L_TO_H|SPI_CLK_DIV_4|SPI_SS_DISABLED );
   data0=spi_read(data);
   data1=spi_read(data);

   output_high(PIN_C2 ); // disable comm to ADE7753.
}

void Read_LAENERGY_Register()
{
   output_low(PIN_C2 );  // enable comm to ADE7753

   setup_spi(SPI_MASTER|SPI_SAMPLE_AT_END|SPI_CLK_DIV_4 |SPI_SS_DISABLED );
   spi_write(0x04 );  // write '0001 0110'. MSB of '0' allows read.
                      // the 'x000 0110' bits address the IRMS Register.  Page 43 of ADE7753
datasheet.
   delay_us(5);       // delay 4 us.  t9 on page 5.
   setup_spi(SPI_MASTER|SPI_L_TO_H|SPI_CLK_DIV_4 |SPI_SS_DISABLED );
   data0=spi_read(data);
   data1=spi_read(data);
   data2=spi_read(data);

   output_high(PIN_C2 ); // disable comm to ADE7753.
}
void Read_RAENERGY_Register()
{
   output_low(PIN_C2);  // enable comm to ADE7753

   setup_spi(SPI_MASTER |SPI_SAMPLE_AT_END|SPI_CLK_DIV_4 |SPI_SS_DISABLED );
   spi_write(0x03);   // write '0000 0010'. MSB of '0' allows read.
                      // the 'x000 0010' bits address the AENERGY  Register.  Page 42 of ADE7753
datasheet.
   delay_us(5);       // delay 4 us.  t9 on page 5.
   setup_spi(SPI_MASTER |SPI_L_TO_H|SPI_CLK_DIV_4|SPI_SS_DISABLED );
   data0=spi_read(data);
   data1=spi_read(data);
   data2=spi_read(data);

   output_high(PIN_C2 ); // disable comm to ADE7753.
}

void Read_CH1OS_Register()
{
   output_low(PIN_C2);  // enable comm to ADE7753

   setup_spi(SPI_MASTER |SPI_SAMPLE_AT_END|SPI_CLK_DIV_4 |SPI_SS_DISABLED );
   spi_write(0x0D);   // write '0000 0010'. MSB of '0' allows read.
                      // the 'x000 0010' bits address the AENERGY  Register.  Page 42 of ADE7753
datasheet.
   delay_us(5);       // delay 4 us.  t9 on page 5.
   setup_spi(SPI_MASTER |SPI_L_TO_H|SPI_CLK_DIV_4|SPI_SS_DISABLED );
   data0=spi_read(data);
   //data1=spi_read(data);
   //data2=spi_read(data);

   output_high(PIN_C2 ); // disable comm to ADE7753.
}

void Write_CH1OS_Register()
{
   output_low(PIN_C2);  // enable comm to ADE7753

   setup_spi(SPI_MASTER |SPI_SAMPLE_AT_END|SPI_CLK_DIV_4 |SPI_SS_DISABLED );
   spi_write(0x8D);   // write '1000 1001'. MSB of '1' allows write.  See Communications Reg.   Page44.
                      // the 'x000 1001' bits address the Mode Register.  Page 42 of ADE7753
datasheet.
   spi_write(0x00);   // write '0000 0000' MSB-> if '0' disables  integrator.


   output_high(PIN_C2 ); // disable comm to ADE7753.
```

```
}

void Read_VRMS_Register()
{
   output_low(PIN_C2);  // enable comm to ADE7753

   setup_spi(SPI_MASTER|SPI_SAMPLE_AT_END|SPI_CLK_DIV_4|SPI_SS_DISABLED);
   spi_write(0x17);   // write '0001 0111'. MSB of '0' allows read.
                      // the 'x000 0111' bits address the VRMS Register.  Page 43 of ADE7753
datasheet.
   delay_us(5);       // delay 4 us.  t9 on page 5.
   setup_spi(SPI_MASTER|SPI_L_TO_H|SPI_CLK_DIV_4|SPI_SS_DISABLED);
   data0=spi_read(data);
   data1=spi_read(data);
   data2=spi_read(data);

