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Evaluation of Airfield Lighting Circuit Performance

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16. Abstract

New requirements for airfield guidance signs have necessitated replacement and purchase of a large number of airfield signs. In the process manufacturers have developed new designs for airfield signs using current technology for the illumination and control. However, as the new signs are placed into service, airports are experiencing problems with the performance of the signs. In order to determine the scope and to investigate these problems, the Federal Aviation Administration (FAA) conducted an evaluation at six different airports. The evaluations showed that the source of the electrical problems was the incompatibility between the signs and the constant-current regulators. The report provides recommendations to improve the operation of airfield lighting circuits.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

ADB	ADB Alnaco
AGI	Architectural Graphics, Inc.
AFL	Airfield lighting circuits
cd	Candela
CCR	Constant-current regulator
C/L	Centerline
C-H	Crouse-Hinds Airport Lighting Products
FAA	Federal Aviation Administration
FAA AC	Federal Aviation Administration Advisory Circular
FC	Foot candela
fL	Footlambert
H-D	Hevi-Duty
ICAO	International Civil Aviation Organization
IEEE	Institute of Electrical and Electronic Engineers
IES	Illumination Engineering Society
K	Kilo, 1000
LEC	Lean Engineering Consultants, Ltd.
m	meters
MTBF	Mean time between failure
MTTR	Mean time to repair
PF	Power factor
R/W	Runway
SCR	Silicon controlled rectifier
SMGCS	Surface movement guidance and control system
THD	Total harmonic distortion
TDZ	Touchdown zone
T/W	Taxiway
VA	Volt-ampere
VAR	Volt-ampere reactive
W	Watt

EXECUTIVE SUMMARY

Background and Approach

New requirements for airfield guidance signs have necessitated replacement and purchase of a large number of airfield signs throughout the United States. In the process, manufacturers have developed new designs for airfield signs using current technology for illumination and control. However, as the new signs are placed into service, airports have experienced problems with the performance of the signs. In order to determine the scope and to investigate these problems, the Federal Aviation Administration (FAA) conducted an evaluation at several different airports.

For the evaluation, a test program was developed which consisted of both photometric and electrical performance testing. Crucial to this program was the need to obtain data on several different types of airfield guidance signs, constant-current regulators, and the different configurations of airfield circuits. Furthermore, it was essential to obtain this data during real-life airfield applications in normal operating conditions. Toward this end data was obtained at six different airports.

The testing program resulted in the development of recommendations to improve the sign performance. These recommendations should also address improvement in airfield lighting circuits as a whole.

Summary of Findings

During the course of this project it became evident that the signage problems encountered were not airport specific, hence, the problems are characteristic of the new airfield signs.

It was concluded that the source of the electrical problems is the incompatibility between the signs and constant-current regulators (CCRs). Contributing to this incompatibility are the harmonics that are present in the signs and the regulators during normal operating conditions. It was also concluded that the photometric output of the sign is impacted by the electrical characteristics and performance of the sign. In particular, the light output is a function of the shape of the CCR output voltage waveform. The more distortion that exists in the waveform the less the photometric output of the sign.

Summary of Recommendations

The study lead to recommendations for improvements to both the signs and the regulators.

To minimize the effects of harmonics and the nonlinear characteristics of the CCR and to improve the photometric performance of the signs as well as the compatibility of the signs and regulators, it is recommended that criteria be established to limit the time which the regulator is not conducting within one complete cycle (dead time) exhibited in the output waveforms at all ranges of connected load. A practical solution for improving the harmonics is the addition of a tap-setting mechanism in the regulator. Two suggested methods include an automatic tap setting and a tap setting that will work in conjunction with the regulator output step setting to accommodate load changes.

In addition to providing for the electrical compatibility of signs with regulators, it is necessary that their photometric performance comply with FAA requirements. To better define the photometric performance parameters of the signs, it is recommended that the FAA standards be revised to include (1) luminance requirements for the red background on mandatory signs, (2) contrast requirement for mandatory signs, and (3) field test procedures to periodically measure the photometric output of the signs.

1. INTRODUCTION.

A new generation of airfield guidance signs has been placed into service as a result of the issuance of the latest FAA Advisory Circular (AC) 150/5345-44F. The AC requires signs to maintain the same relative brightness over all the intensity steps. However, as these new signs are placed into airport service, airports began experiencing problems with the signs. These problems include flickering, flashing, and general lack of brightness (low luminance). There also have been significant problems with the constant-current regulators (CCRs) that operate the signs.

In the requirements for the constant-current regulators design, FAA specifications, in general, have been developed on the basis of loads that could be characterized as either resistive or steady state. When these specifications were developed, loads such as inductive, varying, or short duration pulses were not widely used. As a result, the CCRs manufactured for use today have been designed to meet the FAA resistive load specifications. In light of the sign problems encountered by the airports, the FAA became concerned about the other types of loads introduced into the airfield circuits by the new signs. These other types of loads induce harmonics which have detrimental effects on the regulators performance.

In order to determine the scope of these problems and to investigate the cause, the FAA conducted an evaluation at several airports.

The goal of this study is to investigate the problems associated with signs and recommend possible solutions. These recommendations are in the form of possible revisions to current FAA Advisory Circulars and specifications pertaining to airfield signs and CCRs so that proper performance of new signs and their integration into the current airfield infrastructure can be assured. The following major issues were addressed.

- The reasons for the frequent failure of the signs. Whether the failures are the result of local conditions peculiar to each airport or the results of a specific condition present at all airports and whether the failures are a function of a particular type of sign, manufacturer, or year of production.
- The compatibility of the new generation of airfield signs when introduced into existing circuits powered by various types of constant-current regulators.
- The effect of harmonics on the airfield lighting circuit, in particular the magnitude of the harmonics and their impact on system performance.
- The impact of the circuit's electrical performance on photometric output of the signs.

To address these issues, a program was developed which consisted of both photometric performance and electrical performance testing. Elemental to this program was the need to obtain data on several different types of airfield guidance signs and constant-current regulators, as well as different configurations of airfield circuits. Furthermore, it was crucial to obtain this data under real-life airfield operating conditions. Toward this end, data were obtained at six different airports. The airports selected, together with the reason for their selection, are as follows:

a. Salt Lake City International Airport, Salt Lake City, Utah, has just completed a new Category III runway with all of the required Surface Movement Guidance and Control System (SMGCS) elements. The testing of the newly installed guidance signs, together with these existing signs on the other runways, would provide data to compare the performance of the older signs with the newer ones. All signs at Salt Lake City International Airport have quartz lamps.

b. Denver International Airport, Denver, Colorado, has CCRs from two different manufacturers powering their 3-year old airfield lighting systems. Testing of the sign circuits here would furnish data on the performance of identical signs with different regulators, permitting evaluation of the compatibility of signs with the regulators. It would also provide the opportunity to evaluate any differences between new installations by comparing the performance at Salt Lake City International Airport with the performance at Denver International Airport. All signs at Denver International Airport have quartz lamps.

c. Sky Harbor International Airport, Phoenix, Arizona, still has unresolved problems with their existing signs. The testing at this airport would provide data on sign performance and the configuration of the electrical circuits within these signs. All signs at Phoenix International Airport have quartz lamps.

d. Seattle-Tacoma International Airport (SEA-TAC), Seattle, Washington, has 72 runway guard light installations and 17 inset stop bar installations. Some of the runway guard lights only operate satisfactorily on steps 4 and 5 of the regulator, even though they are on dedicated circuits. According to airport personnel, there are problems with these installations which have not been resolved. This testing program would identify the problems of these airfield elements and possibly provide data for preliminary analysis and evaluation. In addition, data could also be obtained on the performance of the stop bar installations for preliminary analysis and evaluation. All signs at SEA-TAC have quartz lamps.

e. La Guardia International Airport, New York, and Newark International Airport, New Jersey, have signs using fluorescent lamps. They also have a variety of regulators, including regulators with automatic taps. Testing at these airports would provide information on the performance of the fluorescent lighted signs operating from different regulators.

It should be noted that the data obtained at each airport were not exactly the same. Operations and weather conditions varied; for example, direct access to signs in the field was restricted at some airports and maintenance personnel were unable to provide individual signs for evaluation at the airfield lighting vault at all airports. The data obtained varied because of the different configurations and manufacturers of equipment at each airport.

2. BACKGROUND.

This study primarily involves the investigation of the photometric and electrical performance of the new generation of airfield signs which have been placed into service at several airports. This included investigation of the performance of the airfield lighting circuits into which the signs have been introduced and the constant-current regulators (CCRs) which power those circuits.

2.1 CIRCUITS.

Airfield lighting circuits are typically series circuits powered through constant-current regulators. The CCRs provide constant current to the circuits at various operating steps; the higher operating steps produce higher constant current and higher light output from the airfield lights. Different regulator manufacturers use different technologies to achieve the constant-current output required for proper operation of the signs.

The most common type of regulator found today is the silicon-controlled rectifier (SCR) regulator. The type of load represented by the usual airfield lighting fixture is a mostly resistive load.

When airfield signs are introduced into the lighting circuit, a generally reactive load is added to the circuit because of the control mechanism in the internal sign circuit. The control mechanism is designed to keep the sign's light within a narrow range over the various steps of regular operation.

2.2 SIGNS.

There were two types of signs encountered on the airports involved in this study:

a. Styles 2 and 3. These signs operate on 3- and 5-step CCRs, respectively. They are supposed to produce average light outputs of 10 to 30 footlamberts on all steps of operation.

b. Style 5. These signs are designed to work on a output setting of 5.5 amperes, producing the required 10- to 30-footlamberts light output at that setting. Style 5 signs come in two varieties: high VA/low PF and low VA/high PF. (See Glossary for descriptions of these terms.)

Typically, the signs have internal control mechanisms to adjust the sign operation, i.e., the photometric output to meet changes in CCR output. However, manually adjusted signs, i.e., signs with a basic electrical package, were also in operation at Salt Lake City. These signs required the maintenance staff to manually adjust the sign controls to meet changes in CCR output. (The Salt Lake City airport staff preferred to make the necessary adjustments themselves rather than rely on the internal sign controls; they have had problems keeping the internally controlled signs in proper operation.)

2.3 REGULATORS.

The power input to the airfield lighting circuits (and hence the signs on those circuits) is controlled by the CCR for each circuit. Although the CCR supplies constant current to the circuits (and signs) depending on the step of CCR operation, the voltage supplied to the circuit varies with the actual load. Typically, there are three different types of constant-current regulators that can be found in use on airports today:

- Resonant Network Circuit. This dry-type regulator, using rugged magnetic components, is designed to produce constant output current using a resonant network control system. It does not use solid-state components for current regulation.
- Saturable Reactor. This liquid type regulator provides constant output current by controlling the degree of saturation of the reactor via a closed control loop. Again, no solid-state components are included in its output power circuit, although there is a silicon controlled rectifier in its control circuit.
- Silicon-Controlled Rectifier (SCR). This type of regulator uses SCR-type thyristors to convert a constant voltage source into a constant-current output. The control circuit in these regulators is solid state.

The Resonant Network Circuit and the Saturable Reactor types of regulators have been very reliable over the years but fluctuations in input voltage will cause corresponding changes in the output current; periodic recalibration is required to maintain proper output current. Most of the regulators manufactured today are of the SCR type, and this was the most common type of regulator used on the airports which were studied.

In addition, regulators have taps for adjustment to accommodate the actual loads being served by the equipment. Some manufacturers have introduced automatic taps to allow the regulator to automatically meet the requirements of the circuit load. Other regulators have manual taps which are usually set when the regulator is installed but can be changed manually, if necessary, to accommodate changes in the load.

The method of control used on the SCR regulators is very accurate over a wide range of loads and varying input voltage sources. However, the price to be paid for this high level of precision is the production of harmonics, which can cause overheating and noises in regulators.

The power industry has recognized the problem of harmonics since the 1920's when the stored voltage and current waveforms were observed on power lines. The level of harmonics on distribution systems have generally been insignificant in the past. Today, however, the level of harmonic distortion of voltages and currents on distribution systems is becoming a serious problem.

Harmonics are generated by equipment loads that are classified as nonlinear. The current drawn by a linear load will always be a sine wave at the same frequency as the input voltage. These linear loads do not produce harmonics. A nonlinear load draws current in abrupt pulses and distorts the current wave shape. The on-off cycling of the SCR in the SCR type of regulator creates a nonsinusoidal current waveform which does produce harmonics. Typical generators of nonlinear loads on airports today include constant-current regulators, switching power controls, variable speed motor controls, and electronic ballasts for lighting applications.

The degree to which harmonics may be tolerated depends on the susceptibility of the load or power source to these harmonics. The most susceptible type of equipment is that which requires a sinusoidal input. The constant-current regulator assumes a sinusoidal input for its design and operation; therefore, it is quite susceptible to operating problems in the presence of harmonics.

3. EVALUATION METHODS.

3.1 PHOTOMETRICS.

The photometric performance of the signs was measured using a procedure developed by Lean Engineering Consultants, Ltd. (LEC) which involves taking digital color images of the signs. These digital color images are converted to gray-scale images which can be analyzed directly for photometric output. To provide calibration and control for the evaluation of the gray-scale image, direct photometric readings of the light output in footlamberts were taken at several locations on the face of the sign using a J-17 Photometer, which is traceable to a secondary standard of the U.S. National Institute of Science and Technology (NTIS). It is emphasized that the procedure followed in the photometric evaluation of the signs, as described above, is not the FAA prescribed procedure used by ETL Testing Laboratories in its laboratory testing. However, the procedure used is valid for the evaluation of airfield signs under field conditions and it does support the visual observations of the photometric performance of the signs and is significantly less time-consuming in the field.

The specific photometric characteristics of the airfield signs, which were predetermined, include the average intensity of light output in footlamberts and the comparison of the intensity of light output between the background and the legend.

Figures 1A through 1C and 2A through 2C show a color image and a gray-scale image of typical airfield signs. The color image was taken by a digital camera which digitizes the image so that it may be processed in a computer. The digitized color image is converted to a gray-scale image by a computer program. The program then reads the gray-scale value of an array of points on the image which has been developed to approximate FAA standards, that is, a grid of points at a 3-inch spacing. Table 1 shows the gray-scale values for the grid associated with the sign in figure 1A as well as gray-scale values for points around the inside and the outside of the letter "D." These gray-scale values are then averaged, adjacent points compared, and the maximum and minimum determined.

To convert the gray-scale values into footlamberts, which are the units necessary for comparison with FAA requirements, spot measurements were taken directly on the face of the sign using a recently calibrated J-17 Photometer. The J-17 readings are compared to gray-scale values at comparable locations on the face of the sign to determine a conversion factor. The comparison factor is then applied to the gray-scale averages, maximums, and minimums to arrive at the footlambert values shown in table 1. These footlambert values can then be compared with the FAA requirements. Each of the signs were evaluated in this manner.

The photometric output of stop bar installations were measured at SEA-TAC using an array of light sensors mounted on a small motorized cart with a driver/operator. The sensors are connected to a computer system which is also mounted on the cart. The computer system includes a monitor for visual observation of the system's performance and a printer for rapid evaluation of the runway lighting system's performance. The sensors, calibrated using the J-17 Photometer mentioned above, measure the photometric output of the light at various points in space. These measurements are processed in the computer to determine the overall photometric performance of the light, including light intensity, light distribution, and angle of the light beam. The mounting of the unit on a mobile cart and the computerizing of the measurement process allow rapid evaluation of whole runway and/or taxiway lighting systems. The cart moves along the line of lights and takes the light output measurements at intervals, thus measuring light fixture performance in sequence. This procedure has been proven on several other airfield lighting projects to furnish good indications of compliance with FAA requirements and with manufacturer's specifications for fixture performance; although it is not the FAA standard laboratory test procedure. Color and gray-scale images of the tested signs and stop bar lights were obtained using the automated procedure.

3.2 ELECTRICAL CHARACTERISTICS.

At each airport, specific electrical parameters were measured at the constant-current regulators for selected airfield signs and airfield circuits. In cooperation with airport engineering and maintenance staffs, measurements were obtained of various airfield lighting circuits using an Amprobe Harmonalyzer, an oscilloscope, and a computer to record and store data. The specific parameters measured by the Harmonalyzer are listed below:

- Input current to the regulator (Iin).
- Input voltage to the regulator (Vin).
- Output current from the regulator (Iout).
- Output voltage from the regulator (Vout).
- Total power (KVA).
- Reactive power (KVAR).
- Resistive power (KW).
- Power factor (PF).
- Total harmonic distortion of current (THD current).
- Total harmonic distortion of voltage (THD voltage).

Measurements were generally made at an intermediate operating step and at the highest operating step of the regulator. However, circuits with style 5 signs, that is, signs which work only on a fixed step or current output of 5.5 amperes, were measured only at the fixed regulator output required for the type of sign. Measurements were taken of various combinations of constant-current regulators and circuits, some circuits with airfield lights only, some with signs only, and some with a mix of lights and signs. Circuits with lights and resistive loads only were measured to compare with circuits having signs included as a part of their load.

When available, single signs were tested at the airfield lighting vault. This was done only when the airport maintenance staff was able to provide a sign at the vault. Electrical measurements were made on both the input and the output sides of the regulators where possible and also on the secondary side of the isolation transformer of selected signs. The signs provided at the airfield lighting vault were evaluated for photometric performance as well.

Also, electrical measurements were made at several signs in the field on the secondary side of the sign's isolation transformer. Photometric measurements of these signs were also taken. Graphical and tabular outputs of the Amprobe Harmonalyzer were obtained.

In addition, voltage waveforms of various circuit configurations were also obtained using the oscilloscope in an effort to find unusual circuit characteristics.

The photometric and electrical data were then reviewed and analyzed to determine whether similarities existed in the various characteristics and parameters measured for the different configurations of airfield circuits (signs, light fixtures, and regulators). The objective was to identify any common factors among the different conditions which were investigated and to determine the reasons for any abnormalities and deficiencies in sign, regulator, and/or circuit performances.

4. EXISTING INSTALLATIONS.

4.1 SALT LAKE CITY INTERNATIONAL AIRPORT.

Salt Lake City Airport had just completed a new Category III runway with the latest Surface Movement Guidance and Control System (SMGCS) installation at the time of the survey. The new runway installation contains a mix of ADB-Alnaco (ADB) and Crouse-Hinds (C-H) regulators controlling the new airfield lighting circuits. All of the new signs are Crouse-Hinds signs meeting the requirements of the FAA AC 150/5345-44F and are either style 5 signs or signs equipped with the basic electrical package, which allows for manual adjustment of the lamp voltage and current by direct wiring of taps from a coil transformer.

The runway sign installations consist of Crouse-Hinds airfield guidance signs meeting the requirements of FAA AC 150/5345-44E. Most of the signs are equipped with a basic electrical package. These signs, style 2 or 3, can operate on any of three or five steps, respectively, of regulator output. Other signs are style 5 signs operating at a fixed step of 5.5 amperes output from the regulator.

The style 5 signs are considered by the manufacturers to be low VA and high power-factor signs. The basic electrical package signs are not low VA or high PF. A discussion of low versus high VA and low versus high PF is presented in section 6 of this report.

4.2 DENVER INTERNATIONAL AIRPORT.

The Denver International Airport has relatively new airfield electrical systems (about 3 years old). All of the airfield circuits are dedicated, that is, the circuits contain only lights or signs, not both.

The airfield sign installations consist of Crouse-Hinds airfield guidance signs meeting the requirements of FAA AC 150/5345-44E. The signs are style 5, operating only on 5.5-ampere output current of the controlling regulator. It was reported that the lamps in the signs have a very short life; this is currently under discussion with the sign manufacturer. The load of each circuit on its regulator is generally only a fraction of the rated load of the regulator.

The Denver airport installation includes circuits with runway guard lights which were manufactured by ADB. There are both ADB and Crouse-Hinds regulators in the airfield lighting vault.

The designated circuits for SMGCS routing do not have power-line control signals. Some taxiway centerline lights on SMGCS routes were reported to be very bright, particularly on curves.

4.3 SKY HARBOR INTERNATIONAL AIRPORT, PHOENIX.

The majority of signs at Sky Harbor International Airport are illuminated by quartz lamps. The signs were manufactured by Architectural Graphics, Inc. (AGI). Frequent failure of lamps has been reported. All of the constant-current regulators were manufactured by Crouse-Hinds.

The various airfield circuits include those with signs only, with lights only, and with a mixture of signs and lights. Each of the two circuits with signs only (one from each of the two airfield lighting vaults) was equipped with a Hevi-Duty Harmonic Filter because of problems encountered during the early operation of these dedicated circuits.

4.4 SEA-TAC INTERNATIONAL AIRPORT, SEATTLE.

The airfield circuits at SEA-TAC International Airport generally have mixed loads of signs and lights; however, there are several dedicated circuits for the stop bar/runway guard light installations. These dedicated circuits are operated with power-line carrier control signals. The airfield sign installations consist of Crouse-Hinds airfield guidance signs meeting the requirements of FAA AC 150/5345-44E. The signs are style 3, for operation on any of 5 steps of CCR output. The stop bars are manufactured by ADB and the runway guard lights were manufactured by both ADB and Crouse-Hinds. CCRs in the airfield lighting vaults are manufactured by ADB, Crouse-Hinds, and Hevi-Duty.

Some of the stop bar/runway guard light installations produce very little light output at steps 1 and 2 of the regulator, even though they are on dedicated circuits. (There is difficulty in the operation of the power-line carrier control signal system controlling these circuits, and frequent failures of power-line carrier control signal system components were reported.) In addition, the problem of bright taxiway lights reported at Denver was also reported at SEA-TAC.

4.5 NEWARK INTERNATIONAL AIRPORT, NEW JERSEY.

At present, all airfield circuits at Newark International Airport are mixed, that is, the circuits contain both lights and signs; however, it is planned that the circuits will be separated in the near future to provide dedicated circuits for the signs. Most of the signs have fluorescent lamps and are high VA and low PF. The constant-current regulators include those manufactured by Crouse-Hinds, ADB, and Hevi-Duty.

4.6 LA GUARDIA INTERNATIONAL AIRPORT, NEW YORK.

All of the signs at La Guardia International Airport operate on dedicated circuits. Signs are style 3 (5 step) and are operated at the top step at 6.6 amps. The CCRs are SCR controlled, dry type, manufactured by Crouse-Hinds, Hevi-Duty, or ADB. The ADB regulators have automatic taps. Two circuits, when operated at lower steps of the automatic tap regulators, were reported to exhibit flashing and took time to stabilize.

5. FIELD INVESTIGATIONS.

5.1 SALT LAKE CITY INTERNATIONAL AIRPORT, SALT LAKE CITY.

5.1.1 Photometric Testing.

Photometric measurements were taken of signs in the field and in the airfield lighting vault. A summary of the photometric data is presented in table 2A.

5.1.2 Electrical Performance Testing.

Electrical measurements were made on both new and existing airfield circuits, as well as on two signs which were made available for individual testing in the airfield lighting vault. The circuits evaluated were

- Existing circuit with both airfield lights and signs.
- Existing circuit with lights only.
- Existing circuit with signs only.
- New circuit with both airfield lights and signs.
- New circuit with lights only.
- New circuit with signs only.

