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RAILROAD-HIGHWAY GRADE CROSSING SIGNAL VISIBILITY IMPROVEMENT PROGRAM

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101-2296

VOLUME I: FINAL REPORT

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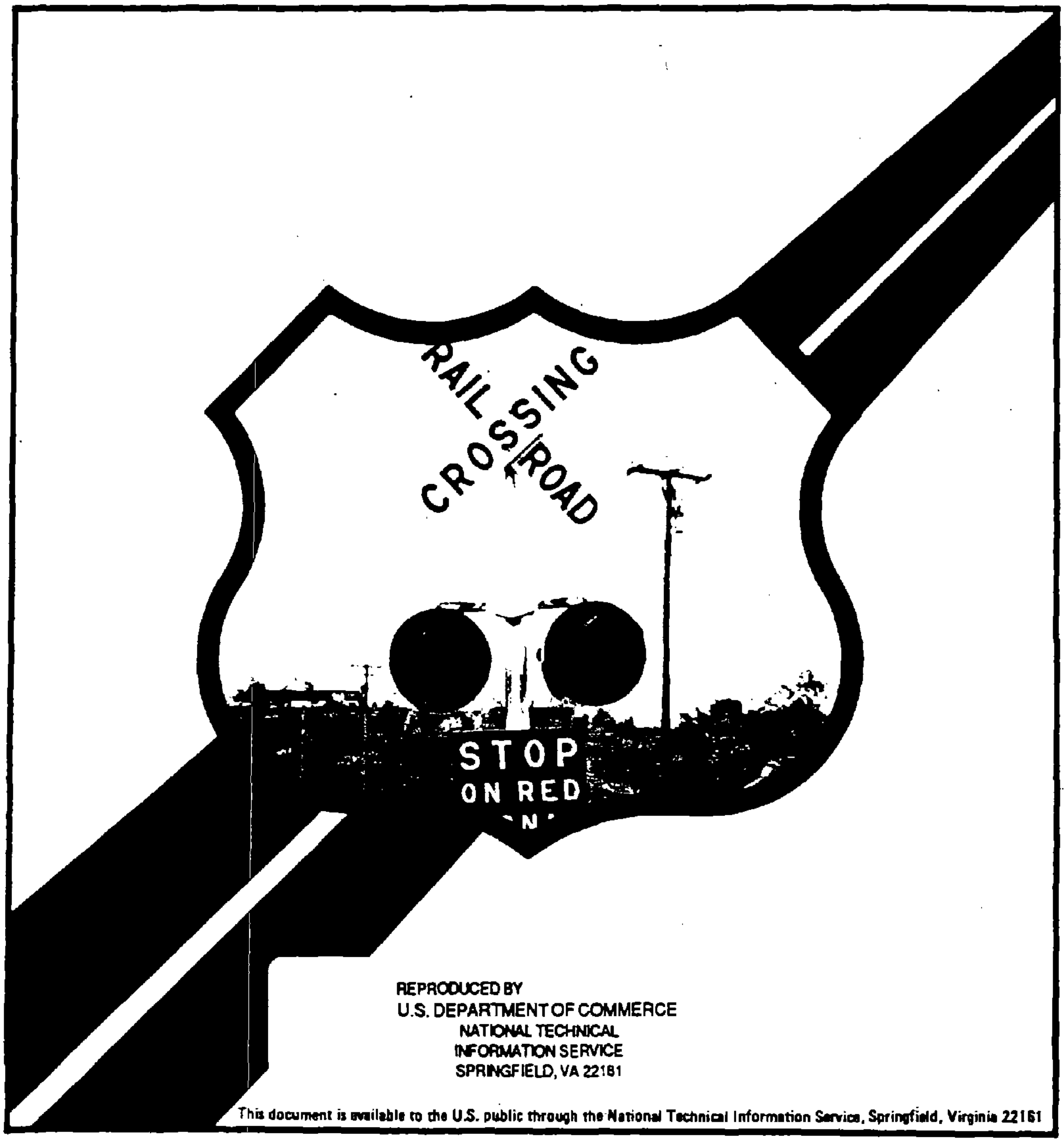
Final Report
July 1987



FOREWORD

This report documents the methodology, development, and findings of the study to improve Railroad-Highway Grade Crossing Signal Visibility. The investigation pursued two approaches to improving signal visibility: (1) modifying signal design, and (2) the development of practical maintenance tools. Several concepts were judged to have significant commercial value. The report should be of interest to Railroad Operations and Maintenance personnel and the Railroad Signal Manufacturing industry.

Research on railroad grade crossing is included in the National Coordinated Program of Highway Research, Development, and Technology as Program A.1, "Traffic Control for Safety;" Project F, "Railroad Grade Crossing." Howard Bissell is the Program Manager.

One copy is being distributed directly to each regional and division office. Additional copies are available from the National Technical Information Service (NTIS), U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

Stanley Byington

Stanley R. Byington, Director
Office of Safety and Traffic
  Operations R&D
Federal Highway Administration

NOTICE

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16. Abstract

This report documents the methodology, developments, and findings of the two-year study. Among the significant results of this project are:

1. A new set of crossing signal visibility specifications based on widely accepted definitions of motorists' requirements and a demonstration that currently available signals exceed these specifications when properly maintained.
2. The evaluation of seven alterations to standard crossing signal design and operation with respect to performance improvement and maintenance requirements. Several of these modifications offer attractive cost/benefit attributes and are recommended for implementation.
3. The development and evaluation of three tools of potential value to signal maintenance crews: an alignment scope to aid in aiming of the signal for maximum effectiveness, a signal focusing tool to aid in the critical positioning of the signal lamp with respect to the reflector, and a signal flux meter for measuring the light output of crossing and traffic signals. All of these tools were proven effective and would be useful to a conscientious maintenance team.