   output_high(PIN_C2); // disable comm to ADE7753.
}

void Read_IRMS_Register()
{
   output_low(PIN_C2);  // enable comm to ADE7753

   setup_spi(SPI_MASTER|SPI_SAMPLE_AT_END|SPI_CLK_DIV_4|SPI_SS_DISABLED);
   spi_write(0x16);   // write '0001 0110'. MSB of '0' allows read.
                      // the 'x000 0110' bits address the IRMS Register.  Page 43 of ADE7753
datasheet.
   delay_us(5);       // delay 4 us.  t9 on page 5.
   setup_spi(SPI_MASTER|SPI_L_TO_H|SPI_CLK_DIV_4|SPI_SS_DISABLED);
   data0=spi_read(data);
   data1=spi_read(data);
   data2=spi_read(data);

   output_high(PIN_C2); // disable comm to ADE7753.
}

void Write_CFNUM_Register()
{
   output_low(PIN_C2);  // enable comm to ADE7753

   setup_spi(SPI_MASTER|SPI_SAMPLE_AT_END|SPI_CLK_DIV_4|SPI_SS_DISABLED);
   spi_write(0x94);   // write '1000 1001'. MSB of '1' allows write.  See Communications Reg.   Page44.
                      // the 'x000 1001' bits address the Mode Register.  Page 42 of ADE7753
datasheet.
   spi_write(0x00);   // write '0000 0000'
   spi_write(0x00);   // write '0000 0000'


   output_high(PIN_C2); // disable comm to ADE7753.
}

void Read_CFNUM_Register()
{
   output_low(PIN_C2);  // enable comm to ADE7753

   setup_spi(SPI_MASTER|SPI_SAMPLE_AT_END|SPI_CLK_DIV_4|SPI_SS_DISABLED);
   spi_write(0x14);   // write '0001 0111'. MSB of '0' allows read.
                      // the 'x000 0111' bits address the VRMS Register.  Page 43 of ADE7753
datasheet.
   delay_us(5);       // delay 4 us.  t9 on page 5.
   setup_spi(SPI_MASTER|SPI_L_TO_H|SPI_CLK_DIV_4|SPI_SS_DISABLED );
   data0=spi_read(data);
   data1=spi_read(data);

   output_high(PIN_C2); // disable comm to ADE7753.
}
void Write_CFDEN_Register()
{
   output_low(PIN_C2);  // enable comm to ADE7753

   setup_spi(SPI_MASTER|SPI_SAMPLE_AT_END|SPI_CLK_DIV_4|SPI_SS_DISABLED);
   spi_write(0x95);   // write '1000 1001'. MSB of '1' allows write.  See Communications Reg.   Page44.
```

```
                      // the 'x000 1001' bits address the Mode Register.  Page 42 of ADE7753
datasheet.
   spi_write(0x07);   // write '0000 0000'
   spi_write(0xD1);   // write '0000 0000' 40


   output_high(PIN_C2); // disable comm to ADE7753.
}

void Read_CFDEN_Register()
{
   output_low(PIN_C2);  // enable comm to ADE7753

   setup_spi(SPI_MASTER |SPI_SAMPLE_AT_END|SPI_CLK_DIV_4 |SPI_SS_DISABLED);
   spi_write(0x15);   // write '0001 0111'. MSB of '0' allows read.
                      // the 'x000 0111' bits address the VRMS Register.  Page 43 of ADE7753
datasheet.
   delay_us(5);       // delay 4 us.  t9 on page 5.
   setup_spi(SPI_MASTER |SPI_L_TO_H|SPI_CLK_DIV_4|SPI_SS_DISABLED );
   data0=spi_read(data);
   data1=spi_read(data);

   output_high(PIN_C2); // disable comm to ADE7753.
}

void Write_WGAIN_Register()
{
   output_low(PIN_C2);  // enable comm to ADE7753

   setup_spi(SPI_MASTER |SPI_SAMPLE_AT_END|SPI_CLK_DIV_4 |SPI_SS_DISABLED);
   spi_write(0x92);   // write '1000 1001'. MSB of '1' allows write.  See Communications Reg.   Page44.
                      // the 'x000 1001' bits address the Mode Register.  Page 42 of ADE7753
datasheet.
   spi_write(0x00);   // write '0000 0000'
   spi_write(0x00);   // write '0001 0100'14 .. (51)