The circuits with both lights and signs contained signs which could be turned off; thus the circuits with lights only were actually lighting circuits with the signs turned off. The circuits with signs only were dedicated sign circuits.

In addition, two different signs were tested at the airfield lighting vault. Measurements were made of the performance of (a) a style-5 sign and (b) a basic electrical package sign at the input to the sign or the output (secondary) of the isolation transformer. Measurements were also made of the performance of a single airfield lighting fixture for comparison.

Two different regulator manufacturers are represented at Salt Lake City International Airport. The performance of each circuit was measured using each of the two manufacturer's products. Measurements were made at both the input and the output of the regulators. A summary of the electrical data obtained is presented in table 3A.

5.2 DENVER INTERNATIONAL AIRPORT.

5.2.1 Photometric Testing.

Photometric measurements were taken of signs in the field as well as of some taxiway centerline lights on one of the SMGCS routings. A summary of the photometric data is presented in tables 2A and 2B.

5.2.2 Electrical Performance Testing.

Measurements of the electrical performance of the lighting circuits and of the runway guard light/stop bar circuits were made for each of the two different manufacturer's regulators. A summary of the electrical data obtained is presented in table 3B.

5.3 SKY HARBOR INTERNATIONAL AIRPORT, PHOENIX.

5.3.1 Photometric Testing.

Photometric measurements were taken of signs in the field and in the airfield lighting vault. A summary of the photometric data is presented in table 2A.

5.3.2 Electrical Performance Testing.

Electrical measurements were made of three circuits, one with a mix of lights and signs, one with lights only, and one with signs only.

Because of problems in the operation of the sign circuits, the airport staff had installed harmonic filters in each of the dedicated circuits. Measurements of the performance of the sign circuits were made with and without the filters connected to try to evaluate the effect of the filters. The measurements of circuit performances were taken at both the input and the output of the regulators.

Measurements of electrical performance were also made of individual signs, one of which was made available in the airfield lighting vault and two which were made available in the field. The field signs were measured at the secondary of the isolation transformer, and the sign in the airfield lighting vault was measured both on the secondary and the primary sides of the isolation transformer. The sign in the airfield lighting vault was also measured while being powered through a Variac, or pure sine wave generator. As is clearly shown in table 3C, the current in this case did not reach 6.6 amps. This was due to the limited capacity of the Variac. However, it is evident from the data that a sinusoidal power input produces a very low level of harmonic distortion. A summary of the electrical data obtained is presented in table 3C.

5.4 SEA-TAC INTERNATIONAL AIRPORT, SEATTLE.

5.4.1 Photometric Testing.

Photometric measurements were taken of signs in the field. Photometric measurements were also made of some of the stop bar lights and of some taxiway centerline lights on one of the SMGCS routings. These lights were on the power-line carrier. A summary of the photometric data is presented in tables 2A and 2C.

5.4.2 Electrical Performance Testing.

The airfield circuits at SEA-TAC have both lights and signs connected, except for the circuits powering the runway guard lights/stop bars which are dedicated circuits. There are several circuits with power-line carrier control signals. However, due to operating problems with these power-line carrier control signals, the airport staff has added ballasts on the output of the regulator controlling the circuits believed to be causing the problems.

It was noted that one set of runway guard lights produced very little light output at the lower steps of regulator operation. The airport is in discussion with the runway guard light manufacturer regarding the operating difficulties which have been encountered.

Measurements were made of the electrical performance of the dedicated runway guard light/stop bar circuits with both C-H and Hevi-Duty regulators. The mixed, lights and signs, circuits were measured while powered by the C-H regulator.

Measurements were also made of a power-line carrier control signals, first, with the power-line carrier control signal regulator alone, then with the circuit connected to the power-line carrier control signal regulator. This procedure produced data on the power-line carrier control signal output, independent of the imposed or controlled circuit or load. Since ballasts had been added to the regulator's controlling circuits of those units which were believed to be causing problems, measurements were taken of the power-line carrier control signal performance both with and without the ballasts in the adjacent systems.

The airport staff was able to furnish a sign in the airfield lighting vault for detailed testing. Measurements of the sign performance were made on the primary and the secondary sides of the isolation transformer. Measurements were also made with the sign added to a loaded circuit. A summary of the electrical data obtained is presented in table 3D.

5.5 NEWARK INTERNATIONAL AIRPORT, NEW JERSEY.

5.5.1 Photometric Testing.

Photometric measurements were taken of signs in the field, and a summary of the data is presented in table 2A.

5.5.2 Electronic Performance Testing.

There are no dedicated sign circuits at Newark International Airport at the present time, but engineers are in the planning stages of converting all circuits to fully dedicated circuits, either with signs only or with lights only.

Measurements of circuit performance were made on three different circuits; one was reportedly overloaded, one underloaded, and one on a normally loaded circuit. Measurements were made of both the input and the output of the regulators for these circuits. In addition, measurements were made of the electrical characteristics of one sign in the field on the secondary side of the isolation transformer. A summary of the electrical data obtained is presented in table 3E.

5.6 LA GUARDIA INTERNATIONAL AIRPORT, NEW YORK.

5.6.1 Photometric Testing.

Photometric measurements were taken of signs in the field, and a summary of the data is presented in table 2A.

5.6.2 Electrical Performance Testing.

At La Guardia International Airport the sign circuits are dedicated and operate from CCRs with automatic taps which adjust automatically for changes in regulator output when changing steps. These circuits present loads to the regulators which are significantly less than the rated loads. Some of the signs, which are illuminated with fluorescent lamps, flash when the regulator is set at steps 1 or 2.

The electrical performance characteristics of three of the sign circuits were measured at each step of output of the controlling regulator. Because of the light loads on the regulators, one regulator was loaded with two circuits to more closely approach its rated load, and its performance was measured both at the input and the output of the regulator. A summary of the electrical data obtained is presented in table 3F.

6. EVALUATION.

Extensive data were taken during the course of this study. A summary of the data is presented in the tables 3A through 3F. In the process of reviewing and evaluating the data, it became clear that the problems encountered in the operation of the signs were common to all airports. The problems were associated with

- Photometric performance, which is to a certain extent, a function of the electrical performance of the circuit.

- Variable voltage outputs that respond to changes in intensity settings as well as improper operation of regulators such as abnormal noises and failure.

- Presence of harmonics in the circuits.
- Power factor and efficiency of the circuits.

As discussed in the introduction, limited investigations were made into power-line control signals, runway guard lights, and stop bar installations. These operating systems were also found to have problems. These problems are addressed in section 6.5.

6.1 PHOTOMETRICS.

FAA standards for airfield sign performance may be summarized as follows:

- Average light output shall be between 10 and 30 footlamberts at all steps of regulator operation. (The International Civil Aviation Organization (ICAO) defines minimum light output for each color in the sign.)
- Adjacent readings of the luminance shall not exceed a ratio of 1:1.5. (ICAO adds a requirement that the ratio of the maximum reading to the minimum reading shall not exceed 6:1.)
- Signs shall be discernible at 800 ft.
- Signs shall operate without flickering at all steps of regulator output and shall be compatible with all FAA approved type regulators.

Visual observation and the evaluation of the photometric data indicates that the Newark and La Guardia International Airport signs generally meet the FAA criteria. These signs were procured on the basis of ICAO criteria which are more stringent than FAA standards. (For example, ICAO requires a measure of contrast which is not required by FAA standards.) Since the Newark and La Guardia International Airport signs generally met FAA standards, they were used as the basis for comparison of sign performance at the other airports. Color images of two of the Newark and La Guardia International Airport signs are given in figures 1B and 1C as an example of good photometric performance.

Table 2A shows that the photometric output of the Newark and La Guardia International Airports signs were generally in the range of 10 to 30 footlamberts for the yellow and white legends. The notable exception was the Y/4R-22L sign at step 5 operation, where the white legend was very bright. The data also show that the light output of these signs stayed within the FAA criteria during step changes in the regulator with, for one example, an output of 15.72 footlamberts at step 2 and 32.38 lamberts at step 5. The Newark and La Guardia International Airports signs typically provided about 15 footlamberts at lower intensity settings and about 30 footlamberts at the upper steps, compared with FAA requirements of 10 footlamberts minimum and 30 footlamberts maximum.

Although the Newark and La Guardia International Airport signs were procured on the basis of ICAO requirements, the actual performance in the field was slightly below the ICAO standards. This is probably due to the deterioration of the lamp performance over time and the deterioration of the series circuit. The series circuit often deteriorates as a result of leakage on the secondary side of the isolation transformer and due to the distortion of the voltage supplied by the regulator.

In general, visual observation of the signs at the other airports indicated that many have dark areas, others have bright spots, and some colors are not true (reds with a distinct yellow shading) affecting the legibility of the sign. These conditions may be seen in the color images taken in the field. Figures 2A through 2C show examples of these conditions.

Although contrast is not an FAA criteria, it is noted that all of the mandatory signs measured met the ICAO requirement for contrast to be between 5:1 and 10:1 for the white legend on the red background.

The photometric performance is related to the electrical power that is supplied to the signs. Low-VA signs were introduced to reduce power consumption and energy costs for sign operation. Some low-VA signs produced satisfactory photometric output, and in several cases, better than some of the high-VA signs. This demonstrates that the low-VA signs can perform acceptably with a lower energy requirement, thus more economy of operation.

Dedicated sign circuits also produce mixed results. All of the circuits at Denver are dedicated. Some signs produced acceptable photometric output while others did not. The Newark International Airport has mixed circuits; that is, signs and lights on the same circuit, while circuits at La Guardia International Airport are all dedicated with only signs on those circuits measured. In both cases, all signs met the FAA photometric output requirements.

The FAA specifications for light output of airfield lighting fixtures are based on step 5 operation and were developed when the standard lamp for high-intensity runway lights was 200 watts. Concurrently, the FAA, in its Order 7110.65, defines the light intensity settings to be used under specific visibility ranges. With newer technology, the lighting fixtures now have lower wattage lamps to reduce the power requirements of the system. Typically, the manufacturer has checked the photometric performance at the highest intensity step only, in accordance with FAA requirements. However, the photometric performance of the new light fixtures has not been tested in terms of visibility at lower steps. It should be noted that the reduction in the sign's luminance (lamp light output) is not linearly proportional to the reduction of the sign's wattage. This may be the reason that the light output of newer technology-type lights at the highest intensity of operation is sufficient and meets FAA standards, but at the lower intensities, the light output produced is below required operational levels. Therefore, the complaint from some users that there is insufficient light output can be understood. This assumption may also be applied to the runway lighting system as well.

6.2 VARIABLE VOLTAGE.

The regulator, in providing a constant-current output according to the step at which it is set, also produces a changing voltage output waveform to meet the power requirements of the connected load. The ideal voltage output waveform approximates a sine wave similar to the voltage input waveform. If the circuit load is close to the rated capacity of the regulator, including consideration of the tap setting, then the voltage output waveform will approach that of the input waveform, unless the circuit load feeds back a condition to the regulator affecting its output. If the regulator output is a true constant current and the voltage waveform approximates a sine wave, then the introduction of signs into an airfield lighting circuit does not significantly affect the performance of the circuit; that is, lights and signs will perform satisfactorily from an electrical standpoint.

Problems occur when the waveforms of input current and voltage to the sign become irregular or consist of short duration pulses. When the pulses are short, flickering of the sign may occur. Short duration pulses increase harmonic output, which in turn increases the circuit load to the regulator. The field tests indicate that reliable sign performance is jeopardized when dead time (see Glossary) exceeds 10 percent of the cycle time. It should be noted that dead time increases as the load on the regulator is reduced below 80 percent of its rated capacity. Power conditioning circuitry presently installed in signs requires a constant power input with short dead time to assure proper operation.

Waveforms of the voltage input and output of constant-current regulators for a wide variety of circuit configurations and conditions were obtained in an attempt to define electrical characteristics which were affected by signs in the circuits. The following are selected waveforms illustrating specific conditions which were encountered.

a. The output voltage waveform of an SCR-type regulator with a constant load which is near the rated capacity of the regulator is presented in figure 3A. The load consists of airfield lights only—no airfield guidance signs. Note the sinusoidal form of the output voltage. This form approaches the ideal voltage output of a constant-current regulator.

b. The output voltage waveform of an SCR-type regulator with a full load, that is, a load near its rated capacity, consisting of style 5 signs is shown in figure 3B.1. These signs present an irregular load to the regulator. Note the approximation to the ideal sine wave. The irregularities in the waveform are caused by the electronics in the signs. Figure 3B.2 is the same waveform as figure 3B.1, with a different horizontal scale, showing a large number of periods or cycles. Note the repeating cycles of changing output voltage as the CCR tries to maintain a controlled constant-current output. These changing voltages cause stress in the regulator, sometimes indicated by noises emanating from the regulator.

c. The output voltage waveform of an overloaded CCR with style 5 signs on the circuit is shown in figure 3C. (This CCR could not reach its full rated output of 6.6 amperes.) The waveform, approximating a sine wave, indicates the full to overload condition. The irregularities are the result of load changes which are caused by the electronic control mechanism within the signs.

d. The output voltage waveform for an overloaded regulator is shown in figure 3D. Note the output voltage changes which are reactions to the changing load caused by the electronic control mechanisms in the signs.

e. The output voltage waveform of an SCR-type regulator with a constant load of less than 50 percent of the rated capacity of the regulator is shown in figure 3E. This form (with long periods of no voltage—horizontal portions of the curve) is distinctly different than that of a fully loaded regulator. The SCR is conducting during the time that the waveform is above or below the horizontal reference axis; it is not conducting during the time that the waveform is running along the horizontal reference line. The time during which the SCR is not conducting is called dead time and is greater than 50 percent of the total time.

f. The output voltage waveform for a lightly loaded regulator controlling a circuit with both airfield lights and signs is presented in figure 3F. Note that the large transient voltage just after the SCR is triggered. Load requirements are changing due to the sign's intensity setting control mechanism.

These figures show the variations in the voltage output of the regulator under various conditions of circuit load. Also shown is the response of the regulator, in terms of its output voltage, to changes in the load due to the sign's internal control systems. These responses to load changes led to a deeper investigation of the relationship between the sign's power requirements and the CCR's control system as it tried to furnish those requirements.

There are some reflected voltages and currents caused by reactive loads within the sign because the sign loads are not purely resistive. It was thought, initially, that these reverse voltages were the cause of sign and regulator problems. However, extensive testing indicates that this is not the case. Although regulator operating conditions would improve if the sign load was resistive, the varying load requirements were found to be causing more problems. To evaluate the effect of the changing load requirements, a single style 3 sign was connected directly to a regulator in the airfield lighting vault. Thus, the regulator was very lightly loaded. Voltage waveforms were obtained at two locations simultaneously: (a) the output of the regulator and (b) the input to one lamp of the sign, that is, on the secondary side of the isolation transformer serving the sign. The following is a description of those waveforms:

a. Figure 4A shows the waveform of the voltage output from the regulator in the upper curve and the voltage waveform of the input to one lamp of the sign in the lower curve. The regulator output voltage waveform is somewhat distorted due to the type of load represented by the sign. Nevertheless, the pulses of voltage output are distinguishable. The lower curve presents pulses which represent the sign control mechanism requesting power. The pulses in both the curves occur about the same time, that is, the pulses are synchronous. The sign and regulator operated satisfactorily from an electrical point of view with no flickering of the sign nor noises from the regulator.

b. Expanded waveforms (to better show the timing conditions between the regulator output voltage, input voltage to the sign, and the input voltage to a lamp in the sign) are shown in figure 4B. Note that the pulses are synchronistic, that is, the sign's request for power occurs at the same time that the CCR is supplying power. The lamp voltage was 6.1 volts root mean square (rms) (measured by a voltmeter) and remained essentially constant during this condition. The pair of curves demonstrates that there is compatibility between the sign and the regulator.

c. In figure 4C the sign control mechanism has been adjusted so that the request of the sign for power leads the regulator's output pulse by a few microseconds. The input to the lamp has changed significantly and the rms voltage applied to the lamp is about 1.6 volts (measured by a voltmeter), much less that the 6.1 volts rms shown in figure 4B. The sign's power curve leading the regulator indicates a degree of incompatibility between the sign and regulator. When the sign's intensity setting control mechanism is adjusted so that the sign's request for power leads the CCR's waveform output by an additional amount, the regulator began to emit abnormal noises and the sign began to flash on and off. This condition is evidence of the incompatibility between the sign and regulator.

d. The expanded waveforms shown in figure 4D are formed when the request for power by the sign's intensity setting control mechanism leads to CCR voltage output pulses. The voltage across the lamp was about 1.1 to 1.4 volts rms (measured by a voltmeter) and the lamp output was low.

These figures show that it is important for the sign's request for power to be satisfied by the regulator in a timely or synchronous manner if the system is to operate correctly.

The variation in voltage experienced by the signs also explains their premature lamp burnout. Field measurements of the voltage and current at the lamp sockets were made for some signs, see table 4 for a summary. This data shows that the voltage regulation for some signs was not maintained at the different intensity settings of the regulator (Salt Lake City and Phoenix airports). Thus, the average photometric output of the signs changed significantly as the regulator step settings changed. At the Phoenix airport, for example, the voltage (up to 37 volts) significantly exceeded the manufacturer's specification for lamp voltage (11-12 volts). This is the reason for the high rate of lamp burnouts. However, at Newark, where the lamps were fluorescent, it appears that the voltage and current were maintained during the step changes of the CCR. This shows good voltage regulation in the sign.

6.3 HARMONICS.

From a harmonics point of view, an airfield lighting system is quite different from commercial or industrial power distribution systems. Figure 5 shows a typical airfield lighting circuit with signs.

The CCR is usually located in an airfield lighting vault close to the power distribution system. The signs are installed at various locations on the airfield and may be as far as 2-3 miles (3.2-

4.8 km) from the CCR. The CCR presents a nonlinear load to the main power source, which generally consists of a single-phase linear supply and a sine waveform. At the same time, the CCR is a nonlinear power source for the nonlinear sign load. Due to the CCR's step settings, the circuit load varies over a wide range. The nonlinear power source output varies in response. For example, a 20 KW CCR may provide only 2-3 KW to the load when it is operated at steps 1 or 2; it may provide a full 20 KW to loads when operating at step 5. As the loads vary, the harmonics, which are a function of the nonlinear loads, also change, both in the load and in the CCR. The linear power source will see the cumulative harmonic effect. In commercial/industrial systems, nonlinear loads, such as variable speed motors, are not connected in series to the linear power source. In addition, the nonlinear loads do not become nonlinear power sources to other loads connected further down the line.

The peaks noted in the waveforms shown in figures 4A through 4D indicate the presence of high orders of harmonics. We know that harmonics are produced by the regulators, particularly when lightly loaded.

At the Salt Lake City airport, for example, the investigation of a single light fixture connected to an SCR regulator indicates that the regulator generates over 100 percent total harmonic distortion (THD) whether for current or voltage. As the circuit load increases toward the regulator's rated capacity, the CCR's harmonics are reduced and the output waveform approaches a sine wave. Thus, it is evident that the SCR type of CCRs is a major contributor of harmonics into airfield circuits.

In general, the new airfield guidance signs have electronic ballasts and an electronic light intensity control mechanism which are both nonlinear load components; thus, these signs induce harmonics into the circuits to which they are connected. The harmonics generated by the signs respond to the waveform provided by the circuit power source, the regulator. Measurements with a VARIAC, a pure sine wave generator powering one of the signs, indicated a very low level of harmonics, both current and voltage, caused by the sign were in a range of less than 3 percent. Because the sine wave input to the sign is maintained regardless of the power requirements, there is a low level of harmonics. However, when the power comes from an underloaded regulator and has a nonsinusoidal waveform, the sign can generate some 25 percent THD current and over 100 percent THD voltage. As the regulator loading approaches rated capacity, the harmonics generated by the signs are reduced significantly when the waveform approaches a sine wave. Thus, there is an impact on the regulator imposed by the harmonics of each sign on the circuit. This impact is cumulative and depends on the response of each sign to circuit conditions.

When the CCR is connected to various circuit configurations, as was done in this study, the data shows that the THD measured at the output of the regulator varies as the load varies (see table 5). When the load applied to the regulator is small with respect to its rated capacity, the THD is large, and when the applied load approaches the rated capacity of the regulator, then the THD is substantially smaller. It is also noted that the configuration of the load has little impact on THD. Loads that consist of signs only do not induce any higher THD than loads which are a mixture of signs and airfield lights. This is due to the nonlinear components of the circuit load. This finding supports the conclusion that the regulator is a source of harmonic distortion as well as the source of power to the circuit. In addition, since the sign is a nonlinear load, it responds to the regulator by generating harmonics, which ultimately increases waveform distortion.

The effect of harmonics on the true power factor can be seen in table 6. When the load does not include nonlinear components and the regulator is loaded to approximately 80 percent of its capacity, the THD measured on the output side of the regulator is 4.5 percent and 12.4 percent for current and voltage THD, respectively, and the true power factor is 0.97. However, when the regulator load does include nonlinear components and it is loaded near its rated capacity, the current and voltage THD measured at the output of the regulator are 107 percent and 128 percent respectively, and the true power factor is 0.82. Several cases of this occurrence can also be seen in table 5.

Harmonics also have an impact on the apparent power kilovolt-ampere (KVA) of the regulator output. The definition of power factor which is equal to the cosine of the displacement between voltage and current is true only where there are sinusoidal currents and voltages. This is not the case with nonlinear loads, such as the airfield guidance signs. The definition of true power factor (see Glossary) must be used for these conditions. As the rms input current is reduced due to harmonics, the KVA required will be reduced, resulting in an improved power factor. Table 6 also shows that an increase in harmonics results in a decrease in the true power factor and the kilovar (KVAR) value as a percentage of KVA is increased.

Table 5 shows that the voltage THD on the input side of the regulator is generally very low (1 to 5 percent) regardless of the characteristics of the circuit loads or the size of the load with respect of regulator capacity. The input current THD, however, is significantly higher (10 to 90 percent) and its magnitude is a function of the characteristics and size of the load. On the output side of the regulator, both the voltage and the current THD vary with the load characteristics and with its percentage of rated capacity of the regulator. This phenomenon is the result of an input to the regulator which is a voltage regulated system; that is, the voltage input to the regulator does not change as the circuit load on the regulator changes. The input current to the regulator, however, does change with the regulator loading. Therefore, the input current THD is effected by changes in the circuit load. On the output side of the regulator, the voltage is not regulated and, thus, varies with the voltage THD generated by the regulator as well as by the connected, nonlinear loads. When the voltage THD rises, the current THD follows.

An example showing high current THD causing a reduction in the power factor and an increase in the apparent power is shown in table 7. The real input power measured to the 30-KW regulator was 20.5 KW, the reactive input power was 24.2 KVAR, and the apparent power was 33.9 KVA. The regulator required 33.9 KVA to generate the 20.5 KW real power necessary to power the connected resistive load. This 33.9 KVA is a consumption of approximately 100 percent of the regulator output capacity at unity power factor in order to produce about 66 percent of its rated capacity. In other words, the high-current THD caused the regulator to operate at its full capacity, or possibly in an overloaded condition, to power loads which consumed 60 percent or less of the rated capacity. Several cases of this occurrence are shown in table 8.

Two circuits with a load of style 5 signs powered by 30-KW regulators were measured with and without a harmonic filter. Local maintenance personnel had inserted a filter into these circuits in an attempt to neutralize the input of harmonics. On one of these circuits, the measured regulator output voltage THD with the filter was 769 percent and without the filter was 177 percent. The filter actually caused an increase in the voltage THD. Apparently, the 60 Hz filter does not perform well in the presence of high orders of harmonics. High orders of harmonics are generated when there are sharp rises or peaks in the voltage waveform. Also on this same circuit, the instantaneous KVA rose to 200 KVA and the regulator output instantaneous voltage approached 40,000 volts (see table 8). This instantaneous voltage can have a significant effect on the primary power cable, including breakdown of cable insulation at any weak points which may exist in the circuit loop. It should be noted that these circuits are about two years old. There is no apparent difference in THD between new circuits (less than 2 years old) and old circuits (3 years old and up).

6.4 POWER FACTOR AND EFFICIENCY.

6.4.1 Power Factor.

FAA Advisory Circular 150/5345-10E, par. 3.3.3, defines the requirements for power factors for constant-current regulators. For those regulators 10 KW or less, the power factor shall be not less than 90 percent; for those regulators larger than 10 KW, the power factor shall be not less than 95 percent. The basis for measuring the power factor is quoted from the AC: "The power factor shall be measured with the regulator operating on the maximum intensity setting, at rated input voltage, and into a rated load with unity power factor."

Regulators are often operated at steps below their maximum intensity setting. Thus, the basis for measuring power factor under the standards quoted above has a limited value in evaluating the overall regulator performance. Unity power factor is a characteristic of resistive loads, such as airfield lights. There are nonpure resistive loads, for example, loads presented by signs or runway guard lights, that are nonlinear but have reactive components. The basis for measuring regulator power factor as quoted above may not be adequate for today's types of circuit loads. Most of the data obtained in this study were for regulators operating at less than maximum setting or step, and it is readily seen from the data that the power factors for these conditions are well below the FAA requirement of 90 or 95 percent.

6.4.2 Efficiency.

The basis for measuring regulator efficiency is the same as that for the measurement of power factor. That is, it is measured at a rated input voltage into a full load that has a unity power factor. Values of efficiency which are required, again depend on the size of the regulator, with a minimum efficiency of 90 percent for regulators less than 30 KW and efficiency requirements rising from 90 percent. From table 7, it can be seen that the apparent output power in one case is 20.0 KVA and the input power was 33.9 KVA, resulting in an efficiency of around 60 percent, well below the 90 percent specified. Even though this regulator was manufactured to FAA standards, it does not maintain its efficiency at loads below its rated capacity.

The Advisory Circular also calls for a rating of output real power (KW) related to input current (amps). Table 7 shows a real input power of 20.5 KW with an apparent input power of 33.9 KVA and an input current of 70.0 amps, close to the full capacity of 73 amps printed on the name plate. Thus, the regulator is operating at 66 percent of its capacity (based on name plate capacity of 30 KW and measured output power of 19 KW) and consumes 97 percent of its input current capacity. This is the result of harmonics and reactive loads in the circuit. There is no assurance that the regulator will not experience overload conditions even when the real power consumption is within the rated load.

6.5 RUNWAY GUARD LIGHTS AND POWER-LINE CONTROL SIGNALS.

6.5.1 Runway Guard Lights.

In general, the runway guard lights were operated on step 1 of a 3-step intensity control system. It was observed that some of the runway guard lights did not deliver sufficient light output, especially during daytime operation, when operating on step 1.

The runway guard light consists of lamps which follow a pattern of turning on and off. Tests performed on the circuits that had operational runway guard lights indicated that the runway guard light system is a varying load to the regulator. The no-load or open-circuit condition that occurs when one of the lamps is off causes a significant distortion in the regulator output voltage waveform. Figure 6 shows the effect the runway guard light system has on the voltage output waveform.

6.5.2 Power-Line Control Signal.

During field investigations, it was found that the stop bar installations and some of the taxiway centerline lights were controlled by the power-line control signal. In order to investigate the problems with these installations, power-line control signals must also be investigated. The purpose of this part of the evaluation was to determine whether the lights, installed and controlled (each light was controlled individually) by the power-line control signal system, produce satisfactory light output.

6.5.2.1 Stop Bar Installations.

It should first be noted, that at the time of this publication, there are no FAA specifications or standards for stop bar installations relating to photometric output, type of fixture, and installation details. However, a new Advisory Circular is being developed with intensity levels as follows: 1000 candela for yellow lights and 500 candela for red lights.

The lights used for the stop bar consist of a mix of two types of lamps; modified FAA type L-852A (made by ADB Alnaco) and modified FAA type L-850B (made by Crouse-Hinds [named L-850 BS]). These light fixtures were tested when the constant-current regulator was powered to its highest setting, 6.6 amps at step 5.

The photometric output of the fixtures shown in table 2C indicate an average of about 415 candela for the amber lights and 287 candela for the red lights, respectively. This is well below the FAA desired level. However, since standards have not yet been established, manufacturers have not produced stop bars to comply with any standards. Therefore, the low light output of the stop bars can be attributed to the type of fixtures used rather than to the impact of power-line control signals on the light fixture itself. Photometric tests were also performed on the same fixtures when the regulator was powered to 4.1 amps at step 3. These test results, however, are not presented since they are below the minimum value that the test equipment could measure.

In general, these test results support the visual inspection and affirm that the stop bars do have low light output intensity.

6.5.2.2 Taxiway Centerline Lights Controlled by Power-Line Signal.

A sample of the green taxiway centerline lights (from SEA-TAC), which are controlled by the power-line control signal system, was also tested. These lights consist of a mix of two lamps; FAA type L-852C specified for CAT III operation, and FAA type L-852A specified for other than CAT III operation.

The testing was performed when the regulator was powered to its highest setting, 6.6 amps at step 5. The photometric output of these light fixtures is shown in table 2C. The higher results (600 cd and above) are measured for the L-852C fixtures and the lower results (126 cd and below) are for the L-852A fixtures. It is important to note that the test results for L-852C light fixtures are significantly higher than FAA standards. Some L-852C type fixtures had output levels that measured 1000 candela and above. These lights appeared to be very bright and (based on information given by airport personnel) can produce glare for the pilots, especially in fog. The reason for this brightness is not known.

6.5.2.3 Taxiway Centerline Lights used for SMGCS Routing.

In order to better investigate the impact of power-line control signals on the light fixtures, it was necessary to take some measurements on light fixtures that were not controlled by power-line control signals. The taxiway center lights used for the SMGCS routing (at the Denver airport) are not controlled by the power-line control signal system. They are not controlled individually but as a group of lights.

The lights installed are FAA type L-852C. The photometric testing was performed on a sample of light fixtures. These tests were taken when the regulator was powered to its highest step, 6.6 amps at step 5. The test results shown in table 2B indicate that the lights produced sufficient light output.

From the preliminary observations discussed, it appears that the airport staff has experienced difficulties in bringing the power-line control signal systems to proper operation. These preliminary observations give rise to several major issues:

- The effectiveness of power-line control signal on the primary cable of a series circuit.
- The effect of the 100-300 kHz power-line control signal on the cable insulation.
- The impact of low- and high-resistance shorts between ground and cable insulation.
- The impact of high-order harmonics present in the circuit on the power-line control signal.
- The impact of the power-line control signal on the photometric output of the light fixture.

7. CONCLUSIONS.

7.1 MAJOR CONCLUSIONS.

The source of sign failure is the incompatibility between the sign and the regulator. The pulsed output of the SCR regulator must be synchronized with the pulsed demand of the sign intensity setting control mechanism for compatibility. Lack of synchronization will lead to regulator or sign malfunction or failure. Compatibility can be measured by computing the time difference (from the waveform) between the pulsed output of the regulator and the pulsed demand of the sign's intensity setting control mechanism. Complete synchronism is achieved when the time difference between those two pulses is zero. However, it is important to note that in practice (in the field) it will be very difficult to achieve perfect synchronization.

Style 5 signs exhibit incompatibility since the voltage regulation mechanism operates on a narrower range of voltage regulation than sign style 2 or 3. Some sign manufacturers equipped their signs with a field voltage regulation adjustment mechanism. Those signs may better tolerate the incompatibility. However, it was observed that the field adjustment procedure was complicated and was based on trial and error rather than on certain methodology.

It can be shown that when the dead time of the regulator output waveform is not more than 10 percent of the cycle, sufficient compatibility is achieved to assure proper operation of the regulator and the sign. Once again, the dead time is defined as the time which the SCR is not conducting within one complete cycle. In general, dead time of less than 10 percent can be achieved if the regulator is loaded to 80 percent or more of its capacity throughout the range of intensity settings.

The photometric output of the sign is affected by the electrical characteristics and performance of the sign. In particular, the light output is a function of the shape of the CCR output voltage waveform. The more distortion or spikes that exist in the waveform the less the photometric output of the sign. Furthermore, when the regulator operates significantly below its full rated capacity, the photometric output of the sign generally decreases significantly.

The harmonics on an airfield lighting circuit are a function of both the harmonics induced by the regulator and the harmonics induced by distorting loads. The effects of the harmonics from sign control circuitry are reduced as the total circuit load on the CCR approaches the rated load of the CCR. Current and voltage THD at the output of the CCR should be maintained below 10 percent. The data shows that this level of harmonics is achievable if the regulator can be loaded to about 80 percent of its rated capacity.

It is demonstrated at the Newark and La Guardia airports that satisfactory photometric performance can be achieved with the low-VA signs. It is not necessary to have high VA-rated global signs to produce the required levels of photometric output. Reducing the VA consumption may allow the use of smaller sizes of regulators and other circuit elements and will reduce energy consumption.

Many signs have dark and/or bright areas. This may indicate that the diffusers in the signs are not adequate or that the number of lamps in the signs is not sufficient. It was observed that to achieve good visibility of the signs it was necessary to achieve high uniformity and correct contrast between background and legend.

7.2 OTHER CONCLUSIONS.

Automatic taps on CCRs do not perform well at the lower operating steps. In addition, automatic taps can generate large output overvoltages in the event of a short to ground, to such an extent that it could damage the primary cable.

The basis for measuring the regulator power factor as presented in the FAA Advisory Circular may not be adequate for today's types of circuit loads. Most of the data obtained in this study were for regulators operating at less than maximum setting or step; it is readily seen from the data that the power factor for these conditions is well below the FAA requirement of 90 or 95 percent and that the efficiency, at these intermediate steps, is also below FAA standards.

A decrease in the harmonics of the regulator output will help improve the power factor of the circuit, and as a result, the power factor for the regulator input also improves.

The data does not provide any indication that the current or voltage THD induced in circuits is any higher for circuits with newer components (the current generation of airfield signs) than for circuits with older components (transformers, cables, lights). Tests to measure the impact of THD on primary series cables are not within the scope of this study. However, it has been established that the flow of nonsinusoidal current in a conductor will result in additional heating of the conductor. This skin effect or proximity effect varies as a function of frequency as well as the size and spacing of conductors.

It appears that there is no specific benefit, with respect to photometric or electrical performance, in installing dedicated circuits for signs. On the contrary, mixed circuits, circuits consisting of light fixtures and signs, improve the photometric and electrical performance of the circuit. In particular, mixed loads will decrease harmonics in the circuit and improve the power factor.

7.2.1 Runway Guard Light Performance.

The regulator has difficulties operating the runway guard lights. However, because in most cases the regulators are oversized, operating difficulties do not include regulator failure or malfunction. Review of the magnitude of the total harmonic distortion present in circuit and regulator output waveform suggests that the regulators are affected by circuit changes that occur on the secondary side of the isolation transformer. In particular, during the switching time between one light to the other; that is, the time between one light turning on and another turning off.

The runway guard light circuits should be improved to eliminate the condition where open circuit conditions are presented to the isolation transformer serving the runway guard light units. This would significantly improve the runway guard light unit's compatibility with existing regulator circuits.

7.2.2 Power-Line Control Signal.

At several airports, frequent failure of power-line control signal system components have been reported. If power-line control signal systems are to be installed as configured presently, several areas need to be investigated and design criteria need to be developed to assure proper operation of the system. These include the following:

- The effect of power-line control signal operating frequency on the primary cable of the airfield lighting systems in terms of conductivity and resistance.
- The impact on the power-line control signal system of shorts to ground in the primary cable as well as power cable conditions and age.
- The effect of high-order harmonics on power-line control signal systems.
- The presence of crosstalk or other interference with adjacent circuits or other communications systems.
- The need, if any, to establish routing criteria for power-line control signals.
- The need to research the effect of power-line control signals on the photometric output of light fixtures.

7.2.3 Stop Bars.

The stop bars tested were on circuits with a power-carrier control signal system. Specific conclusions cannot be reached as to performance of stop bars since

- there is no FAA standard for stop bar performance. (In any event, the ones tested do seem to produce a photometric output well below the levels apparently desired by the FAA.)
- there is no FAA standard for power-line control signal systems.
- it was not possible to compare stop bar performance on circuits with and without power-line control signal systems.

8. RECOMMENDATIONS.

8.1 BASIS FOR RECOMMENDATIONS.

The testing and evaluation detailed in previous sections of this report identified some deficiencies in the photometric performance of signs and various problems in the electrical operation of airfield circuits with signs connected. The source of the electrical problems and, thus, some of the deficiencies in photometric performance are due to incompatibility between the signs and the CCRs. Contributing to this incompatibility are the harmonics which are present in the signs, as well as the regulators, in normal operations. To solve this problem of incompatibility, it is necessary to provide improvements to either the sign or the regulator; it is not necessary to modify both items. However, the approach taken in this study leads to recommendations for improvements to both the signs and the regulators; this will provide a more comprehensive solution to the major problems which were encountered. This comprehensive approach will also assure that the regulator will better withstand the future introduction of new loads. These new loads will not only include resistive loads but reactive loads and variable loads (e.g., flashing lights) as well.

This comprehensive approach is supported by the guidance offered in the Institute of Electrical and Electronic Engineers (IEEE) Standard 519-1992, Recommended Practice and Requirements for Harmonics Control in Electrical Power Systems. In Chapter 10, the following quote addresses the situation:

> It would be ideal if it were possible to control harmonics to such an extent that harmonic effects caused by connections of harmonic-producing loads were nil at every point in the entire system encompassing the consumer's own circuit.

It is recognized that some problems are more severe than others; for example, the frequent failure of lamps in the signs is far more serious than poor operational efficiency of the CCR. Recommendations are presented for improving existing signs, regulators, and systems currently in operation as well as for revising Advisory Circulars and specifications for future procurements.

8.2. COMPATIBILITY OF SIGNS AND REGULATORS.

To assure the compatibility of the signs with each type of L-828 and L-829 regulator certified under the FAA Airport Lighting Equipment Certification Program it is recommended that the output control mechanism of the sign be designed to provide a constant output, that is, constant power that will keep the photometric output within the FAA specified limits while being powered with an input which may have an irregular shape with short duration pulses or long dead times between pulses. Constant output is defined as output which remains unchanged in amplitude and waveform, within specified limits, during changes in input voltage and waveforms. Changes in output are determined by deviations from the standard sine waveform and peak amplitudes required to produce the rms average output voltage. Specified limits for CCR output waveform distortion and amplitude should be ±5%.

8.3 HARMONICS EFFECTS ON COMPATIBILITY AND PHOTOMETRIC PERFORMANCE.

8.3.1 Harmonics.

To minimize the effects of harmonics and the nonlinear characteristics of the CCR and to improve the photometric performance of the signs, as well as improve the compatibility of the signs and regulators, it is recommended that criteria be established to limit the dead time exhibited in the output waveforms at all ranges of connected load. Subject to further investigation, it is suggested that the dead time not exceed 10 percent.

It is recommended that the harmonics of the 3-phase power system serving the airfield lighting vault upstream from the regulators be investigated to ascertain what, if any, influence the harmonics may have on the electrical power distribution system.

Subject to further study to validate the suggested limits, it is recommended that the THD for current and voltage of the regulator output be limited to 10 percent for all loads and the current THD for the input to 5 percent. It is recommended that periodic testing be performed to assure that harmonics remain within the limits which may be specified.

8.3.2 Tap Setting.

A practical solution for improving the harmonics problem is the addition of a tap setting mechanism in the regulator. Two methods are suggested for consideration.

a. Automatic tap setting, but it must be further investigated to assure proper operation, particularly at lower tap settings and low levels of connected load. It is also recommended that, when automatic taps are used, means be provided to prevent over-voltages in the event of shorts to ground.

b. Include tap setting in conjunction with changes in the regulator output step setting to accommodate the change in connected load.

8.4 PHOTOMETRICS.

In addition to providing for the electrical compatibility of signs with regulators, it is necessary that their photometric performance, which depends on the electrical characteristics of the sign and its power source, comply with FAA requirements. To better define the photometric performance parameters of the signs, it is recommended that the FAA standards be revised to include:

a. A minimum luminance requirement for red background on mandatory signs (suggested range of 2 to 6 footlamberts).

b. A contrast requirement for mandatory signs (suggested ratio of average luminance of white legend to red background between 5:1 and 10:1).

c. A requirement for an overall limit of maximum to minimum luminance values to provide better uniformity of light output (suggested 5:1).

d. A 10 percent increase in the recommended photometric levels for newly installed signs to accommodate losses and a maximum level of deterioration in the photometric output over the expected life of the lamps.

e. Field test procedures to measure the photometric output of the signs periodically.

It is also recommended that further investigation be undertaken to determine how to establish criteria for color, i.e., true red, yellow, etc. It is believed to be necessary to establish such limits to assure proper recognition of sign type by pilots under all operating conditions.

8.5 SPECIFIC PERFORMANCE PARAMETERS.

8.5.1 Service Life for Lamps.

It is recommended that the FAA establish a minimum service life for the lamps in the signs when operating at the highest intensity setting.

8.5.2 Power Factor for Signs.

It is recommended that a minimum power factor of 0.85 be specified for the signs for all intensity settings of sign operation, not just the maximum intensity setting.

8.5.3 Volt Ampere Rating of Signs.

To avoid increasing the sizes or rated capacities of elements of the power distribution system and/or the regulator, it is recommended that the VA consumption of the signs be limited as follows:

• Module sign (3-4 ft. in length)	150 VA
• Module sign (5-7 ft. in length)	250 VA
• Module sign (8-12 ft. in length)	300 VA
• Module sign (13-14 ft. in length)	400 VA

VA shall be measured at the input to the isolation transformer to which the sign is connected.

8.5.4 Reliability of Signs.

To avoid early or frequent failures of the sign's electrical control system and its lamps, it is recommended that criteria be established for a mean time between failure (MTBF) for

- lamps in the signs and
- sign intensity setting control mechanisms.

8.5.5 Maintainability of Signs.

To avoid long periods of sign outages, it is recommended that criteria be established for

- mean time to repair (MTTR) lamps and
- mean time to repair/replace of sign intensity setting control mechanisms.

To assist the industry in defining these criteria, it is recommended that the FAA provide models to enable the manufacturer to generate the data necessary to establish the actual values.

8.6 POWER FACTOR AND EFFICIENCY OF REGULATORS.

It is recommended that the FAA specifications for regulators include a requirement for power factor and efficiency at each step setting of the regulator when the regulator is operating between 50 and 100 percent of its rated capacity. Subject to further investigation, the following limits are suggested:

Regulator - Step	Power Factor	Efficiency
3-step regulator, step 1	0.85	0.85
3-step regulator, steps 2 and 3	FAA standard	FAA standard
5-step regulator, steps 1 and 2	0.85	0.85
5-step regulator, steps 3 and 4	0.90	0.90
5-step regulator, step 5	FAA standard	FAA standard

8.7 REGULATOR INPUT RATING.

It is recommended that the regulator manufacturer be required to include the KVA input at full load in the name plate data.

8.8 RUNWAY GUARD LIGHTS.

Subject to further study, it is recommended that the control circuitry which turns off the runway guard light lamps be created by shorting the isolation transformer. Shorting the isolation transformer causes significantly less change in total harmonic distortion and voltage output variations. Laboratory and field tests of a similar types of control circuitry have been developed for a different research project and was successfully demonstrated to FAA headquarters' personnel.

8.9 NEW ADVISORY CIRCULAR FOR AIRFIELD LIGHTING CIRCUITS.

It is recommended that a new Advisory Circular be developed to establish standards of performance for airfield lighting circuits as a whole. This approach should assure the proper integration and compatibility of all elements of the airfield lighting circuit including lights, signs, stop bars, runway guard lights, power-line control signal systems, and regulators. Among the items which should be included are

- Definition of resistive load.
- Definition of reactive load.
- Definition of circuit power factor.
- Limits on voltage and current THD.

8.10 SUGGESTED REVISIONS TO FAA ADVISORY CIRCULARS.

8.10.1 Advisory Circular 150/5345-44F.

Add the following items under Par. 4.1:

Power Factor. The power factor of the sign shall be not less than 0.85 at all intensity settings.

VA Rating. The VA rating of signs measured at the input to the isolation transformer shall not be greater than:

Module sign (3-4 ft. in length)	150 VA
Module sign (5-7 ft. in length)	250 VA
Module sign (8-12 ft. in length)	300 VA
Module sign (13-14 ft. in length)	400 VA

Add the following to Par. 4.1.4.1:

- The backgrounds of Type L-858R signs shall have an average luminance of 2 to 6 footlamberts.

Add the following under Par. 4.8.4.4:

- Measurements shall be made with the sign connected to an L-828 SCR-type constant-current regulator with a total load of no more than 25 percent of its rated capacity.

- The ratio of the maximum measurement to the minimum measurement shall not exceed 5:1. For mandatory signs, the ratio of the average luminances of the white legend and the red background of the sign shall not be less than 5:1 nor greater than 10:1.

8.10.2 Advisory Circular 150/5345-10E.

Add the following under Par. 3.3.2:

In addition, the efficiency of the regulator, when operating between 50 and 100 percent of its rated load, shall not be less than the following values at the indicated steps:

Regulator - Step	Efficiency
3-step regulator, step 1	0.85
3-step regulator, steps 2 and 3	As in table 2
5-step regulator, steps 1 and 2	0.85
5-step regulator, steps 3 and 4	0.90
5-step regulator, step 5	As in table 2

Add the following to Par. 3.3.3:

- In addition, the power factor of the regulator, when operating between 50 and 100 percent of its rated load, shall not be less than the following values at the indicated steps:

Regulator - Step	Power Factor
3-step regulator, step 1	0.85
3-step regulator, steps 2 and 3	As above
5-step regulator, steps 1 and 2	0.85
5-step regulator, steps 3 and 4	0.90
5-step regulator, step 5	As above

Add the following item under Par. 3.4.13:

- KVA Input at Full Load ____________

Add the following under Par. 4.2:

Any dead time (time during which the regulator is not conducting) in the output waveforms shall not exceed 10 percent of the cycle time.

9. GLOSSARY OF TERMS.

Constant output. Defined as output which remains unchanged in amplitude and waveform, within specified limits, during changes in input voltage and/or waveforms.

Dead time. The time which the regulator is not conducting within one complete cycle.