   output_high(PIN_C2); // disable comm to ADE7753.
}

void Write_APOS_Register()
{
   output_low(PIN_C2);  // enable comm to ADE7753

   setup_spi(SPI_MASTER |SPI_SAMPLE_AT_END|SPI_CLK_DIV_4 |SPI_SS_DISABLED);
   spi_write(0x91);   // write '1000 0001'. MSB of '1' allows write.  See Communications Reg.   Page44.
                      // the 'x000 1001' bits address the Mode Register.  Page 42 of ADE7753
datasheet.
   spi_write(0xFE);   // write '0000 0000'
   spi_write(0x75);   // write '0001 0100' -35


   output_high(PIN_C2); // disable comm to ADE7753.
}

void Write_IRQEN_Register()
{
   output_low(PIN_C2);  // enable comm to ADE7753

   setup_spi(SPI_MASTER |SPI_SAMPLE_AT_END|SPI_CLK_DIV_4 |SPI_SS_DISABLED);
   spi_write(0x8A);   // write '1000 1010'. MSB of '1' allows write.  See Communications Reg.   Page44.
                      // the 'x000 1001' bits address the IRQEN Register.  Page 42 of ADE7753
datasheet.
   spi_write(0x00);   // write '0000 0000'
   spi_write(0x04);   // write '0000 0100' Set Bit 2, which is "CYCEND".

   output_high(PIN_C2); // disable comm to ADE7753.
}

void Write_IRQEN1_Register()
{
   output_low(PIN_C2);  // enable comm to ADE7753
```

```
   setup_spi(SPI_MASTER|SPI_SAMPLE_AT_END|SPI_CLK_DIV_4|SPI_SS_DISABLED);
   spi_write(0x8A);   // write '1000 1010'. MSB of '1' allows write.  See Communications Reg.  Page44.
                      // the 'x000 1001' bits address the IRQEN Register.. Page 42 of ADE7753
datasheet.
   spi_write(0x00);   // write '0000 0000'
   spi_write(0x10);   // ZERO CROSSING

   output_high(PIN_C2); // disable comm to ADE7753.
}

void Read_IRQEN_Register()
{
   output_low(PIN_C2);  // enable comm to ADE7753

   setup_spi(SPI_MASTER|SPI_SAMPLE_AT_END|SPI_CLK_DIV_4|SPI_SS_DISABLED);
   spi_write(0x0A);   // write '0000 1010'. MSB of '0' allows read.
                      // the 'x000 0111' bits address the IRQEN Register.  Page 43 of ADE7753
datasheet.
   delay_us(5);       // delay 4 us.  t9 on page 5.
   setup_spi(SPI_MASTER|SPI_L_TO_H|SPI_CLK_DIV_4|SPI_SS_DISABLED);
   data0=spi_read(data);
   data1=spi_read(data);

   output_high(PIN_C2); // disable comm to ADE7753.
}
/*for(;;) // infinite loop
            {
            do {
                     printf("\r\n 1. Write  Hex. ");
                     printf("\r\n 2. Read Hex. ");
                     printf("\r\n 3. Write  Long. ");
                     printf("\r\n 4. Read Long. ");
                  cmd=getc();
                  cmd=toupper(cmd);
                  putc(cmd);
               } while ( (cmd!='1') && (cmd !='2') && (cmd!='3') && (cmd! ='4') );

               printf("\n\rLocation: ");
               address = get_long();     // offset address bits


               if(cmd=='1')
               {
                  printf("\r\nNew HEX value : ");
                  hex_value = gethex();        // get hex value
                  printf("\n\r");
                  write_ext_eeprom(address,  hex_value);
                  //write_ext_eeprom(EEPROM _ADDRESS address, BYTE data)
               }

               if(cmd=='2')
               {  //read_ext_eeprom(EEPROM_ ADDRESS address) {
                  printf("\r\nHEX Value: %X \r\n", read_ext_eeprom( address) );
               }

               if(cmd=='3')
               {
                  printf("\r\nNew value: ") ;
                  long_value = get_long();        // get long value
                  printf("\n\r");
                  write_long_ext_eeprom(address, long_value);
               }

               if(cmd=='4')
               {
                  printf("\r\nValue: %ld\r\n", read_long_ext_eeprom( address) );
               }
         } // end for infinite loop*/
```

```
#include <18f252.h>
#include <RXTX1.h>
#include <input.c>
#include <stdlib.h>
#include <stdio.h>


/*****************************************
*   Frequency Error Indicator Function   *
*****************************************/

void put_fei()
{
    byte fei_LSB,fei_MSB;
    long dataout_fei,val1,bitrate=0x2580,fei;

    //Get 12-bit FEI value
    fei_LSB = read_RFconfig(0xAD);
    fei_MSB = read_RFconfig(0xAC);

    //Clear 4 of the 8 most significant bits
    bit_clear(fei_MSB,4);
    bit_clear(fei_MSB,5);
    bit_clear(fei_MSB,6);
    bit_clear(fei_MSB,7);

    //Make one value out of fei_MSB and fei_LSB
    dataout_fei = make16(fei_MSB,fei_LSB);

    //Calculate FEI using formula specified in data sheet
    val1 = bitrate/2;
    fei = val1 * dataout_fei;
    fprintf(CPU,"\r\nFrequency Error: %lu",fei);
    fprintf(CPU," Hz\r\n");
}


/*****************************************
*              RSSI Function             *
*****************************************/
void put_RSSI()
{
    byte RSSI;

    //Read 2-bit RSSI value
    RSSI = read_RFconfig(0xAC);

    //Clear the 6 MSBs
    bit_clear(RSSI,0);
    bit_clear(RSSI,1);
    bit_clear(RSSI,2);
    bit_clear(RSSI,3);
    bit_clear(RSSI,4);
    bit_clear(RSSI,5);

    //Print RSSI value
    fprintf(CPU,"\r\nRSSI: %X",RSSI);
    fprintf(CPU," dBm\r\n");
}


void main()

{
    byte i=0;
    char handshake[5],dataout[20],datain[10],Sleep[10],WakeAll[7],Wake[10],SendData[10];
    init_PIC18f252();

    strcpy(Wake,"$WK#1234|");
    strcpy(Sleep, "$SLP#1234|");
    strcpy(SendData,"$DAT#1234|");
    strcpy(WakeAll,"$WK#A|");
```

```
    strcpy(handshake,"SPC");


    do{
        init_transceiver();
        fprintf(CPU,"\r\fPhotocontrol Program\r\n");
        RF_setup();
        delay_us(10);
        RF_receive();
        i = 0;

        do{
            datain[i] = fgetc(RF);
        }while(datain[i]!='$');

        fputc(datain[i],CPU);

        do{
            if((isalnum(datain[i])) || (datain[i]=='$') || (datain[i]=='#') || (datain[i]=='|'))
            {
                i++;
                datain[i] = fgetc(RF);
                fputc(datain[i],CPU);
            }
            else
            {
                break;
            }
        }while(datain[i]!='|');

        if(strncmp(datain,WakeAll,5)==0)
        {
            fprintf(CPU,"\r\nWake All");
            RF_transmit();
            delay_ms(750);
            fprintf(RF,"$OK#1234|");
            fprintf(CPU,"\r\nConfirmation Sent...");
            delay_ms(5000);
        }

        if(strncmp(datain,Wake,8)==0)
        {
            fprintf(CPU,"\r\nWake Single");
            RF_transmit();
            delay_ms(750);
            fprintf(RF,"$OK#1234|");
            fprintf(CPU,"\r\nConfirmation Sent...");
            delay_ms(5000);
        }

        if(strncmp(datain,Sleep,9)==0)
        {
            fprintf(CPU,"\r\nSleep");
            RF_transmit();
            delay_ms(750);
            fprintf(RF,"$SLP#1234|");
            fprintf(CPU,"\r\nConfirmation Sent...");
            delay_ms(10000);
        }

        if(strncmp(datain,SendData,9)==0)
        {
            fprintf(CPU,"\r\nSend Data");
            RF_transmit();
            delay_ms(750);
            fprintf(RF,"$DAT#1234$RMS=120$EGY=10|");
            fprintf(CPU,"\r\nData Sent...");
            delay_ms(5000);
        }

    }while(1);
}
```

```
#include <18f252.h>
#include <RXTX1.h>
#include <input.c>
#include <stdlib.h>
#include <stdio.h>


/****************************************
*   Frequency Error Indicator Function   *
****************************************/

void put_fei()
{
    byte fei_LSB,fei_MSB;
    long dataout_fei,val1,bitrate=0x2580,fei;

    //Get 12-bit FEI value
    fei_LSB = read_RFconfig(0xAD);
    fei_MSB = read_RFconfig(0xAC);