Harmonic. A sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental frequency. Note, for example, component frequency which is twice the fundamental frequency is called a second harmonic.

Harmonic characteristics. Those harmonics that are produced by semiconductor converter (switching) equipment in the course of normal operations.

High power-factor signs. Signs which have a power factor of no less than 0.85 at each intensity setting of operation. Low power-factor signs are defined as signs which have a power factor of less than 0.85.

Low-VA signs. Name provided by the sign manufacturers to distinguish between signs which consume low apparent power versus signs that consume high apparent power. The value for low VA varies between sign manufacturers. In this report it is assumed that the upper value for low-VA signs is 300 VA per sign. High-VA signs are defined as any value above 300 VA.

Nonlinear Load. A load that draws a nonsinusoidal current wave when supplied by a sinusoidal voltage source. For the purposes of this report, nonlinear load and distorting load are synonymous.

Taps. Regulators have taps for adjustment to accommodate the actual loads being served by the equipment.

rms. Root mean square.

Total Harmonic Voltage or Current Distortion (THD). The THD is used to define the effect of harmonics on the power system voltage or current. It is used in low-, medium-, and high-voltage systems. It is expressed as a percent of the fundamental and is defined as

THD voltage (current) = A/B

where A = sum of all squares of amplitude of harmonic voltages (currents) ^.5
B = square of the amplitude of the fundamental voltage (currents) ^.5

True power factor. The ratio of the total power input (to the regulator or to the load) in watts to the total apparent power (volt-ampere) input to the regulator or to the load. The following notes apply to this definition:

1. This definition includes the effect of harmonic components of current and voltage distortion on power factor as well as the effect of the phase displacements between current and voltage.

2. The power factor is measured in this project at the AC line terminals in three places. The input to the regulator, the output from the regulator, and at the input to the signs.

Style 2. Powered from a series lighting circuit (4.8 to 6.6 amperes).

Style 3. Powered from a series lighting circuit (2.8 to 6.6 amperes or 8.5 to 20 amperes).

Style 5. Powered from a series lighting circuit (5.5 amperes).

Volt-ampere (VA). The unit given to the apparent power. The apparent power is defined as the product of rms voltage and rms current.

Volt-ampere reactive (VAR). The reactive (imaginary) component of the apparent power.

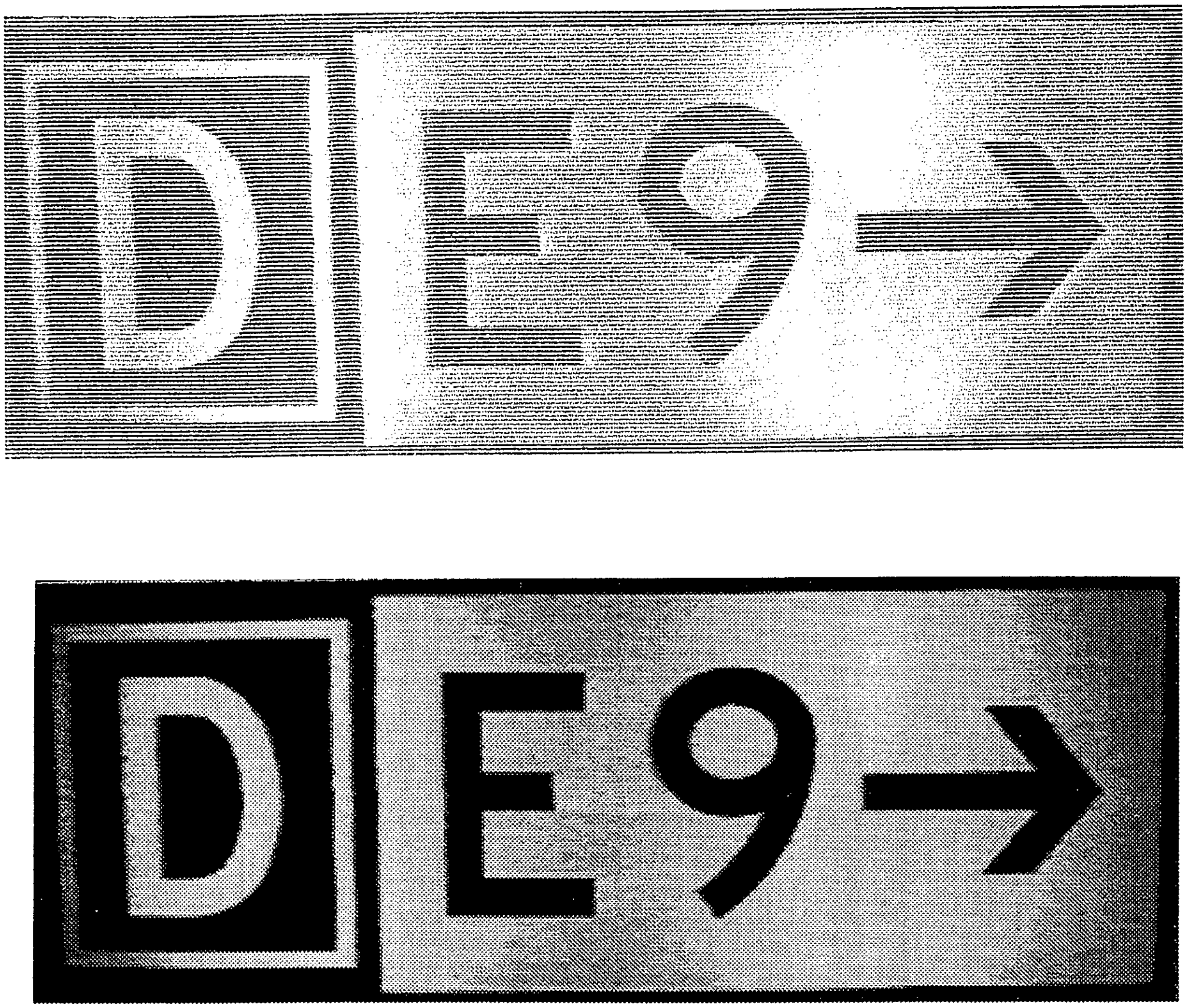
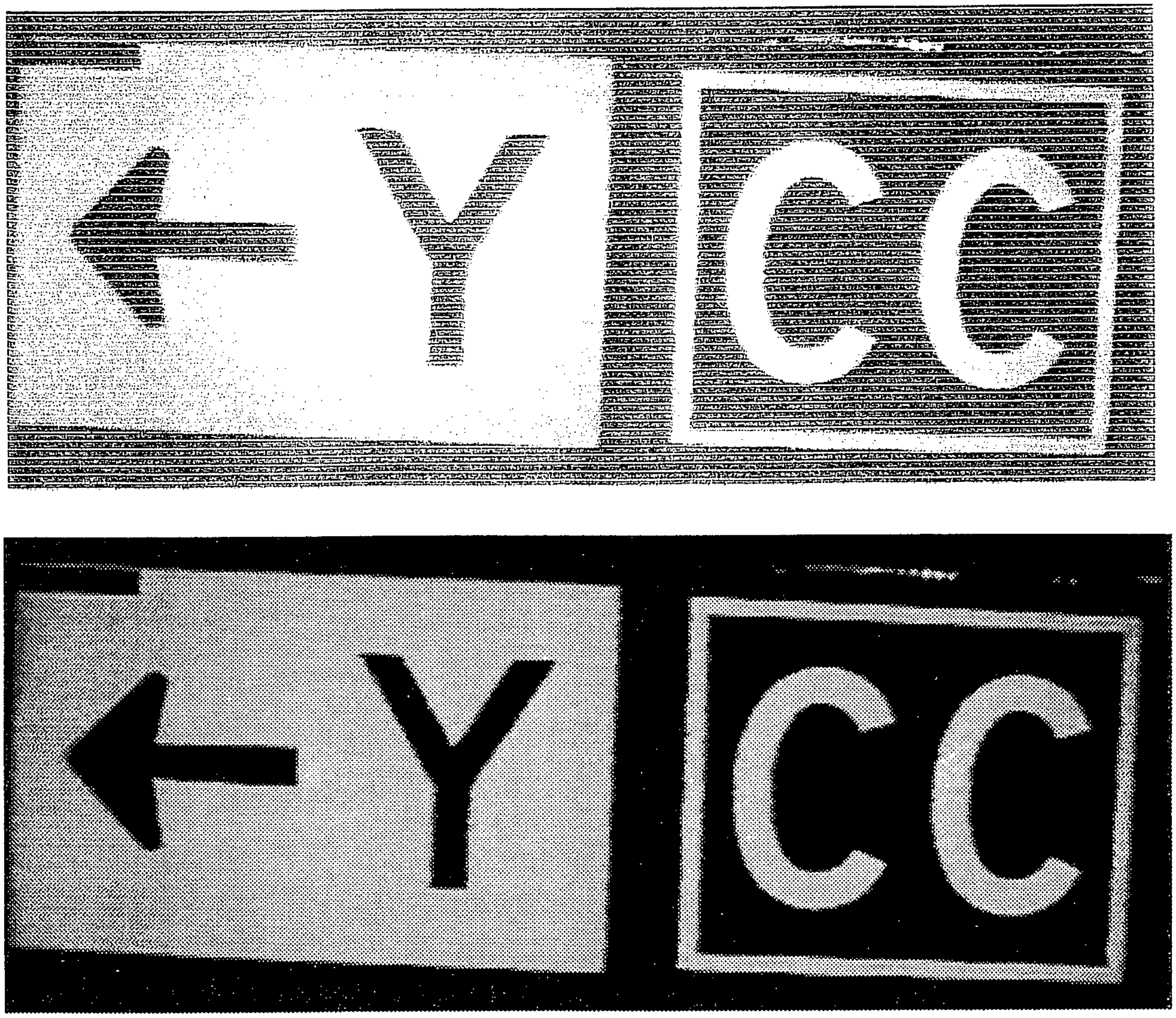


FIGURE 1A. COLOR AND GRAY-SCALE IMAGE OF AN AIRFIELD SIGN AT SKY HARBOR INTERNATIONAL AIRPORT, PHOENIX

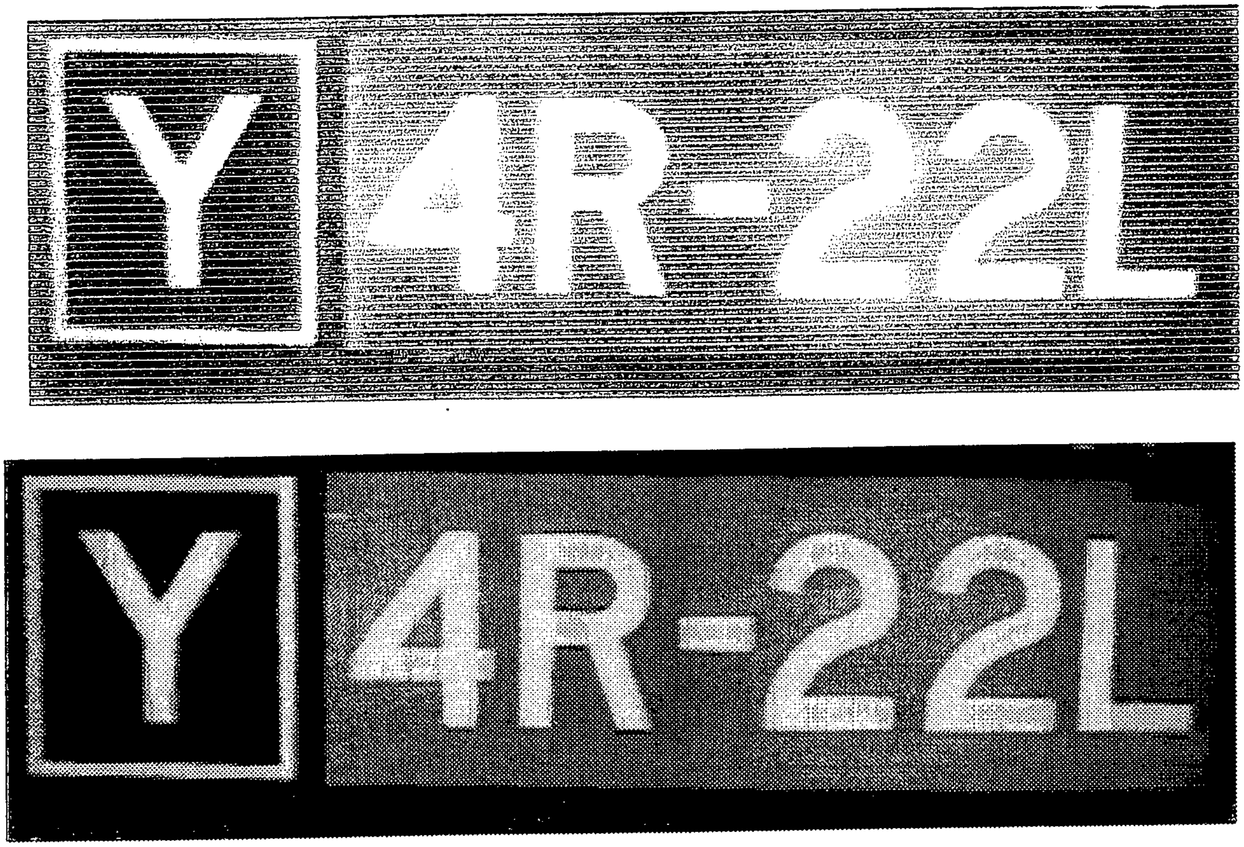
PHOTOMETRIC MEASUREMENTS OF AIRFIELD SIGN
NEWARK INTERNATIONAL AIRPORT, NEW JERSEY



		Photometric Output in Footlamberts		
Step	Color	Average	Maximum	Minimum
Step 5	Yellow	16.52	19.36	9.70

FIGURE 1B. AN AIRFIELD SIGN WITH GOOD PHOTOMETRIC PERFORMANCE

PHOTOMETRIC MEASUREMENTS OF AIRFIELD SIGN
NEWARK INTERNATIONAL AIRPORT, NEW JERSEY

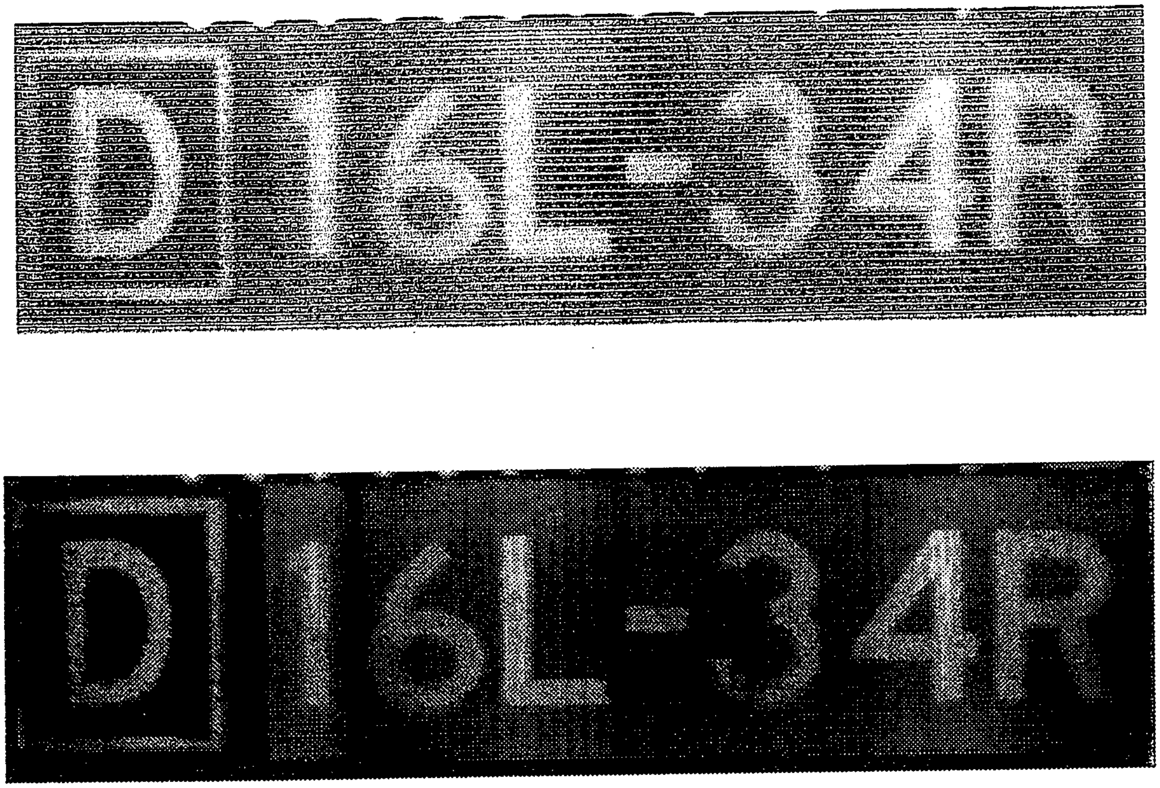


		Photometric Output in Footlamberts		
Step	Color	Average	Maximum	Minimum
Steps 5, 3, 2	Yellow	32.38, 20.97, 15.72	34.04, 22.05, 16.53	30.65, 19.85, 14.88
Steps 5, 3, 2	White	58.25, 34.72, 21.03	60.60, 36.13, 21.88	53.92, 32.14, 19.47
Steps 5, 3, 2	Red	6.13, 3.39, 2.53	8.27, 4.58, 3.41	3.27, 1.81, 1.35

Step 5: White/Red contrast value = 9.50, (based on ICAO method)

FIGURE 1C. AN AIRFIELD SIGN WITH GOOD PHOTOMETRIC PERFORMANCE

PHOTOMETRIC MEASUREMENTS OF AIRFIELD SIGN
SEA-TAC INTERNATIONAL AIRPORT, SEATTLE

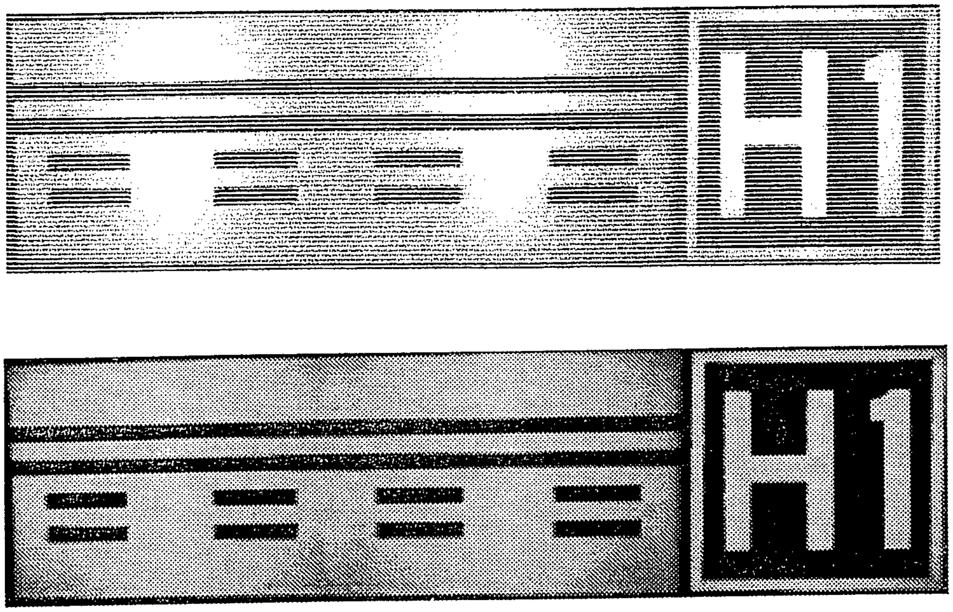


		Photometric Output in Footlamberts		
Step	Color	Average	Maximum	Minimum
Steps 3 and 4	Yellow	3.65	4.52	3.01
Steps 3 and 4	Black	0.00	0.00	0.00
Steps 3 and 4	White	3.17	4.89	2.20
Steps 3 and 4	Red	0.54	0.98	0.26

Step 4: White/Red contrast value = 5.87, (based on ICAO method)

FIGURE 2A. VISUAL OBSERVATION OF SIGN'S DARK SPOTS

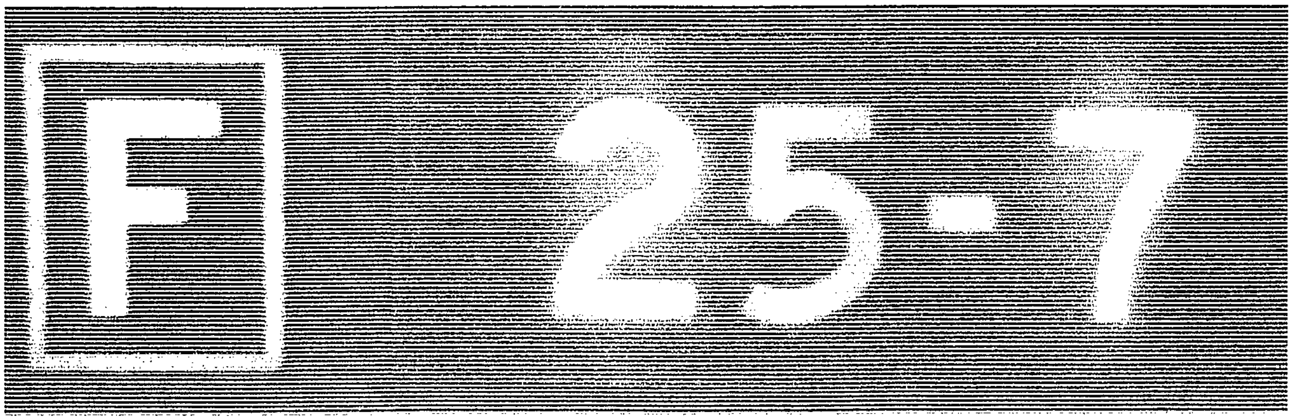
PHOTOMETRIC MEASUREMENTS OF AIRFIELD SIGN
SALT LAKE CITY INTERNATIONAL AIRPORT

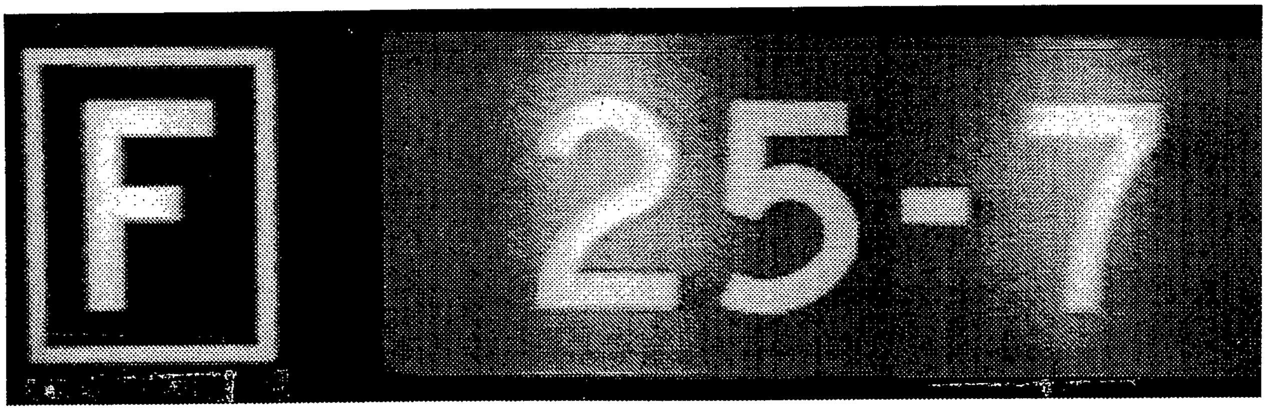


		Photometric Output in Footlamberts		
Step	Color	Average	Maximum	Minimum
One Step	Yellow	12.76	35.30	4.60