    //Clear 4 of the 8 most significant bits
    bit_clear(fei_MSB,4);
    bit_clear(fei_MSB,5);
    bit_clear(fei_MSB,6);
    bit_clear(fei_MSB,7);

    //Make one value out of fei_MSB and fei_LSB
    dataout_fei = make16(fei_MSB,fei_LSB);

    //Calculate FEI using formula specified in data sheet
    val1 = bitrate/2;
    fei = val1 * dataout_fei;
    fprintf(CPU,"\r\nFrequency Error: %lu",fei);
    fprintf(CPU," Hz\r\n");
}

void put_RSSI()
{
    byte RSSI;

    //Read 2-bit RSSI value
    RSSI = read_RFconfig(0xAC);

    //Clear the 6 MSBs
    bit_clear(RSSI,0);
    bit_clear(RSSI,1);
    bit_clear(RSSI,2);
    bit_clear(RSSI,3);
    bit_clear(RSSI,4);
    bit_clear(RSSI,5);

    //Print RSSI value
    fprintf(CPU,"\r\nRSSI: %X",RSSI);
    fprintf(CPU," dBm\r\n" );
}


void main()

{
    byte i=0;
    char datain[10],Sleep[12],WakeAll[7],Wake[10],SendData[10],ReadReg[10];
    float z=0;
    RF_address address;
    init_PIC18f252();
    init_transceiver();
    delay_us(20);
    strcpy(Wake,"$WK#1234|");
    strcpy(Sleep,"$SLP#1234|");
    strcpy(SendData,"$DAT#1234|");
    strcpy(WakeAll,"$WK#A|");
```

```
    strcpy(ReadReg,"$register|");

    z = 0;
    do{
        fprintf(CPU,"\fPDA Program\r\n");
        RF_setup();
        delay_us(10);
        i = 0;
        RF_transmit();

        do{
            fprintf(CPU,"\r\nEnter Command: ");
            datain[i] = fgetc(CPU);
            fputc(datain[i],CPU);
        }while(datain[i]!='$');

        do{
            i++;
            datain[i] = fgetc(CPU);
            fputc(datain[i],CPU);
        }while(datain[i]!='|');

        if(strncmp(datain,WakeAll,5)==0)
        {
            i=0;
            fprintf(CPU,"\r\nConfirmation: ");
            fprintf(RF,"$WK#A|");
            RF_receive();
            do{
                datain[i] = fgetc(RF);
            }while(datain[i]!='$');

            fputc(datain[i],CPU);

            do{
                i++;
                datain[i] = fgetc(RF);
                if((isalnum(datain[i])) || (datain[i]=='$') || (datain[i]=='|') || (datain[i]=='#')
|| (datain[i]=='='))
                {
                    fputc(datain[i],CPU);
                }
            }while(datain[i]!='|');
            fprintf(CPU,"\r\nWait 4 seconds to continue...");
            delay_ms(4000);
        }

        if(strncmp(datain,Wake,8)==0)
        {
            i=0;
            fprintf(CPU,"\r\nConfirmation: ");
            //fprintf(RF,"SPC");
            fprintf(RF,"$WK#1234|");
            RF_receive();
            do{
                datain[i] = fgetc(RF);
            }while(datain[i]!='$');

            fputc(datain[i],CPU);

            do{
                i++;
                datain[i] = fgetc(RF);
                if((isalnum(datain[i])) || (datain[i]=='$') || (datain[i]=='|') || (datain[i]=='#')
|| (datain[i]=='='))
                {
                    fputc(datain[i],CPU);
                }
            }while(datain[i]!='|');
            fprintf(CPU,"\r\nWait 4 seconds to continue...");
            delay_ms(4000);
        }
```