FIGURE 2B. VISUAL OBSERVATION OF SIGN'S BRIGHT SPOTS

PHOTOMETRIC MEASUREMENTS OF AIRFIELD SIGN
DENVER INTERNATIONAL AIRPORT





		Photometric Output in Footlamberts		
Step	Color	Average	Maximum	Minimum
One Step	Yellow	22.99	23.76	21.80
One Step	Black	0.00	0.00	0.00
One Step	White	15.07	16.53	11.60
One Step	Red	2.56	4.04	0.97

White/Red contrast value = 5.89, (based on ICAO method)

FIGURE 2C. VISUAL OBSERVATION OF SIGN'S RED WITH YELLOW SHADING

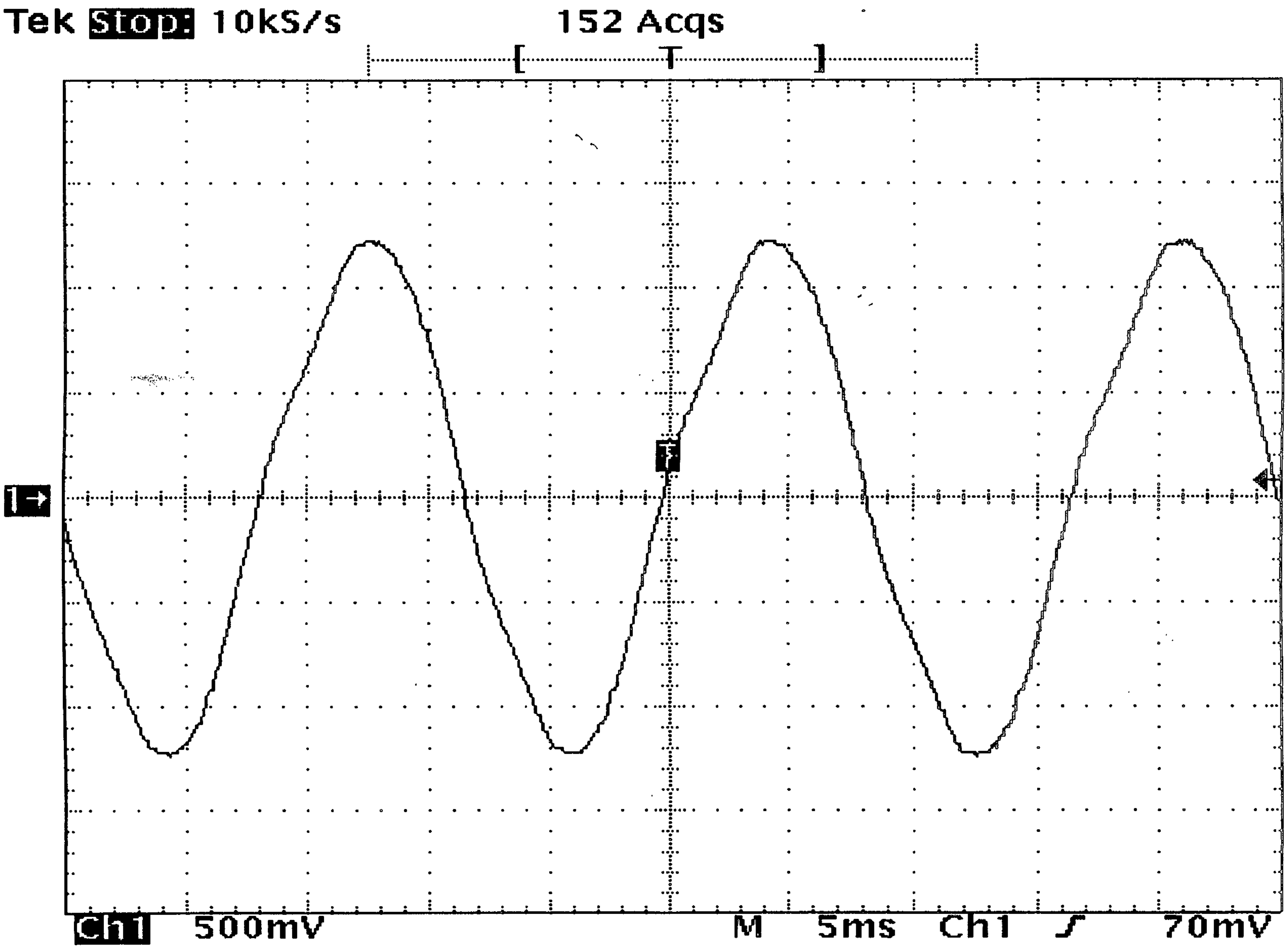
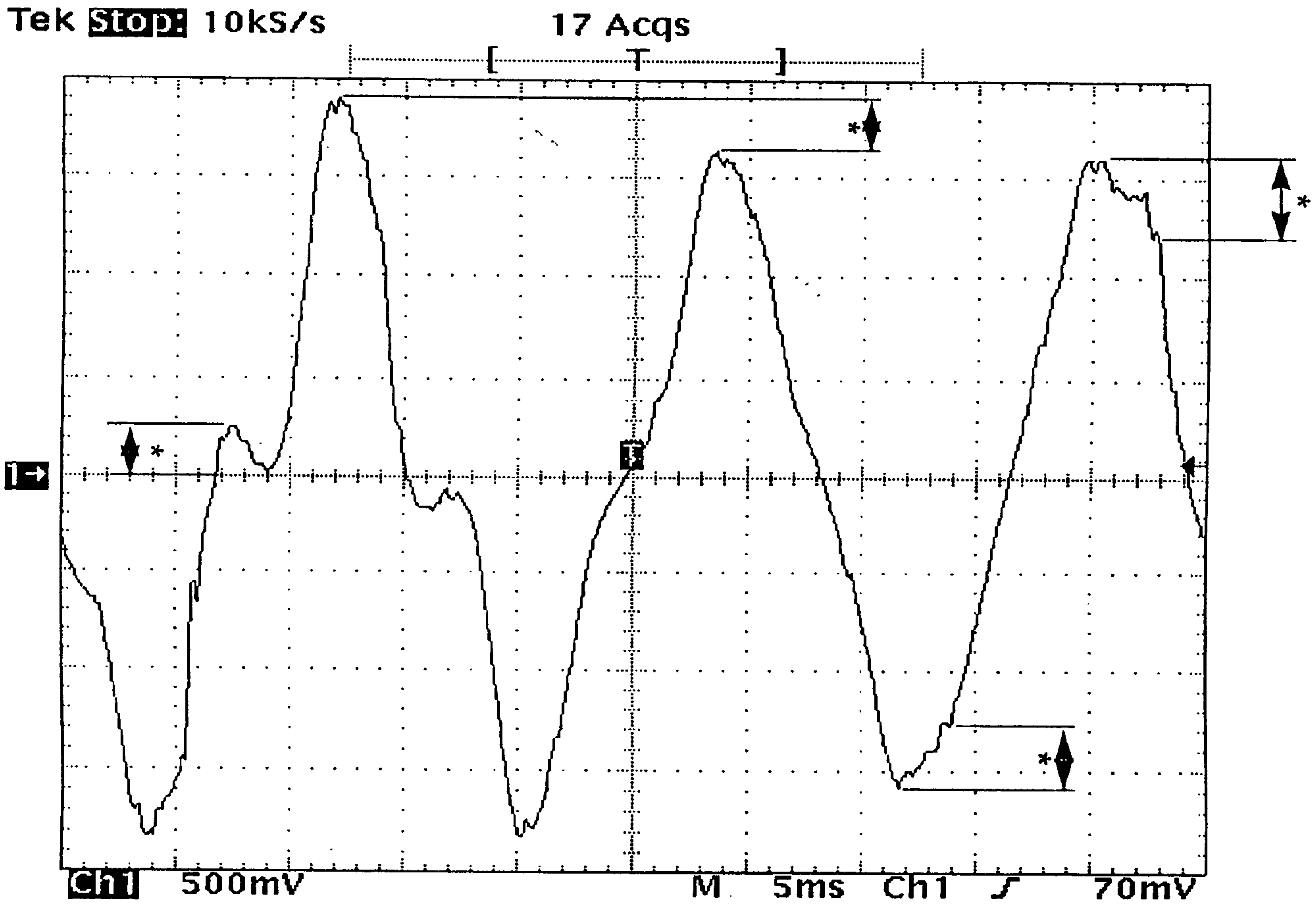
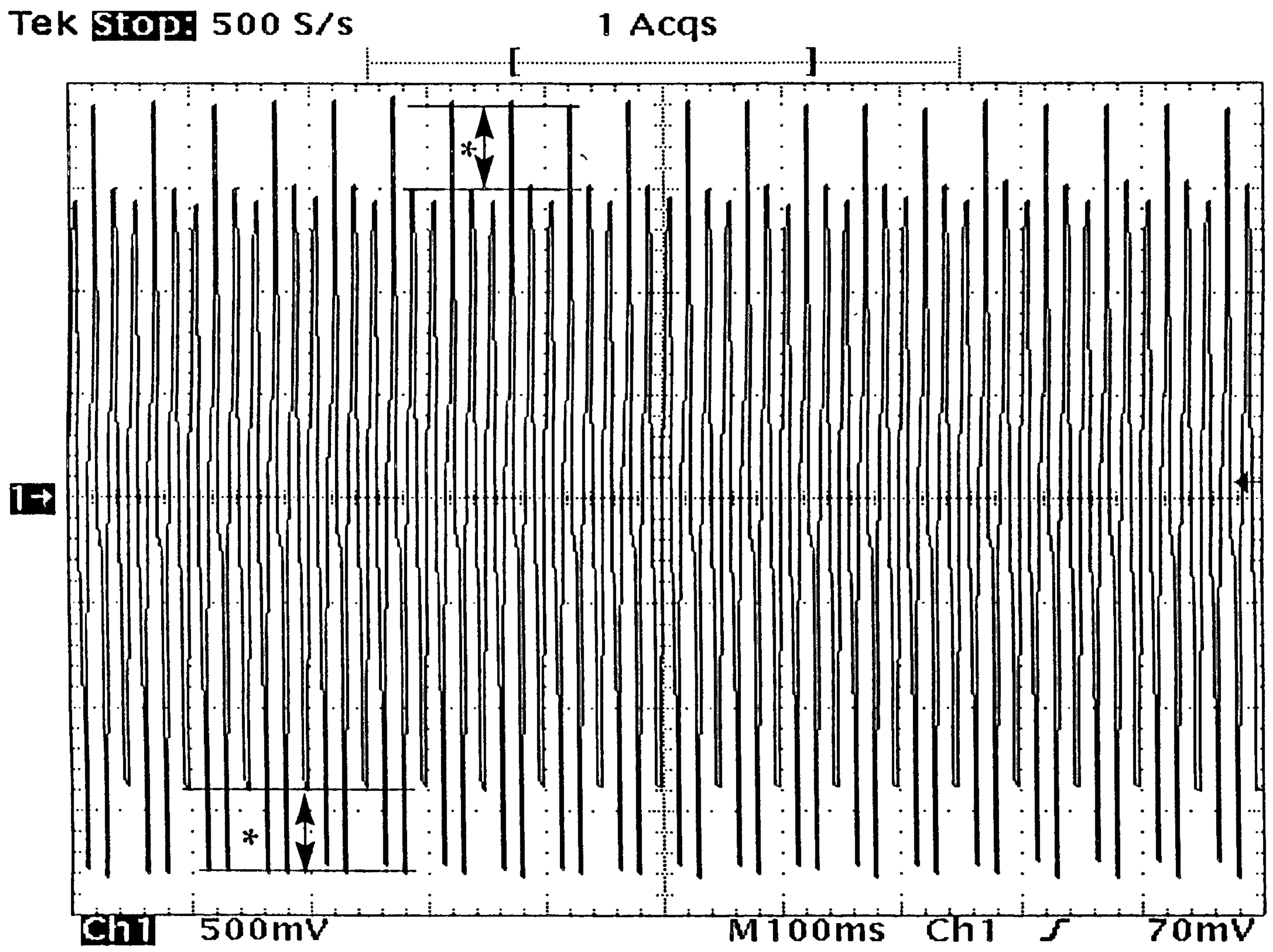


FIGURE 3A. OUTPUT VOLTAGE WAVEFORM CCR 2, C-H FIXTURES, STEP 5



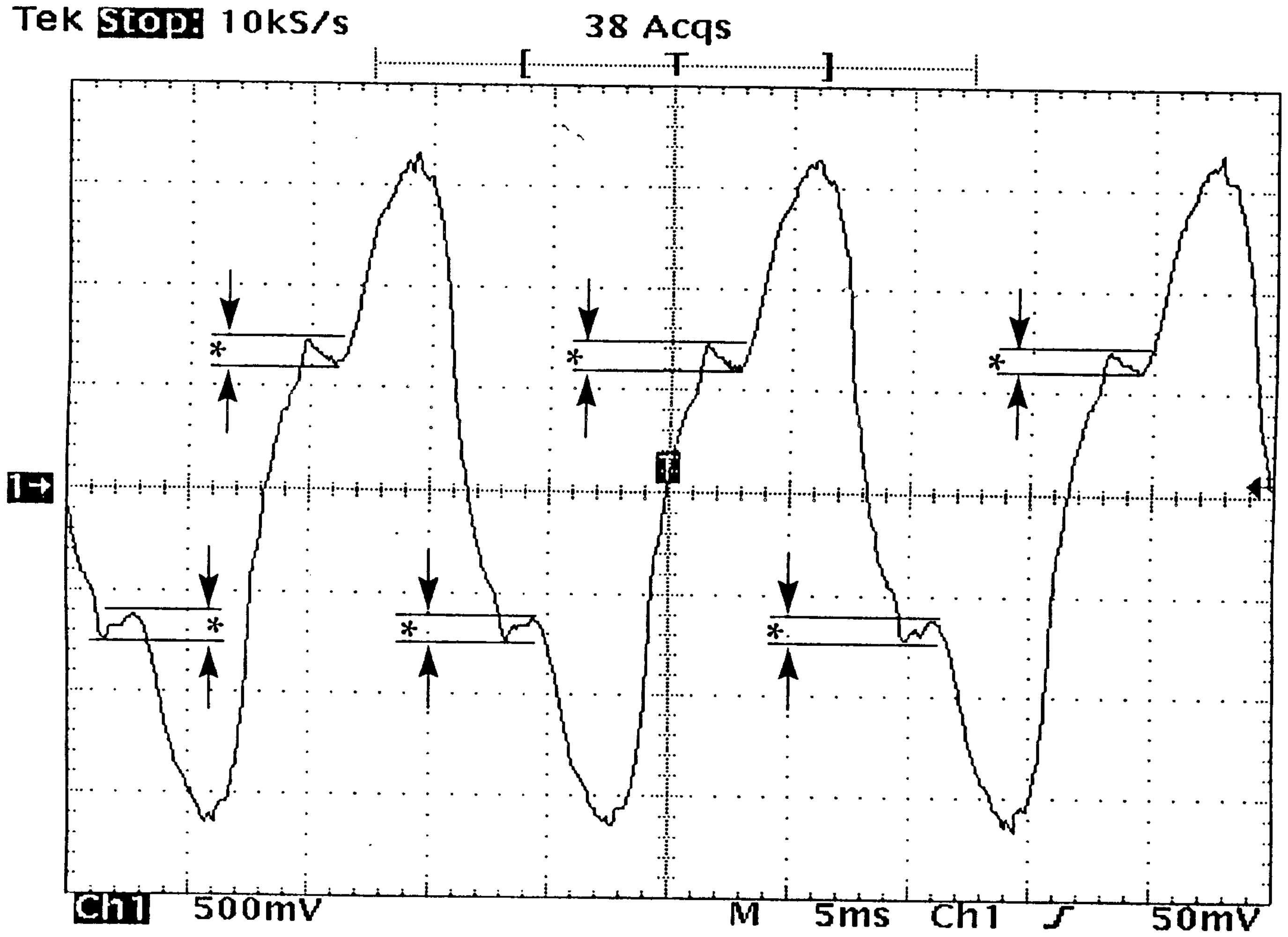
* IRREGULARITIES CAUSED BY ELECTRONIC CONTROL MECHANISM IN SIGN

FIGURE 3B.1. OUTPUT VOLTAGE WAVEFORM SOUTH AIRFIELD LIGHTING VAULT, SIGNS ONLY, STEP 2, WITH HARMONIC FILTER



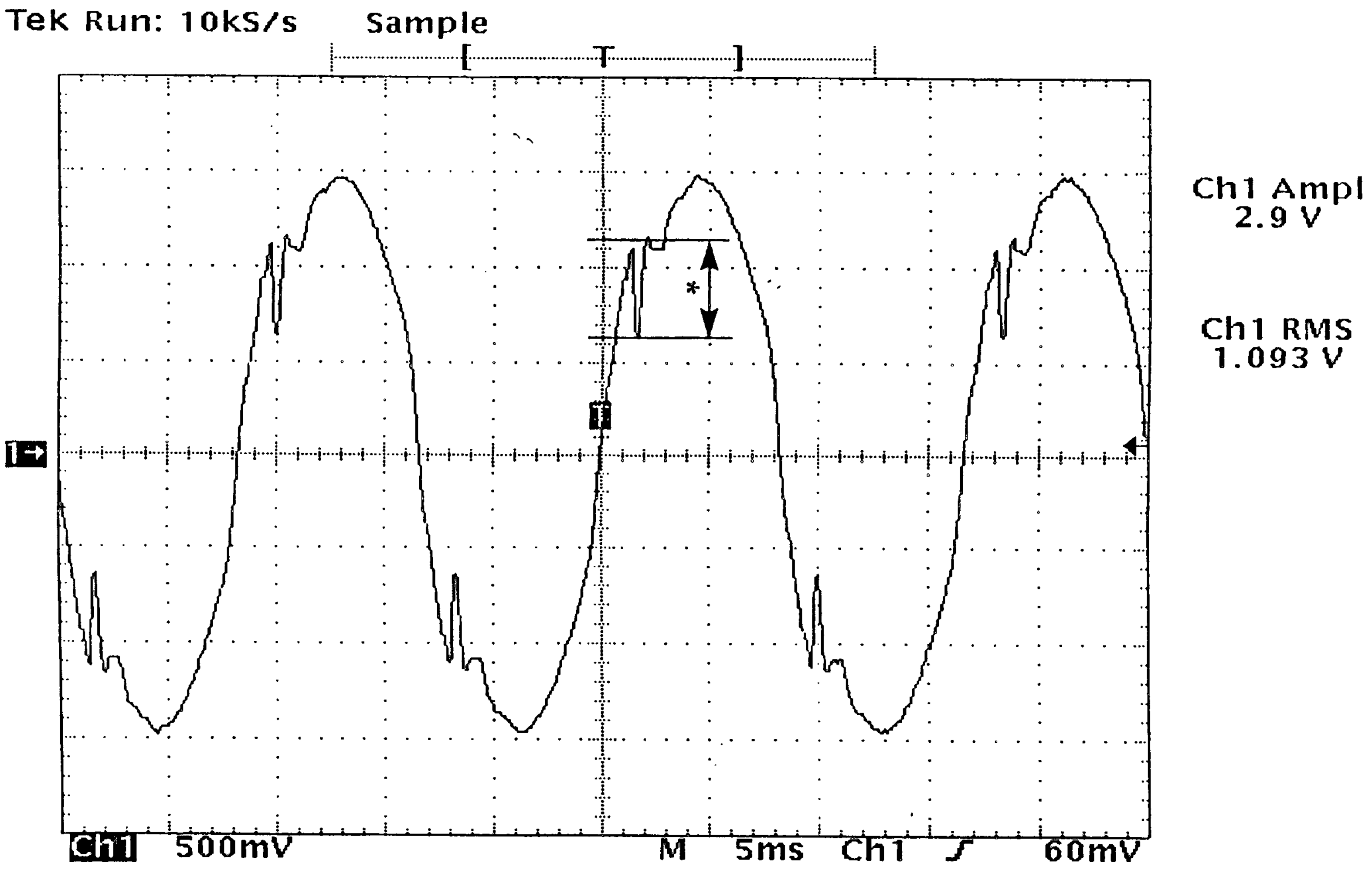
* CHANGING OUTPUT VOLTAGES TO MAINTAIN CONSTANT CURRENT

FIGURE 3B.2. OUTPUT VOLTAGE WAVEFORM SOUTH AIRFIELD LIGHTING VAULT, SIGNS ONLY, STEP 2, WITH HARMONIC FILTER, SUPPLEMENT 1 TO WAVEFORM SHOWING IRREGULARITIES



* LOAD CHANGES CAUSED BY ELECTRONIC CONTROL MECHANISM IN SIGNS

FIGURE 3C. OUTPUT VOLTAGE WAVEFORM SOUTH AIRFIELD LIGHTING VAULT, SIGNS ONLY, STEP 2, WITHOUT HARMONIC FILTER



* OUTPUT VOLTAGE CHANGES IN REACTION TO CHANGEING LOAD (CAUSED BY ELECTRONIC CONTROL MECHANISMS IN SIGNS)