```
        if(strncmp(datain,Sleep,9)==0)
        {
            i=0;
            fprintf(CPU,"\r\nConfirmati on: ");
            //fprintf(RF,"S PC");
            fprintf(RF,"$SLP#1234|");
            RF_receive();
            do{
                datain[i] = fgetc(RF);
            }while(datain[i]!='$');

            fputc(datain[i],CPU);

            do{
                i++;
                datain[i] = fgetc(RF);
                if((isalnum(datain[i])) || (datain[i]=='$') || (datain[i]=='|') || (datain[i]=='#')
|| (datain[i]=='='))
                {
                    fputc(datain[i],CPU);
                }
            }while(datain[i]!='|');
            fprintf(CPU,"\r\nWait 4 sec onds to continue...");
            delay_ms(4000);
        }

        if(strncmp(datain,SendData,9)==0)
        {
            i=0;
            fprintf(CPU,"\r\nConfirmati on: ");
            //fprintf(RF,"S PC");
            fprintf(RF,"$DAT#1234|");
            RF_receive();
            do{
                datain[i] = fgetc(RF);
            }while(datain[i]!='$');

            fputc(datain[i],CPU);

            do{
                i++;
                datain[i] = fgetc(RF);
                if((isalnum(datain[i])) || (datain[i]=='$') || (datain[i]=='|') || (datain[i]=='#')
|| (datain[i]=='='))
                {
                    fputc(datain[i],CPU);
                }
            }while(datain[i]!='|');
            fprintf(CPU,"\r\nWait 4 sec onds to continue...");
            delay_ms(4000);
        }

        if(strncmp(datain,ReadReg,8)==0)
        {
            fprintf(CPU,"\r\nEnter addr ess: ");
            address = gethex();
            fprintf(CPU,"\r\nValue: %X\ r\n",read_RFconfig(address));
            fgetc(CPU);
        }

    }while(1);
}
```

```
//#fuses HS,PUT,NOWDT,WDT1,NOPROTECT,NOLVP, DEBUG,NOBROWNOUT
#fuses HS,PUT,NOWDT,WDT1,NOPROTECT,NOLVP,NOBROWNOUT
#use delay (clock=30000000)
#use rs232(baud=9600, xmit=PIN_C6, rcv=PIN_C7, parity=N, bits=8, stream=CPU)
#use rs232(baud=9600, xmit=PIN_A1, rcv=PIN_A1, parity=N, bits=8, stream=RF)


/*******************************************
*      PIC18F252 Pin Configuration       *
*******************************************/
#define RF_EN       PIN_A0
#define RF_DATA     PIN_A1
#define RF_PATT     PIN_A2
#define RF_DATAIN   PIN_A3
#define ADE_IRQ     PIN_A4
#define MAX3001_EN  PIN_A5
#define RF_DCLK     PIN_B0
#define RF_TX       PIN_B1
#define ADE_RESET   PIN_B2
#define MEM_HOLD    PIN_B3
#define ADE_EN      PIN_B4
#define MEM_EN      PIN_B5
#define RF_RX       PIN_C0
#define RELAY2      PIN_C1
#define RELAY1      PIN_C2
#define RF_SCK      PIN_C3
#define RF_SO       PIN_C4
#define RF_SI       PIN_C5

#define RF_ADDRESS byte
#define RF_SEND char


/*******************************************
*      XE1203 R/W Command Addresses      *
*******************************************/
#define RF_WRITE                 0x80
#define RF_READ                  0xA0
#define RF_STOP                  0xC0


/*******************************************
*    PIC Register Address Definitions    *
*******************************************/
#define T3CON    0xfb1
#define ADCON1   0xfc1
#define ADCON0   0xfc2
#define SSPCON1  0xfc6
#define SSPSTAT  0xfc7
#define SSPBUF   0xfc9
#define T2CON    0xfca
#define T1CON    0xfcd
#define WDTCON   0xfd1
#define T0CON    0xfd5
#define PORTA    0xf80
#define PORTB    0xf81
#define PORTC    0xf82
#define LATA     0xf89
#define LATB     0xf8a
#define LATC     0xf8b
#define TRISA    0xf92
#define TRISB    0xf93
#define TRISC    0xf94


void init_PIC18F252()
{
    #asm
    movf  ADCON0,W      //moves the value at ADCON0 to WREG
    andlw 0x38          //AND the value 0x38 (00100110) with WREG ( returning
    iorlw 0x1           //Inclusive OR 0x01 with WREG (returning
    movwf ADCON0        //moves WREG to Special Function Register ADCON0
```