FIGURE 3D. OUTPUT VOLTAGE WAVEFORM CCR T-7, STEP 5

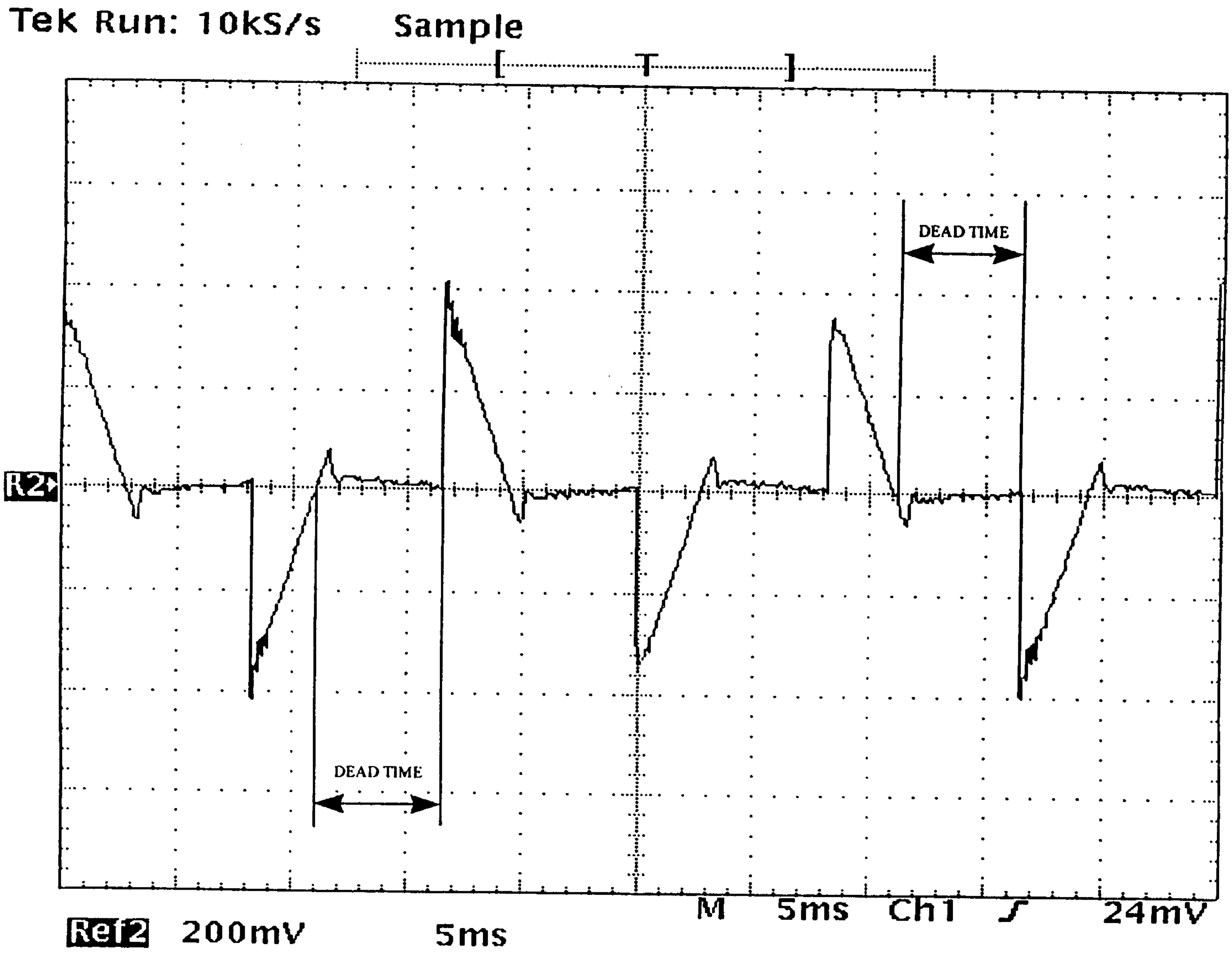


FIGURE 3E. OUTPUT VOLTAGE WAVEFORM CCR 16, ADB RUNWAY GUARD LIGHTS, STEP 2

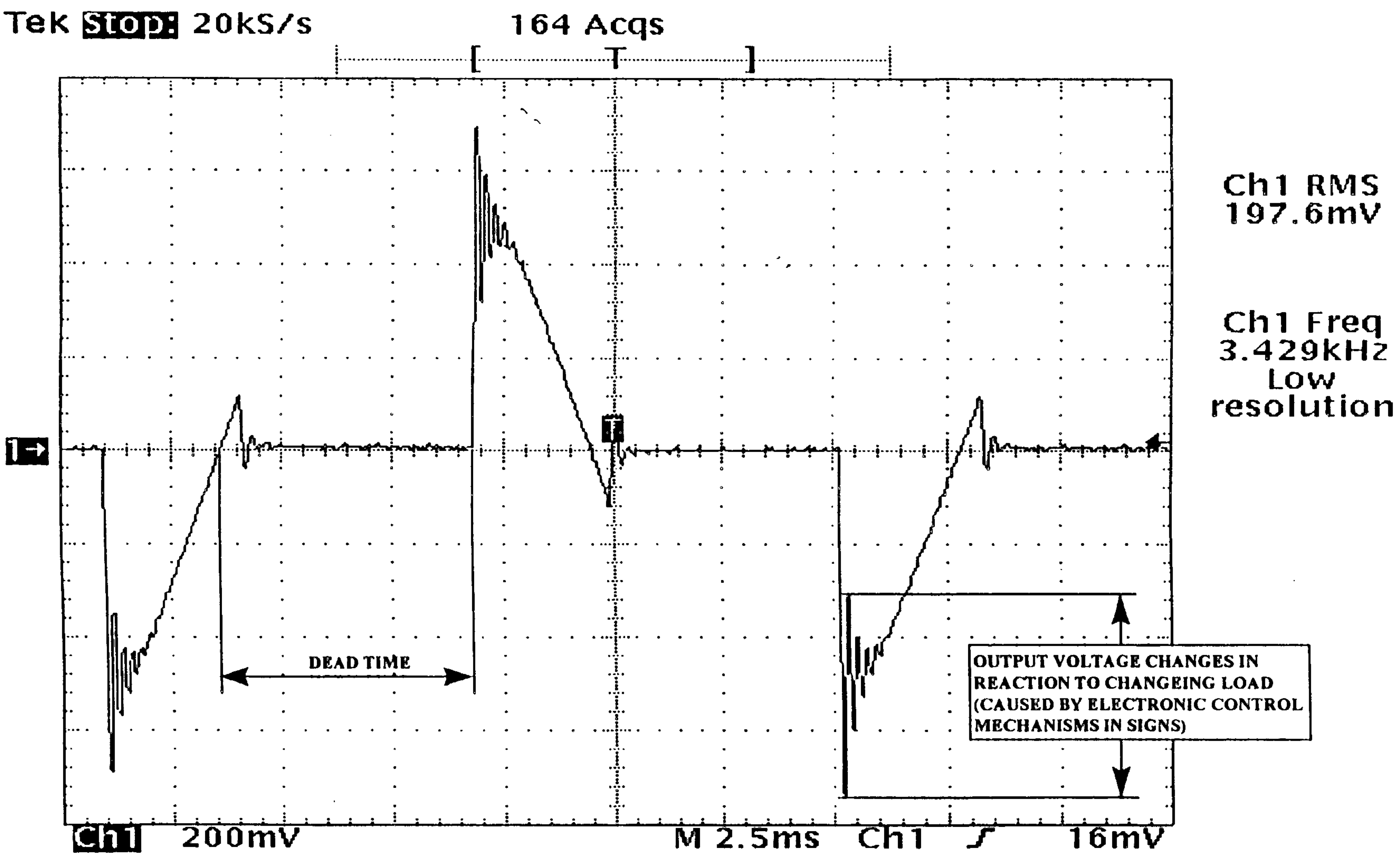


FIGURE 3F. OUTPUT VOLTAGE WAVEFORM CIRCUIT WITH LIGHTS AND SIGNS, STEP 2

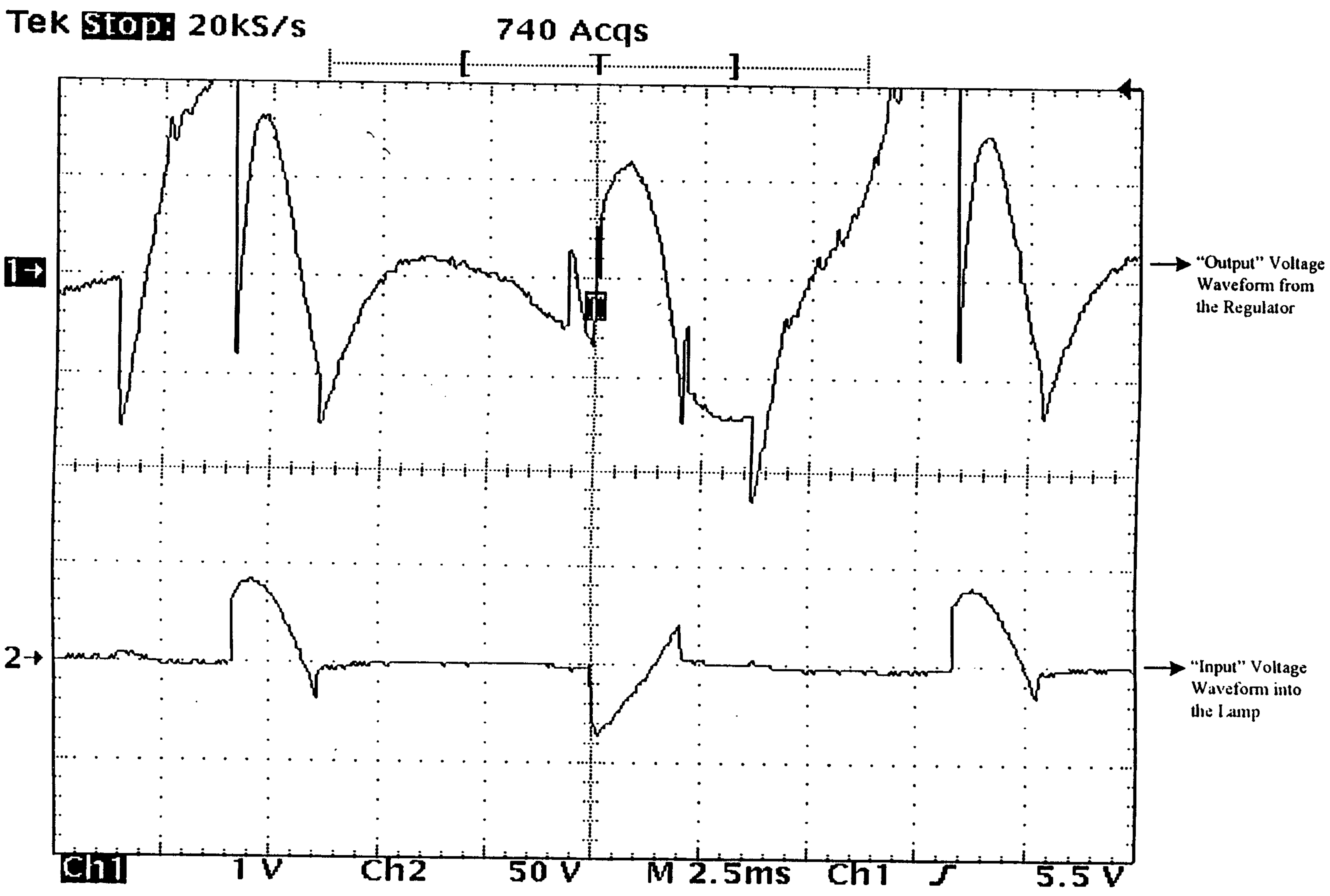


FIGURE 4A. POWER REQUEST FROM SIGN SYNCHRONIZED WITH VOLTAGE PULSE FROM REGULATOR, STEP 2

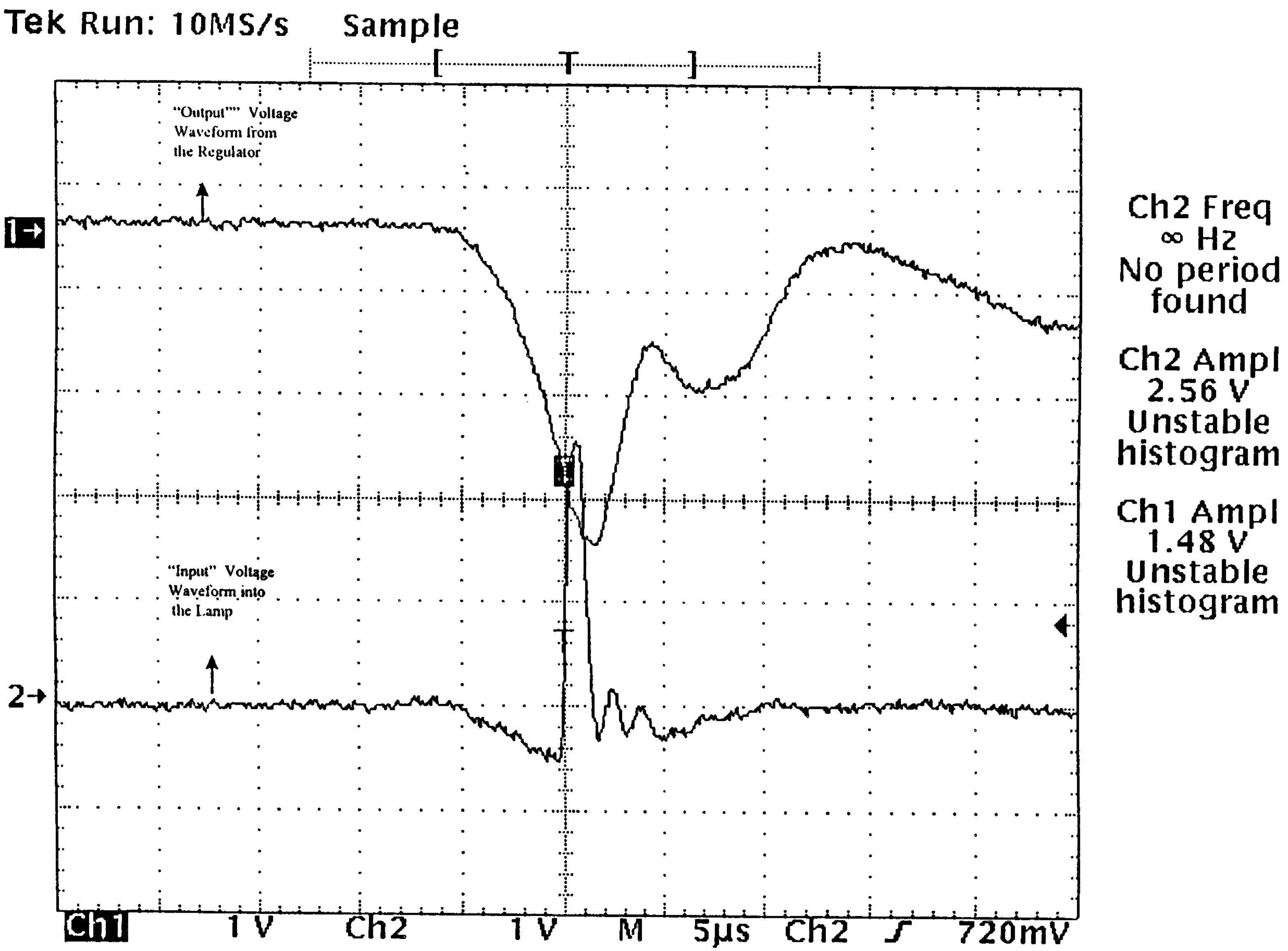


FIGURE 4B. POWER REQUEST FROM SIGN SYNCHRONIZED WITH VOLTAGE PULSE FROM REGULATOR, EXPANDED VIEW

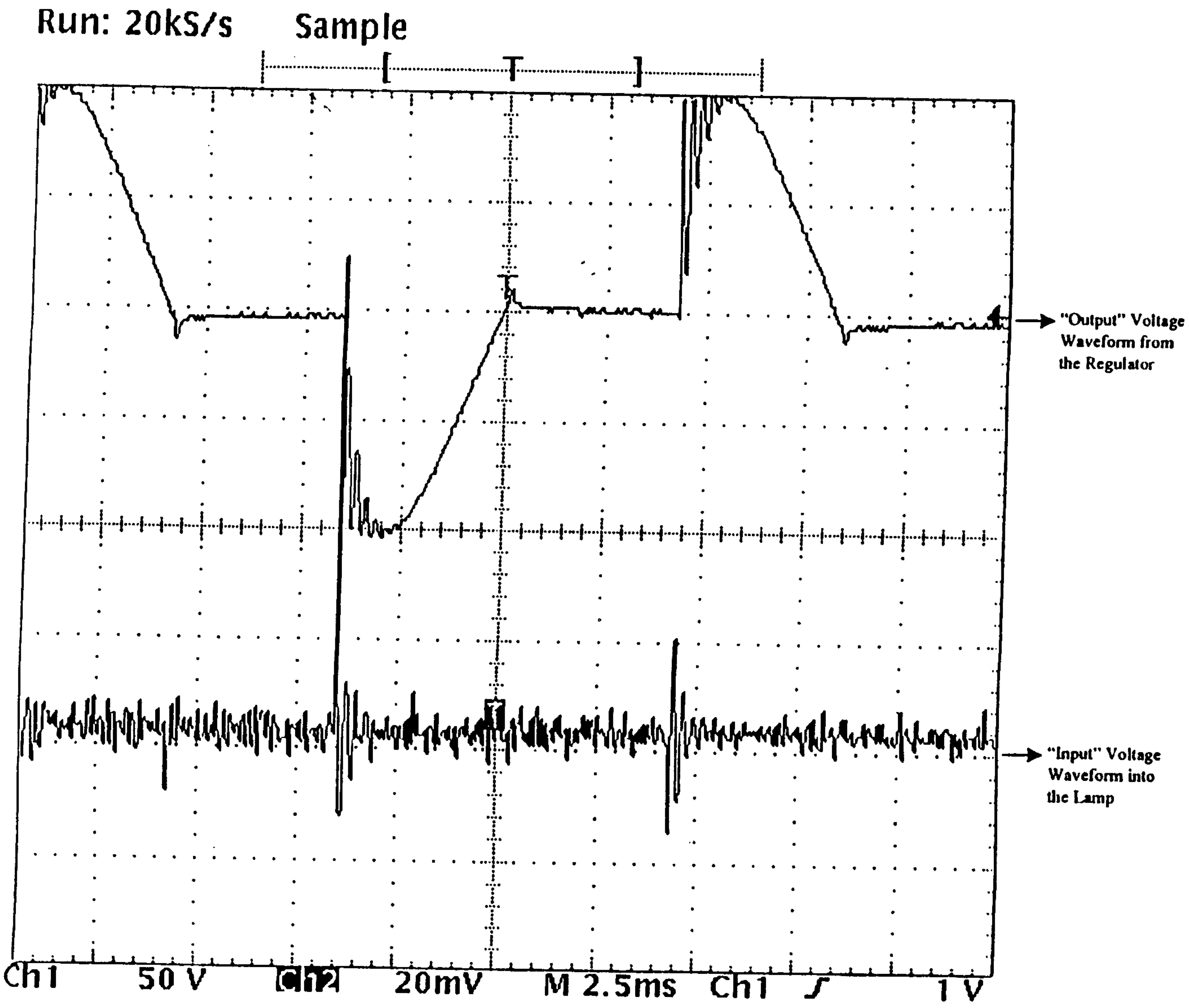


FIGURE 4C. REQUEST FROM SIGN LEADS OUTPUT VOLTAGE PULSE FROM REGULATOR

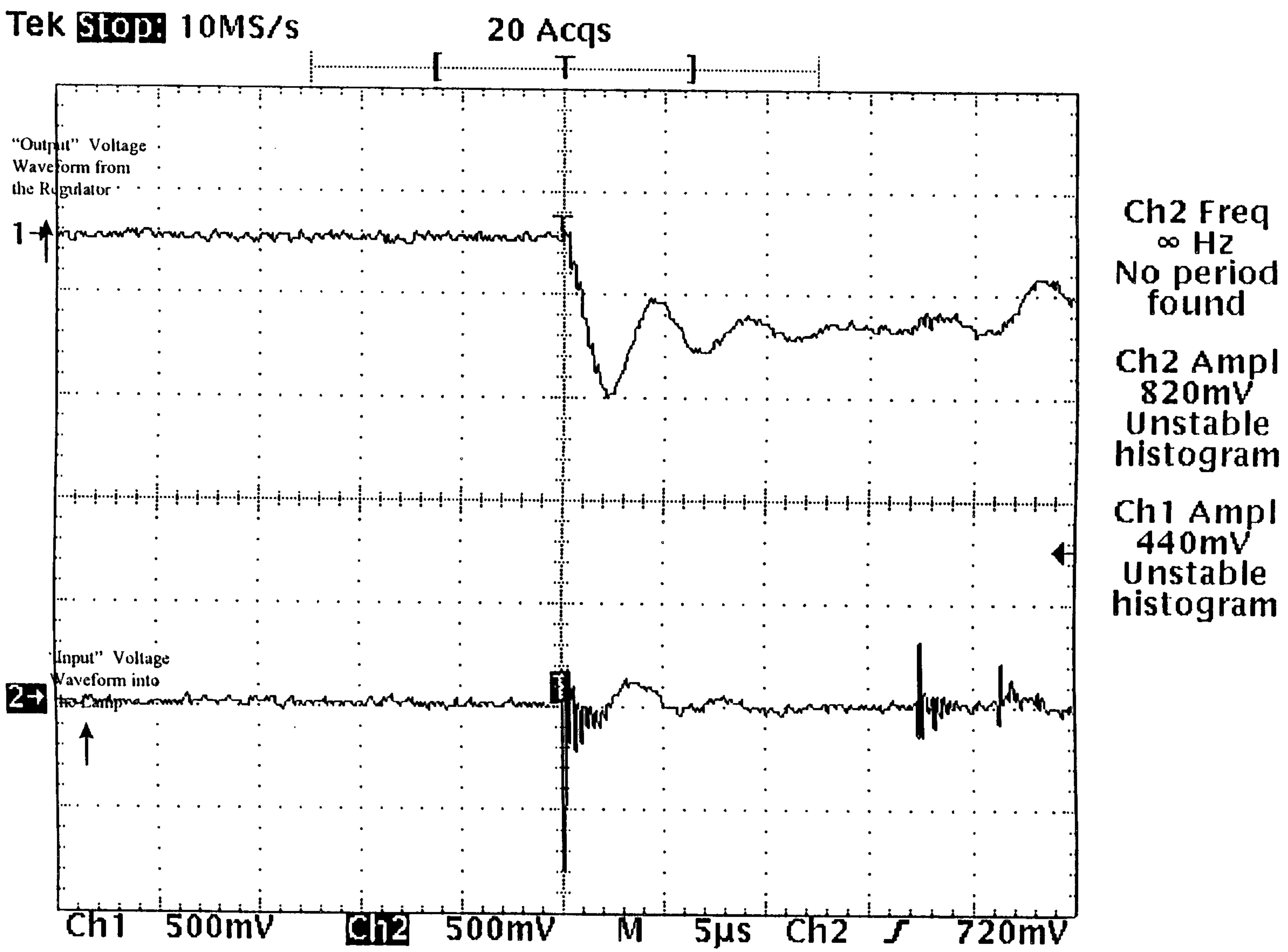
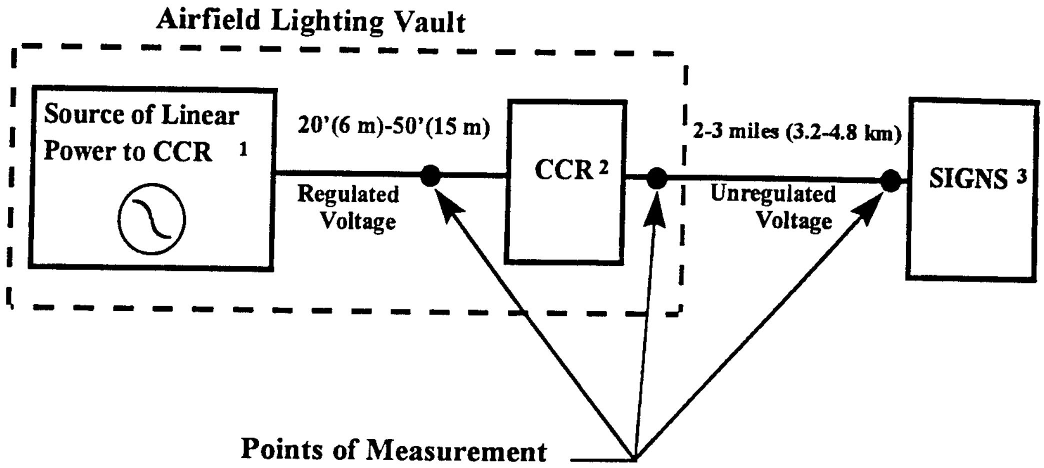


FIGURE 4D. REQUEST FROM SIGN LEADS OUTPUT VOLTAGE PULSE FROM REGULATOR, EXPANDED VIEW



1 - CCR is nonlinear power source to the signs
2 - CCR is nonlinear load for power distribution system
3 - SIGNS are distorting load for CCR

FIGURE 5. A TYPICAL AIRFIELD LIGHTING CIRCUIT WITH SIGNS

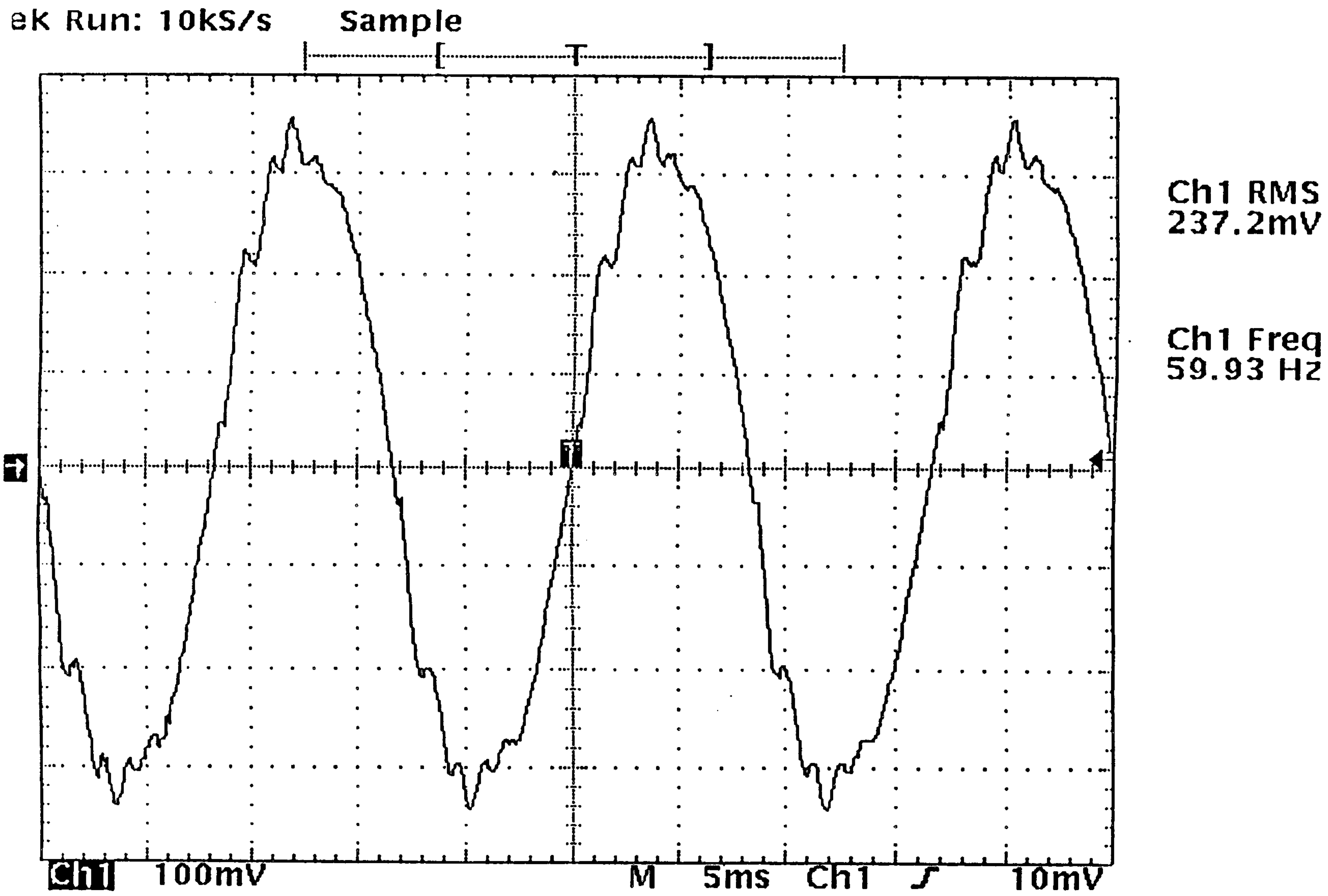


FIGURE 6. OUTPUT VOLTAGE WAVEFORM CIRCUIT D-2 WITH RUNWAY GUARD LIGHTS, STEP 1

TABLE 1. COLOR TO GRAY-SCALE CONVERSION

1" = 6.11 PIXEL

READING INSIDE "D"
STARTING
@ UPPER-LEFT CORNER - CLOCKWISE
127 152 170 180 185 185 196 192 193 186 166 155 136 131 134 136 132 137 134

READING AROUND "D"
STARTING
@ UPPER-LEFT CORNER - CLOCKWISE
88 98 118 134 162 177 189 220 202 219 198 209 193 200 191 204 227 206 217
CONT'D ——► 194 192 162 135 97 78 62 81 88 93 103 100 93 97 96 91

READING "E9"

PIXEL LOCATION ——►

PIXEL LOC ↓

X/Y	183	201	220	238	256	275	293	311	330	348	366	385	403	421	440	458	476	495	513	531	550	568
18	178	152	129	121	115	116	115	121	123	132	155	166	176	198	198	166	155	133	107	97	85	68
36	195	164	142	130	124	120	122	126	130	150	164	179	197	221	224	183	166	143	119	102	89	70
54	198	166					128	132				201	198	220	217	180	166	145	123	111	95	75
72	204	176		142	130	126	128	129		153	180		204	219	217	179	174			116	98	81
90	201	178		140	129	128	130	119		155	171		192	203	197	175	165	152		107	102	80
108	203	174				138	131	127					191								107	83
126	197	171		136	124	125	128	132	139	150			184	180	176	165	162	150		113	100	79
144	205	174		142	131	128	126	125	138	161		201	196	187	181	181	171		106	112	101	75
162	211	175					122	125	128		175	192	191	187	185	186	169	148	123	112	101	76
180	218	176	149	134	126	121	121	126	133	151	170	193	204	203	196	196	173	144	119	107	99	62
198	190	161	131	118	105	115	113	119	123	132	158	174	191	198	188	183	161	130	112	96	86	41

AVERAGE GRAY SCALE	149
MAXIMUM GRAY SCALE	227
MINIMUM GRAY SCALE	41

READING WITH J-17 IN FOOT LAMBERTS	SAME LOCATION GRAY SCALE VALUE	GRAY/J-17
5.8	129	22.2
5.8	131	22.6
5.8	133	22.9
10.6	182	17.2
9.2	173	18.8
5.2	127	24.4
5.2	125	24.0
7.6	162	21.3
17.8	232	13.0
11.6	200	17.2
3.6	67	18.6

1 GRAYSCALE = 0.05 FOOT LAMBERTS

AVERAGE FOOT LAMBERTS	**7.45**
MAXIMUM FOOT LAMBERTS	**11.35**
MINIMUM FOOT LAMBERTS	**2.05**

TABLE 2A. SUMMARY OF PHOTOMETRIC DATA—SIGNS

			AVERAGE OUTPUT FT LAMBERTS			MAXIMUM OUTPUT FT LAMBERTS			MINIMUM OUTPUT FT LAMBERTS			CONTRAST	
AIRPORT	LEGEND	STEP	YEL	WHI	RED	YEL	WHI	RED	YEL	WHI	RED	ICAO STD	IES STD
SLC	CARGO	3	10.23			23.50			4.00				
	CARGO	1	6.94			18.90			2.40				
	17-35	3		16.14	2.31		40.90	4.60		7.40	1.60	6.99	0.86
	17-35	1		11.86	1.65		29.80	3.30		5.50	1.10	7.19	0.86
	HOLD LINE	W/VAR	11.11			22.70			5.40				
	HOLD LINE	W/REG	9.24			18.40			4.40				
	A1/34L	W/VAR	15.91	21.39	2.66	19.50	38.40	4.70	10.30	10.70	1.30	8.04	0.88
	A1/34L	W/REG	13.22	18.30	2.58	15.70	32.00	3.60	8.70	9.00	1.20	7.09	0.86
	HOLD/H1	5.5A*	12.76			35.30			4.60				
	H1/16-34	5.5A*	15.81	19.86	2.51	26.10	39.80	4.60	8.10	7.40	1.20	7.91	0.87
	G/F	3	3.92			9.70			1.60				
	G/F	1	3.20			8.10			0.90				
	F/H	3	5.07			14.90			1.80				
	F/H	1	3.49			8.70			1.40				
	HOLD LINE	5.5A*	8.67			12.00			5.77				
	A11/16R	5.5A*	11.87	17.14	2.55	13.79	18.60	3.74	10.36	15.81	1.65	6.72	0.85
	A8/34L-16R	5.5A*	16.38	19.42	2.44	20.15	23.27	5.21	10.66	14.40	0.89	7.96	0.87
	HOLD LINE	5.5A*	8.79			12.99			5.81				
DENVER	HOLD LINE	5.5A*	8.48			14.66			3.96				
	G/25	5.5A*	19.96	12.63	1.53	20.85	14.12	2.37	18.30	9.30	0.59	8.25	0.88
	B/G	5.5A*	18.23			23.86			10.02				
	F/B	5.5A*	3.65			5.51			1.90				
	F/25-7	5.5A*	22.99	15.07	2.56	23.76	16.53	4.04	21.80	11.60	0.97	5.89	0.83
PHOENIX	A/A1	5.5A*	5.41			8.10			2.90				
	A1/A	5.5A*	4.48			9.80			0.60				
	A1/8L	5.5A*	7.97	10.03	1.41	9.49	15.30	2.30	5.29	8.38	0.55	7.11	0.86
	8L/A1	5.5A*	5.10	5.06	1.25	7.20	8.80	2.15	3.07	3.59	0.56	4.05	0.75
	D/E9	5.5A*	7.45			11.35			2.05				
SEA-TAC	D/16L-34R	3 , 4	3.65	3.17	0.54	4.52	4.89	0.98	3.01	2.20	0.26	5.87	0.83
NEWARK	Y/CC	5	16.52			19.36			9.70				
	Y/4R-22L	5	32.38	58.25	6.13	34.04	60.60	8.27	30.65	53.92	3.27	9.5	0.89
	Y/4R-22L	3	20.97	34.72	3.39	22.05	36.13	4.58	19.85	32.14	1.81	10.24	0.9
	Y/4R-22L	2	15.72	21.03	2.53	16.53	21.88	3.41	14.88	19.47	1.35	8.31	0.88
LA GUARDIA	22-4P	5	17.40	23.26	2.86	19.08	40.81	4.04	15.17	13.54	0.55	8.13	0.88
	AA/G	5	33.08			40.02			18.12				
	AA/G	3	21.02			25.42			11.51				
	AA/G	2	16.64			20.12			9.11				

* 5.5 AMPERS FIXED STEP - STYLE 5 SIGN
ICAO STD - BASED ON ICAO METHOD
IES STD - BASED ON IES METHOD

TABLE 2B. SUMMARY OF PHOTOMETRIC DATA—LIGHT FIXTURE, DENVER INTERNATIONAL AIRPORT

AIRPORT	LIGHT TYPE	STEP	COLOR	AVERAGE OUTPUT IN CANDELA	MAXIMUM OUTPUT IN CANDELA	FAA STANDARDS
DENVER	T/W CENTERLINE	5	GREEN	253	321	200
	T/W CENTERLINE	5	GREEN	217	297	200
	T/W CENTERLINE	5	GREEN	175	259	200
	T/W CENTERLINE	5	GREEN	236	331	200
	T/W CENTERLINE	5	GREEN	252	375	200
	T/W CENTERLINE	5	GREEN	215	162	200
	T/W CENTERLINE	5	GREEN	258	194	200
	T/W CENTERLINE	5	GREEN	186	140	200
	T/W CENTERLINE	5	GREEN	230	173	200
	T/W CENTERLINE	5	GREEN	218	164	200

TABLE 2C. SUMMARY OF PHOTOMETRIC DATA—LIGHT FIXTURE, SEA-TAC INTERNATIONAL AIRPORT, SEATTLE

AIRPORT	LIGHT TYPE	STEP	COLOR	AVERAGE OUTPUT IN CANDELA	MAXIMUM OUTPUT IN CANDELA	FAA STANDARDS
SEA-TAC	T/W CENTERLINE	5	GREEN	1148	1220	200
	T/W CENTERLINE	5	GREEN	750	974	200
	T/W CENTERLINE	5	GREEN	820	1023	200
	T/W CENTERLINE	5	GREEN	1050	1179	200
	T/W CENTERLINE	5	GREEN	640	768	200
	T/W CENTERLINE	5	GREEN	120	124	200
	T/W CENTERLINE	5	GREEN	116	111	200
	T/W CENTERLINE	5	GREEN	126	139	200
	T/W CENTERLINE	5	GREEN	96	105	200
SEA-TAC	STOP BAR	5	AMBER	383	391	1500*
	STOP BAR	5	AMBER	627	691	1500*
	STOP BAR	5	AMBER	439	444	1500*
	STOP BAR	5	AMBER	335	366	1500*
	STOP BAR	5	AMBER	50	61	1500*
	STOP BAR	5	AMBER	793	1037	1500*
	STOP BAR	5	AMBER	672	710	1500*
	STOP BAR	5	AMBER	210	221	1500*
	STOP BAR	5	AMBER	195	201	1500*
	STOP BAR	5	AMBER	367	390	1500*
	STOP BAR	5	AMBER	412	432	1500*
	STOP BAR	5	AMBER	501	554	1500*
	STOP BAR	5	RED	287	330	1200*
	STOP BAR	5	RED	470	485	1200*
	STOP BAR	5	RED	329	342	1200*
	STOP BAR	5	RED	285	335	1200*
	STOP BAR	5	RED	29	35	1200*
	STOP BAR	5	RED	406	457	1200*
	STOP BAR	5	RED	219	245	1200*
	STOP BAR	5	RED	112	145	1200*
	STOP BAR	5	RED	453	490	1200*
	STOP BAR	5	RED	319	345	1200*
	STOP BAR	5	RED	198	219	1200*
	STOP BAR	5	RED	332	345	1200*

* No FAA standard has yet to be established,
Standard values given above were suggested by FAA Office of Airport Safety

TABLE 3A. SUMMARY OF ELECTRICAL PERFORMANCE DATA—SALT LAKE CITY INTERNATIONAL AIRPORT

Circuit/Load	Regulator	File Name	Current Amps	Voltage Volts	Current THD %	Voltage THD %	KVA	KVAR	KW	True PF
INPUT TO SIGN OR LIGHT FIXTURE - FOR CIRCUITS AS INDICATED										
T/W C/L Light, only	ADB - 10KW	DISK1-10	6.2	27.4	106.8	108.4	0.2	0.01	0.2	0.99
T/W C/L Light, only	C-H - 10KW	DISK1-12	6.2	26.7	145.7	146.8	0.1	0.02	0.1	0.98
Style 5 Sign only	ADB - 10KW	DISK1-8	6.2	19.0	106.5	106.3	0.1	0.01	0.1	0.99
Style 5 Sign only	C-H - 10KW	DISK1-15	6.1	18.9	145.3	146.5	0.1	0.02	0.1	0.98
B. E. P. Sign only	ADB - 10KW	DISK1-5	6.6	37.8	97.2	154.2	0.2	0.10	0.2	0.75
B. E. P. Sign only	C-H - 10KW	DISK1-19	6.5	41.4	131.1	210.3	0.3	0.20	0.2	0.60
INPUT TO REGULATOR - FOR CIRCUITS AS INDICATED										
Ex. Lts Step 1	ADB - 15KW	DISK2-23	23.5	492.1	78.3	2.0	11.6	8.6	2.9	0.25
Ex. Lts Step 1	C-H - 15KW	DISK2-8	12.5	493.0	65.0	1.6	6.2	4.1	3.1	0.51
Ex. Lts Step 3	ADB - 15KW	DISK2-21	33.0	490.4	61.1	2.4	16.1	12.1	6.2	0.38
Ex. Lts Step 3	C-H - 15KW	DISK2-5	14.0	491.9	38.1	1.6	6.7	1.0	6.2	0.92
Ex. Lts Step 5	ADB - 30KW	ICCR6A	68.0	467.0	10.0	2.1	31.5	5.7	30.8	0.99
New Lts, Step 5	ADB - 30KW	ICCR105A	70.0	486.6	37.0	3.7	33.9	24.2	20.5	0.60
New Lts, Step 5	ADB - 30KW	ICCR104A	71.0	488.2	44.0	2.4	34.0	27.3	14.8	0.40
Ex. Lts & Style 5 Signs, Step 1	ADB - 15KW	DISK2-15	23.5	493.5	74.5	2.2	11.6	8.6	3.3	0.29
Ex. Lts & Style 5 Signs, Step 1	C-H - 15KW	DISK2-1	12.4	491.1	66.0	1.6	6.1	3.7	3.6	0.58
Ex. Lts & Style 5 Signs, Step 3	ADB - 15KW	DISK2-17	32.5	494.2	57.5	2.5	16.2	12.3	6.6	0.41
Ex. Lts & Style 5 Signs, Step 3	C-H - 15KW	DISK2-3	14.9	493.1	46.1	1.9	7.4	0.6	6.6	0.90
Ex.Style 5 Signs Step 2	ADB - 15KW	DISK2-10	24.5	475.2	58.5	3.4	11.6	7.9	6.0	0.51
Ex.Style 5 Signs Step 2	C-H - 15KW	DISK2-12	17.5	494.2	35.5	1.4	8.7	0.8	8.1	0.94
New Style 5 Signs Step 2	ADB - 15KW	ICCR103A	23.4	495.7	88.0	2.1	11.6	8.3	2.6	0.20
OUTPUT FROM REGULATOR - FOR CIRCUITS AS INDICATED										
Ex. Lts, Step 5	ADB - 30KW	OCCR6A	20.0	1296	4.5	12.4	26.0	6.20	25.0	0.97
New Lts, Step 5	ADB - 30KW	OCCR105A	6.6	2984	37.0	48.0	20.0	3.75	19.0	0.96
New Lts, Step 5	ADB - 30KW	OCCR104A	6.5	2134	45.0	54.6	14.0	3.22	13.0	0.95
New Lts. & Style 5 Signs, Step 1	ADB - 7.5KW	O1061A	4.8	1601	107.0	128.0	8.1	3.37	6.7	0.82
New Lts. & Style 5 Signs, Step 1	ADB - 7.5KW	O1063A	6.5	2295	92.0	112.5	15.0	54.48	13.0 *	0.89
New Style 5 Signs Step 2	ADB - 15KW	OCCR103A	5.6	589	79.0	85.1	3.27	0.62	3.2	0.97

LEGEND

C-H - Crouse Hinds
T/W - Taxiway
Ex. - Existing
Lts. - Lights
* - Circuit load exceeded rated capacity of regulator

ADB - ADB Alnaco
C/L - Centerline Lights
B.E.P - Basic Electrical Package

TABLE 3B. SUMMARY OF ELECTRICAL PERFORMANCE DATA—DENVER INTERNATIONAL AIRPORT

Circuit/Load	Regulator	File Name	Current amps	Voltage volts	Current THD %	Voltage THD %	KVA	KVAR	KW	True PF
INPUT TO REGULATOR - FOR CIRCUITS AS INDICATED										
R/W TDZ Lights,Step 5	ADB - 20KW	IR2ADB5	26.0	484	13.0	2.5	12.7	0.3	12.6	0.99
R/W TDZ Lights,Step 5	C-H - 20KW	IR2CH5	31.0	486	11.6	2.4	15.3	1.6	15.1	0.99
Wigwags, Step 1	ADB - 10KW	IR16AD1	7.0	481	88.9	2.6	3.4	2.3	1.2	0.34
Wigwags, Step 2	ADB - 10KW	IR16AD2	8.0	483	82.4	2.5	3.9	2.6	1.6	0.41
Wigwags, Step 1	C-H - 10KW	IR43CH1	7.0	473	81.9	2.8	3.3	2.2	1.4	0.43
Wigwags, Step 2	C-H - 10KW	IR43CH2	8.0	473	70.1	2.8	3.9	2.5	2.0	0.52
OUTPUT FROM REGULATOR - FOR CIRCUITS AS INDICATED										
R/W TDZ Lights,Step 3	ADB - 20KW	OR2ADB5	4.2	1848	38.8	107.9	6.16	4.36	2.57 +	0.41
R/W TDZ Lights,Step 5	C-H - 20KW	OR2CH5	7.0	2412	4.6	18.7	16.17	10.01	12.06 ++	0.76
Wigwags, Step 1	ADB - 10KW	OR16AD1	4.8	17	88.1	934.0	0.07	0.01	0.01 +	0.19
Wigwags, Step 2	ADB - 10KW	OR16AD2	5.6	17	81.8	1414.2	0.14	0.01	0.01 +	0.06
Wigwags, Step 1	C-H - 10KW	OR43CH1	4.8	10	82.0	1061.4	0.06	0.01	0.01 +	0.11
Wigwags, Step 2	C-H - 10KW	OR43CH2	5.5	10	73.3	1093.1	0.08	0.01	0.01 +	0.09

LEGEND

C-H - Crouse Hinds

ADB - ADB Alnaco

R/W - Runway

TDZ - Touchdown Zone Lights

\+ - Circuit load small compared to rated regulator capacity

++ - Circuit load over 50% of rated regulator capacity.