```
    movlw 0x6           //moves 0x06 (0110) to WREG
    movwf ADCON1        //moves WREG to Special Function Register ADCON1, thereby making
                        //AN0-AN7 ports DIGITAL  (ADCON - 10-bit A/D Converter Module)
    bcf   ADCON1,0x6    //clear bit 6 (ADCS2) of ADCON1
                        //ADSC0:ADSC2 are therefore 0, setting the A/D Conversion Clock to FOSC/2
                        //(ADSC2 - A/D Conversion Clock Select Bit)
    bcf   WDTCON,0x0    //clear bit 0 (SWDTEN) of WDTCON, thereby turning off the Watchdog Timer
                        //(SWDTEN - Software Controlled Watchdog Timer Enable Bit)
    movlw 0x80          //moves 0x80 to WREG
    movwf T0CON         //moves WREG to Special Function Register T0CON, making bit 7 (TMR0ON)
                        //high and thereby enabling Timer0
                        //(T0CON is Timer0 Module timer/counter)
    clrf  T1CON         //clear T1CON, thereby disabling Timer1
    clrf  T2CON         //clear T1CON, thereby disabling Timer2
    clrf  T3CON         //clear T1CON, thereby disabling Timer3
//  movlw 0x16
//  movwf TRISA         //Inputs: A1,A2,A4; Outputs: A0,A3,A5
//  movlw 0x01
//  movwf TRISB         //Inputs: B0; Outputs: B1,B2,B3,B4,B5
//  movlw 0x10
//  movwf TRISC         //Inputs: C4; Outputs: C0,C1,C2,C3,C5
    #endasm
}


void init_transceiver()
{
    #asm
    movlw 0x80
    movwf SSPSTAT
    movlw 0x21          //set spi parameters
    movwf SSPCON1
    #endasm

    output_high(MAX3001_EN);
    output_high(RF_SI);
    output_high(RF_SCK);
}

void write_RFconfig(RF_ADDRESS address1,address2)
{
    output_low(RF_EN);
    spi_write(address1);
    spi_write(address2);
    spi_write(0xC0);
    output_high(RF_SI);
    output_high(RF_EN);
}

BYTE read_RFconfig(address)
{
    BYTE value;
    output_low(RF_EN);
    spi_write(address);
    value=spi_read(0);
    delay_us(10);
    output_high(RF_SI);
    output_high(RF_EN);
    return(value);
}

void RF_receive()
{
    output_low(RF_TX);
    output_high(RF_RX);
    write_RFconfig(0x86,0x80);
}

void RF_transmit()
{
    output_low(RF_RX);
    output_high(RF_TX);
```

```
    write_RFconfig(0x86,0xF0);
}

void RF_setup()
{
    output_low(RF_EN);
    write_RFconfig(0x81,0xB8);
    delay_us(100);
    write_RFconfig(0x82,0x03);
    delay_us(100);

    write_RFconfig(0x83,0x37);  //FSParam_Dev: frequency deviation(7-0) = 55kHz
    delay_us(100);

    write_RFconfig(0x84,0x0F);  //FSParam_Change_Osr(7): default BR defined by FSParam_Br
    delay_us(100);              //FSParam_Br(6-0): Bit Rate = 9600bps

    write_RFconfig(0x86,0x40);  //SWParam_mode_1(7-6): Standby Mode
    delay_us(100);              //SWParam_Power_1(5-4): Transmitter output power = 0dBm
                                //SWParam_Rmode_1(3): Receiver mode = Mode A (high sensitivity)
                                //RESERVED(2-0)

    write_RFconfig(0x87,0x00);
    delay_us(100);
    write_RFconfig(0x88,0x00);
    delay_us(100);

    write_RFconfig(0x8E,0x00);  //16-bit pattern recognition word
    delay_us(100);              //0 tolerated errors for pattern

    write_RFconfig(0x8F,0x00);
    delay_us(100);
    write_RFconfig(0x90,0x00);
    delay_us(100);
    write_RFconfig(0x91,0x00);  //AD_Param_disable_data_bidir(7): DATA port bidirectional mode
enabled
    delay_us(100);              //AD_Param_disable_data_bidir(6-0): Threshold for Barker tracking
(not used)

    write_RFconfig(0x92,0x80);  //bit sync. = high interference env.
    delay_us(100);
    write_RFconfig(0x93,0x93);  //pattern recogntion 32-bit pattern
    delay_us(100);
    write_RFconfig(0x94,0xAA);
    delay_us(100);
    write_RFconfig(0x95,0x93);
    delay_us(100);
    write_RFconfig(0x96,0xAA);
    delay_us(100);
    output_high(RF_EN);
}

void ptc_test()
{

}
```