TABLE 3C. SUMMARY OF ELECTRICAL PERFORMANCE DATA—SKY HARBOR INTERNATIONAL AIRPORT, PHOENIX

Circuit/Load	Regulator	File Name	Current amps	Voltage volts	Current THD %	Voltage THD %	KVA	KVAR	KW	True PF
INPUT TO SIGNS										
Single Style 5 Sign only, Step 2										
Secondary Side	C-H - 30KW	SGNSEC2	5.5	24.8	21.3	30.0	0.14	0.05	0.12	0.87
Primary Side	C-H - 30KW	SGNPRI2	5.5	27.2	22.1	26.5	0.15	0.06	0.13	0.85
Variac		SGNVAR	3.3	21.5	2.4	1.3	0.07	0.01	0.07	0.99
Info Sign, Field	C-H - 30KW	INFSGNF	5.9	22.6	17.7	63.4	0.13	0.05	0.11	0.80
Mandatory Sign, Field	C-H - 30KW	MANSGNF	5.9	21.7	17.6	63.6	0.13	0.06	0.09	0.73
INPUT TO REGULATOR - FOR CIRCUITS AS INDICATED										
T/W Lights, Step 3	C-H - 15KW	IAWLTS3	17.1	486	16.3	1.1	8.3	3.2	7.6	0.91
T/W Lights & Style 2 Signs, Step 3	C-H - 30KW	IBLTSN3	39.7	486	17.0	0.8	19.4	3.8	18.7	0.97
Style 5 Signs only, Step 2										
With filter, North Vault	C-H - 30KW	IRWSN2F	47.1	487	34.2	1.2	19.5	11.0	14.8	0.76
Without filter, North Vault	C-H - 30KW	IRWSN2	49.8	490	46.0	1.2	23.4	12.8	16.9	0.73
With filter, South Vault	C-H - 30KW	ISVSGNF	31.7	493	42.7	2.5	16.4	8.6	12.4	0.76
Without filter, South Vault	C-H - 30KW	ISVSGN2	33.6	492	73.5	2.5	16.5	5.7	12.1	0.73
OUTPUT FROM REGULATOR - FOR CIRCUITS AS INDICATED										
T/W Lights, Step 3	C-H - 15KW	OAWLTS3	6.6	4106	10.2	42.6	26.9	20.27	14.63 ++	0.54
T/W Lights & Style 2 Signs, Step 3	C-H - 30KW	OBLTSN3	6.6	11547	13.0	229.9	83.4	7.44	32.08 *	0.38
Style 5 Signs only, Step 2										
With Filter, North Vault	C-H - 30KW	ORWSN2F	5.8	39516	25.7	769.6	200.1	25.40	19.76 ++	0.10
Without Filter, North Vault	C-H - 30KW	ORWSN2	5.7	10521	28.7	177.1	62.9	21.04	14.88 ++	0.24
With Filter, South Vault	C-H - 30KW	OSVSGNF	5.8	19245	20.8	773.4	146.0	0.51	25.15 ++	0.17
Without Filter, South Vault	C-H - 30KW	OSVSGN2	5.5	6158	28.6	141.0	38.8	6.67	22.58 ++	0.58

LEGEND

C-H - Crouse Hinds　　ADB - ADB Alnaco
T/W - Taxiway
* - Circuit load exceeded rated capacity of regulator
++ - Circuit load over 50% of rated regulator capacity.

TABLE 3D. SUMMARY OF ELECTRICAL PERFORMANCE DATA—SEA-TAC INTERNATIONAL AIRPORT, SEATTLE

Circuit/Load	Regulator	File Name	Current amps	Voltage volts	Current THD %	Voltage THD %	KVA	KVAR	KW	True PF
INPUT TO REGULATOR										
R/W 24 Wigwags, Step 1	C-H - 15KW	RW24IN1	25.0	247	55.0	1.9	6.3	0.69	5.50	0.87
R/W 24 Wigwags, Step 2	C-H - 15KW	RW24IN2	33.0	247	35.9	1.9	8.3	0.32	7.80	0.94
R/W 24 Wigwags, Step 3	C-H - 15KW	RW24IN3	51.0	247	16.6	1.8	12.5	0.92	12.40	0.98
CCR D-2 Wigwags, Step 1	H-D - 7.5KW	D2IN1	16.0	248	9.6	1.8	3.9	1.70	3.50	0.90
CCR D-2 Wigwags, Step 2	H-D - 7.5KW	D2IN2	22.0	248	7.3	1.9	5.5	2.20	5.10	0.91
CCR D-2 Wigwags, Step 3	H-D - 7.5KW	D2IN3	34.0	248	6.3	1.8	8.4	3.40	7.70	0.91
B-1.4 Lts & Style 3 Signs, Step 1	C-H - 10KW	B14IN1	34.0	247	87.0	2.2	8.2	5.60	2.60	0.31
B-1.4 Lts & Style 3 Signs, Step 2	C-H - 10KW	B14IN2	39.0	247	80.2	1.9	9.5	6.40	3.60	0.38
B-1.4 Lts & Style 3 Signs, Step 3	C-H - 10KW	B14IN3	46.0	247	69.1	1.9	11.3	7.40	5.60	0.50
OUTPUT FROM REGULATOR										
R/W 24 Wigwags, Step 1	C-H - 15KW	RW24O1	4.8	934	24.3	27.8	4.49	0.71	4.41	0.98
R/W 24 Wigwags, Step 2	C-H - 15KW	RW24O2	5.5	1188	17.7	20.3	6.56	0.90	6.49	0.99
R/W 24 Wigwags, Step 3	C-H - 15KW	RW24O3	6.6	1603	8.6	10.4	11.00	1.21	11.00	0.99
CCR D-2 Wigwags, Step 1	H-D - 7.5KW	D2OUT1	5.2	525	7.1	9.3	2.73	0.78	2.59	0.95
CCR D-2 Wigwags, Step 2	H-D - 7.5KW	D2OUT2	5.9	682	6.6	5.7	4.02	0.97	3.88	0.97
CCR D-2 Wigwags, Step 3	H-D - 7.5KW	D2OUT3	7.0	883	6.6	4.9	6.19	1.46	6.00	0.97
B-1.4 Lts & Style 3 Signs, Step 1	C-H - 10KW	B14OUT1	4.7	449	90.0	110.7	2.04	0.63	1.88	0.92
B-1.4 Lts & Style 3 Signs, Step 2	C-H - 10KW	B14OUT2	5.5	540	81.8	94.4	2.91	0.77	2.72	0.93
B-1.4 Lts & Style 3 Signs, Step 3	C-H - 10KW	B14OUT3	6.5	724	68.7	77.9	4.85	1.24	4.46	0.92
Q-2, SmartPower, Step 1	H-D - 10KW	CCRQ2	4.9	706	13.6	18.3	3.49	1.05	3.24	0.93
Q-2 w/N-2,w/blst, Step 1	H-D - 10KW	Q2N2WB	4.9	704	13.3	18.2	3.51	1.05	3.25	0.93
Q-2 w/N-2,w/o blst, St 1	H-D - 10KW	CCRQ2N2	4.9	710	13.0	18.1	3.54	1.05	3.29	0.93
N-2 only w/blst, Step 1	C-H - 7.5KW	CCRN2B1	4.8	301	81.4	99.3	1.49	0.70	1.20	0.80
N-2 only w/blst, Step 3	C-H - 7.5KW	CCRN2B3	6.6	490	65.3	73.9	3.29	1.14	2.96	0.90
N-2 only w/o blst, St 1	C-H - 7.5KW	N2WOB1	4.8	353	88.4	148.6	2.18	0.94	1.18	0.54
N-2 only w/o blst, St 3	C-H - 7.5KW	N2WOB3	6.6	518	71.8	103.2	4.19	1.54	2.91	0.70

LEGEND

C-H - Crouse Hinds
R/W - Runway
w/N-2 - Connected with regulator N-2
w/blst - With ballast
H-D - Hevi-Duty
Lts. - Lights
w/o blst - Without ballast

TABLE 3E. SUMMARY OF ELECTRICAL PERFORMANCE DATA—NEWARK INTERNATIONAL AIRPORT

Circuit/Load	Regulator	File Name	Current amps	Voltage volts	Current THD %	Voltage THD %	KVA	KVAR	KW	True PF
INPUT TO SIGN (At secondary transformer)										
Style 3 Sign in Field, Step 2		SGNSTEP2	3.4	20.6	47.3	63.4	0.071	0.02	0.05	0.73
Style 3 Sign in Field, Step 3		SGNSTEP3	4.1	19.8	42.5	60.2	0.083	0.01	0.07	0.78
Style 3 Sign in Field, Step 5		SGNSTEP5	6.7	18.6	18.1	46.0	0.125	0.03	0.11	0.86
INPUT TO REGULATOR - FOR CIRCUITS AS INDICATED										
T/W Lights & Style 3 Signs, Step 2	ADB - 20KW	T3INST2	37.7	462	35.2	1.4	17.3	11.4	11.8	0.68
T/W Lights & Style 3 Signs, Step 3	ADB - 20KW	T3INST3	44.0	462	28.3	1.4	20.1	12.3	14.9	0.74
T/W Lights & Style 3 Signs, Step 5	ADB - 20KW	T3INST5	63.6 *	460	23.8	1.4	29.3	17.2	22.7	0.78
T/W Lights & Style 3 Signs, Step 2	H-D - 20KW	T7INST2	10.2	462	70.6	1.3	4.7	1.4	3.6	0.76
T/W Lights & Style 3 Signs, Step 3	H-D - 20KW	T7INST3	15.5	462	32.4	1.3	7.2	3.6	5.9	0.82
T/W Lights & Style 3 Signs, Step 5	H-D - 20KW	T7INST5	42.4	462	9.8	1.4	19.6	5.0	18.9	0.96
OUTPUT FROM REGULATOR - FOR CIRCUITS AS INDICATED										
T/W Lights & Style 3 Signs, Step 2	ADB - 20KW	T3OUTST2	3.7	3110	40.9	18.4	11.00	4.63	10.00 ++	0.88
T/W Lights & Style 3 Signs, Step 3	ADB - 20KW	T3OUTST3	4.3	3450	35.8	15.0	15.00	5.49	14.00 ++	0.91
T/W Lights & Style 3 Signs, Step 5	ADB - 20KW	T3OUTST5	5.3	4160	26.3	8.5	22.00	6.98	20.00 ++	0.92
T/W Lights & Style 3 Signs, Step 2	H-D - 20KW	T7OUTST2	3.3	1050	22.6	47.0	3.44	1.3	2.79 +	0.81
T/W Lights & Style 3 Signs, Step 3	H-D - 20KW	T7OUTST3	4.1	1280	15.0	35.1	5.23	1.8	4.54 +	0.87
T/W Lights & Style 3 Signs, Step 5	H-D - 20KW	T7OUTST5	6.7	2590	7.0	21.9	17.00	3.85	16.00 ++	0.96
T/W Lights & Style 3 Signs, Step 2	ADB - 20KW	T1OUTST2	3.4	1390	44.7	38.6	4.78	1.54	4.5 +	0.94
T/W Lights & Style 3 Signs, Step 3	ADB - 20KW	T1OUTST3	4.1	1690	37.4	30.2	6.95	1.9	6.65 +	0.96
T/W Lights & Style 3 Signs, Step 5	ADB - 20KW	T1OUTST5	6.6	3040	12.6	7.6	20.00	2.74	20.00 ++	0.99

LEGEND

H-D - Hevi-Duty
ADB - ADB Alnaco
T/W - Taxiway
* - Input current exceeded rated capacity of regulator
\+ - Circuit load small compared to rated capacity or regulator
++ Circuit load over 50% of rated capacity of regulator

TABLE 3F. SUMMARY OF ELECTRICAL PERFORMANCE DATA—LA GUARDIA INTERNATIONAL AIRPORT, NEW YORK

Circuit/Load	Regulator	File Name	Current amps	Voltage volts	Current THD %	Voltage THD %	KVA	KVAR	KW	True PF
INPUT TO REGULATOR - FOR CIRCUITS AS INDICATED										
Style 3 Signs CCR T-6, Step 1	ADB - 20KW	TS6IN1	4.8	482	51.6	2.3	2.3	15	13	0.58
Style 3 Signs CCR T-6, Step 2	ADB - 20KW	TS6IN2	5.7	480	48.9	2.4	2.8	1.9	1.6	0.59
Style 3 Signs CCR T-6, Step 3	ADB - 20KW	TS6IN3	7.0	480	41.7	2.4	3.3	2.3	2.1	0.62
Style 3 Signs CCR T-6, Step 4	ADB - 20KW	TS6IN4	8.8	480	33.1	2.4	4.3	3.0	2.8	0.65
Style 3 Signs CCR T-6, Step 5	ADB - 20KW	TS6IN5	16.0	480	61.6	2.1	7.5	5.8	3.4	0.44
2 Ckts CCR T-6, Step 2	ADB - 20KW	2T6IN2	16.3	480	41.7	2.4	7.8	4.8	5.4	0.69
2 Ckts CCR T-6, Step 3	ADB - 20KW	2T6IN3	19.7	480	36.2	2.3	9.4	5.8	6.7	0.71
2 Ckts CCR T-6, Step 4	ADB - 20KW	2T6IN4	25.8	477	28.1	2.4	12.4	7.7	9.4	0.76
2 Ckts CCR T-6, Step 5	ADB - 20KW	2T6IN5	36.5	477	26.8	2.9	17.5	11.7	12.3	0.70
OUTPUT FROM REGULATOR - FOR CIRCUITS AS INDICATED										
Style 3 Signs CCR T-6, Step 1	ADB - 20KW	TS6OUT1	2.8	440	60.4	61.4	1.24	0.65	0.92 +	0.74
Style 3 Signs CCR T-6, Step 2	ADB - 20KW	TS6OUT2	3.4	450	54.9	58.7	1.59	0.84	1.18 +	0.74
Style 3 Signs CCR T-6, Step 3	ADB - 20KW	TS6OUT3	4.1	490	46.4	49.2	1.93	0.99	1.54 +	0.80
Style 3 Signs CCR T-6, Step 4	ADB - 20KW	TS6OUT4	5.2	510	40.7	48.2	2.54	1.28	2.04 +	0.80
Style 3 Signs CCR T-6, Step 5	ADB - 20KW	TS6OUT5	6.6	540	31.8	34.5	3.60	1.89	2.87 +	0.80
Style 3 Signs CCR T-3, Step 1	H-D - 20KW	T3OUT1	2.9	490	35.2	38.5	1.43	0.62	1.11 +	0.77
Style 3 Signs CCR T-3, Step 2	H-D - 20KW	T3OUT2	3.5	510	29.6	39.1	1.78	0.75	1.37 +	0.77
Style 3 Signs CCR T-3, Step 3	H-D - 20KW	TSOUT3	4.2	520	24.0	36.1	0.21	0.92	1.71 +	0.79
Style 3 Signs CCR T-3, Step 4	H-D - 20KW	T3OUT4	5.3	540	17.6	34.1	2.85	1.23	2.28 +	0.80
Style 3 Signs CCR T-3, Step 5	H-D - 20KW	T3OUT5	6.3	560	12.9	34.9	3.59	1.60	2.87 +	0.80
Style 3 Signs CCR T-14, Step 1	C-H - 10KW	T14OUT1	2.8	530	84.8	140.1	1.52	0.77	0.80 +	0.53
Style 3 Signs CCR T-14, Step 2	C-H - 10KW	T14OUT2	3.5	530	78.6	122.0	1.90	0.95	1.07 +	0.57
Style 3 Signs CCR T-14, Step 3	C-H - 10KW	T14OUT3	4.2	540	73.7	108.4	2.24	1.22	1.36 +	0.61
Style 3 Signs CCR T-14, Step 4	C-H - 10KW	T14OUT4	5.3	640	67.2	123.7	3.39	1.77	1.84 +	0.54
Style 3 Signs CCR T-14, Step 5	C-H - 10KW	T14OUT5	6.7	680	60.2	114.6	4.93	2.68	2.62 +	0.53
2 Ckts CCR T-6, Step 2	ADB - 20KW	2T6OUT2	3.4	1610	43.4	43.3	5.35	1.84	4.71 +	0.88
2 Ckts CCR T-6, Step 3	ADB - 20KW	2T6OUT3	4.1	1670	38.9	43.6	7.01	2.75	5.96 +	0.85
2 Ckts CCR T-6, Step 4	ADB - 20KW	2T6OUT4	5.2	1860	27.9	23.3	9.76	4.16	8.35 +	0.86
2 Ckts CCR T-6, Step 5	ADB - 20KW	2T6OUT5	6.6	1920	28.6	38.7	13.00	5.17	11.00 ++	0.86

LEGEND

C-H - Crouse Hinds
Ckts. - Circuits
ADB - ADB Alnaco
+ Circuit load small compared to rated capacity of regulator
++ Circuit load over 50% of rated capacity of regulator

TABLE 4. SUMMARY OF FIELD MEASUREMENTS, VOLTAGE AND CURRENT

Sign Legend	Step	Current At Primary Amps	Current At Secondary Amps	Voltage At Secondary Volts	Current At Lamp Amps	Voltage At Lamp Volts	PF	VA	Lamp Watts
SLC									
F | <- H ->	step 1				5.45	7.06			62
	step 3				5.68	7.64			62
A1 | 34L	fixed				6.25		0.90	150.00	62
<- A | A1	step 1				5.34	6.60	0.21		62
	step 3				6.54	9.58	0.21		62
<- 17-35	circuit	5.49	6.23	28.18			0.99	176.70	62
<- 17-35	by itself	5.57	6.33	28.78			0.99	182.00	62
LAGUARDIA									
AA | <-G->	step 2				3.14	16.40			45
	step 3				3.82	17.00			45
	step 5				6.20	17.66			45
NEWARK									
Y |AR-22L	step 2				3.34	20.64	0.73	71.20	45
	step 3				4.04	19.75	0.78	82.90	45
	step 5				6.47	18.78	0.86	124.80	45
PHOENIX									
8L | A1	fixed	5.58	5.50	22.19		37.30	0.73	129.10	50
A | A1->	fixed	5.43	5.44	22.40		31.00	0.79	132.20	50
D | E9->	2, reg	5.30	5.10						50
	3, reg		6.22			4.85	0.87	137.20	50
	3, variac				3.14	8.90	0.99	70.80	50

TABLE 5. TOTAL HARMONIC DISTORTION (THD) AS THE LOAD VARIES

Circuit/Load	Regulator	File Name	Current amps	Voltage volts	Current THD %	Voltage THD %	KVA	KVAR	KW	True PF
INPUT TO REGULATOR - FOR CIRCUITS AS INDICATED										
T/W Lights & Signs, Step 2	H-D - 20KW	T7INST2	10.2	462	70.6	1.3	4.7	1.4	3.6	0.76
T/W Lights & Signs, Step 3	H-D - 20KW	T7INST3	15.5	462	32.4	1.3	7.2	3.6	5.9	0.82
T/W Lights & Signs, Step 5	H-D - 20KW	T7INST5	42.4	462	9.8	1.4	19.6	5.0	18.9	0.96
OUTPUT FROM REGULATOR - FOR CIRCUITS AS INDICATED										
T/W Lights & Signs, Step 2	H-D - 20KW	T7OUTST2	3.3	1050	**22.6**	**47.0**	3.44	1.3	**2.79** +	0.81
T/W Lights & Signs, Step 3	H-D - 20KW	T7OUTST3	4.1	1280	**15.0**	**35.1**	5.23	1.8	**4.54** +	0.87
T/W Lights & Signs, Step 5	H-D - 20KW	T7OUTST5	6.7	2590	**7.0**	**21.9**	17.00	3.85	**16.00** ++	0.96
T/W Lights & Signs, Step 2	ADB - 20KW	T1OUTST2	3.4	1390	**44.7**	**38.6**	4.78	1.54	**4.5** +	0.94
T/W Lights & Signs, Step 3	ADB - 20KW	T1OUTST3	4.1	1690	**37.4**	**30.2**	6.95	1.9	**6.65** +	0.96
T/W Lights & Signs, Step 5	ADB - 20KW	T1OUTST5	6.6	3040	**12.6**	**7.6**	20.00	2.74	**20.00** ++	0.99

NOTE

Numbers in bold show the variation of THD with respect to the load.

LEGEND

H-D - Hevi-Duty ADB - ADB Alnaco
T/W - Taxiway
\+ - Circuit load small compared to rated regulator capacity
++ - Circuit load 80% and above of rated regulator capacity.

TABLE 6. IMPACT OF CIRCUIT CONFIGURATION ON HARMONICS AND IMPACT OF HARMONICS ON POWER FACTOR

Circuit/Load	Regulator	File Name	Current amps	Voltage volts	Current THD %	Voltage THD %	KVA	KVAR	KW	True PF	KVAR/KVA (OUTPUT)
INPUT TO REGULATOR - FOR CIRCUITS AS INDICATED											
Ex. Lts Step 1	ADB - 15KW	DISK2-23	23.5	492.1	78.3 (3)	2.0 (3)	11.6	8.6	2.9	0.25 (4)	
Ex. Lts Step 3	ADB - 15KW	DISK2-21	33.0	490.4	61.1 (3)	2.4 (3)	16.1	12.1	6.2	0.38 (4)	
Ex. Lts Step 3	C-H - 15KW	DISK2-5	14.0	491.9	38.1 (3)	1.6 (3)	6.7	1.0	6.2	0.92 (4)	
New Lts, Step 5	ADB - 30KW	ICCR104A	71.0	488.2	44.0 (3)	2.4 (3)	34.0	27.3	14.8	0.40 (4)	
OUTPUT FROM REGULATOR - FOR CIRCUITS AS INDICATED											
Ex. Lights, Step 5	ADB - 30KW	OCCR6A	20.0	1296	4.5 (1)	12.4 (1)	26.0	6.20	25.0	0.97	0.24
New Lights & Signs Step 1	ADB - 7.5KW	O1061A	4.8	1601	107.0 (2)	128.0 (2)	8.1	3.37	6.7	0.82	0.42

NOTES

(1) Low THD, increased power factor - Low KVAR/KVA
(2) High THD, reduced powr factor - High KVAR/KVA
(3) Input voltage THD low and unchanged at each circuit configuration.
Input current THD high and varies as circuit configuration changes.
(4) As input current THD decreases input power factor is improved.

LEGEND

C-H - Crouse Hinds
Ex. - Existing
ADB - ADB Alnaco
Lts. - Lights

TABLE 7. IMPACT OF TOTAL HARMONIC DISTORTION ON APPARENT POWER (KVA)

Circuit/Load	Regulator	File Name	Current amps	Voltage volts	Current THD %	Voltage THD %	KVA	KVAR	KW	True PF
INPUT TO REGULATOR - FOR CIRCUITS AS INDICATED										
New Lights, Step 5	ADB - 30KW	ICCR105A	70.0	486.6	37.0	3.7	*33.9*	24.2	20.5	0.60
OUTPUT FROM REGULATOR - FOR CIRCUITS AS INDICATED										
New Lights, Step 5	ADB - 30KW	OCCR105A	6.6	2984	37.0	48.0	*20.0*	3.75	19.0	0.96

NOTE

Regulator is operated at 97% of its input rated current. However, it has an efficiency 60% = (20.0/33.9) *100.

LEGEND

ADB - ADB Alnaco

TABLE 8. IMPACT OF FILTERS ON TOTAL HARMONIC DISTORTION (THD)

Circuit/Load	Regulator	File Name	Current amps	Voltage volts	Current THD %	Voltage THD %	KVA	KVAR	KW	True PF
INPUT TO REGULATOR - FOR CIRCUITS AS INDICATED										
Style 5 Signs only, Step 2										
Without filter, South Vault	C-H - 30KW	ISVSGN2	33.6	492	73.5	2.5	16.5	5.7	12.1	0.73
OUTPUT FROM REGULATOR - FOR CIRCUITS AS INDICATED										
Style 5 Signs only, Step 2										
With Filter, North Vault	C-H - 30KW	ORWSN2F	5.8	39516	25.7	769.6	200.1	25.40	19.76 ++	0.10
Without Filter, North Vault	C-H - 30KW	ORWSN2	5.7	10521	28.7	177.1	62.9	21.04	14.88 ++	0.24
With Filter, South Vault	C-H - 30KW	OSVSGNF	5.8	19245	20.8	773.4	146.0	0.51	25.15 ++	0.17
Without Filter, South Vault	C-H - 30KW	OSVSGN2	5.5	6158	28.6	141.0	38.8	6.67	22.58 ++	0.58

LEGEND

C-H - Crouse Hinds
++ - Circuit load over 50% of rated regulator capacity.