The prototype signal hardware underwent rigorous laboratory, environmental, and field tests. The maintenance tools were evaluated under laboratory conditions.

This volume is the first in a series. The others in the series are:

Vol. II, FHWA/RD-86/187, "Data and Hardware Details."
Vol. III, FHWA/RD-86/188, "Hardware User's Guide."

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Metric Conversion Factors.

Metric unit	Alternate Unit	Conversion
lumen/meter^2 (lm/m^2)	footcandle (ft-c)	1 lm/m^2 = 0.0929 ft-c
lumen/meter^2 (lm/m^2)	luxl	lm/m^2 = 1.000 lux
candela/meter^2 (cd/m^2)	foot-Lambert (ft-L)	1 cd/m^2 = 0.2918 ft-L
candela/meter^2 (cd/m^2)	Lambert (L	1 cd/m^2 = 0.000314 L
millimeter (mm)	inch (in)	1 mm = 0.0393 in
meter (m)	foot (ft)	1 m = 3.281 ft
meter (m)	inch (in)	1 m = 39.37 in
kilometer (km)	mile (mi)	1 km = 0.6214 mi
kilogram (kg)	pound-mass (lb$_m$)	1 kg = 2.205 lb$_m$

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EXECUTIVE SUMMARY

As a continuation of the Federal Highway Administration-sponsored investigation "Alternative Ways to Improve the Visibility of Railroad-Highway Crossing Signals" (DTFH61-81-C-00059) by Allard, Inc.,(1) this study addressed reported problems in the visibility of grade crossing warning signals. Two independent approaches were used. The first approach was to enhance the standard crossing signal's effectiveness through minor design changes that would provide a consistently brighter signal without altering the signal's familiar appearance, increasing its cost, or complicating its maintenance. The second approach was to evaluate and, if necessary, to develop devices for the signal maintainer to use in adjusting the signal and verifying satisfactory performance.

Essential to these efforts were (1) a derivation of signal performance and environmental specifications, (2) surveys of commercially available signal light hardware and photometric instrumentation, and (3) selection of hardware modifications and maintenance aids for further development and evaluation. Prototype signals were subjected to rigorous environmental and reliability tests. Prototype maintenance aids were evaluated by accuracy checks and by use in setting up and characterizing the prototype signal hardware.

The study yielded the following significant findings and developments:

- The visibility of several commercially available signal light units was shown to be more than adequate when they are properly adjusted and maintained.

- The high sensitivity of a signal's light output pattern to proper focusing was verified.

- A significant increase (~50 percent) in lamp life was demonstrated by applying a "warming current" to the lamp filament between flashes.

- A rigid, permanently focused tripod lamp mounting bracket was developed and proven effective in improving visibility and reducing maintenance requirements.

- A permanently focused integral reflector and lamp-mount assembly was developed and proven effective in improving visibility and reducing maintenance requirements.

- Evaluation of 12°-V lamp power was shown to be unacceptable for crossing signals in most situations.

- An antireflective coating on each surface of the signal roundel provided a measurable increase in light output, but the improvement was small in comparison to increases obtained by other, less costly techniques.

- A commercially available narrow-view photometer was evaluated and judged valuable in characterizing light units in a laboratory but was considered to be of limited value in the field.

- An inexpensive tool was developed for checking (and in some cases, adjusting) light unit focus in the field and for easy optimization of focus in a laboratory.

- An inexpensive tool was designed for rapid and accurate alignment of a signal light in the field.

- An easy-to-use photometer was developed for field evaluation of total light flux from signals.

1. INTRODUCTION

Summaries of the issues, constraints, and technical concepts on which the following chapters are based are presented here. Appendix A provides a summary of photometry terminology.

1.1 HUMAN FACTORS

Grade crossing signal light units and the more familiar traffic signal units are similar in many aspects of function, design and operation. Important differences exist, however. A discussion of these similarities and differences and how they relate to human factors is included as appendix B. The primary human factor concern in designing grade crossing warning signals is the signal's ability to get the driver's attention and to be recognized in time for him to stop safely before his vehicle reaches the crossing. Thus, the signal must be visible and recognizable at a greater distance from the crossing than the distance traveled during the driver's recognition/reaction period and stopping time. This distance is a function of the driver's visual acuity and color sensitivity, his reaction time and skill, the type and condition of his vehicle, the approach velocity, and the road surface and condition.

The widely accepted color sensitivity for a "standard observer" as described on the "photopic curve" (fig. 1.1)(2) indicates sensitivity to red or even orange-red light is 50 percent less than the sensitivity to yellow-green light--a negative finding for designers of red warning indicators. Brown and Cole(3) established the intensity requirements for detection and recognition of a red traffic light (the same criteria usually applied to crossing signals) against a bright sky background as graphed in figure 1.2. The slight color differences between traffic signals and crossing signals are not significant for this study (except as applied to certain color-blind observers) because the dependent variable is light intensity. (See the discussion of photometric units in appendix A.)

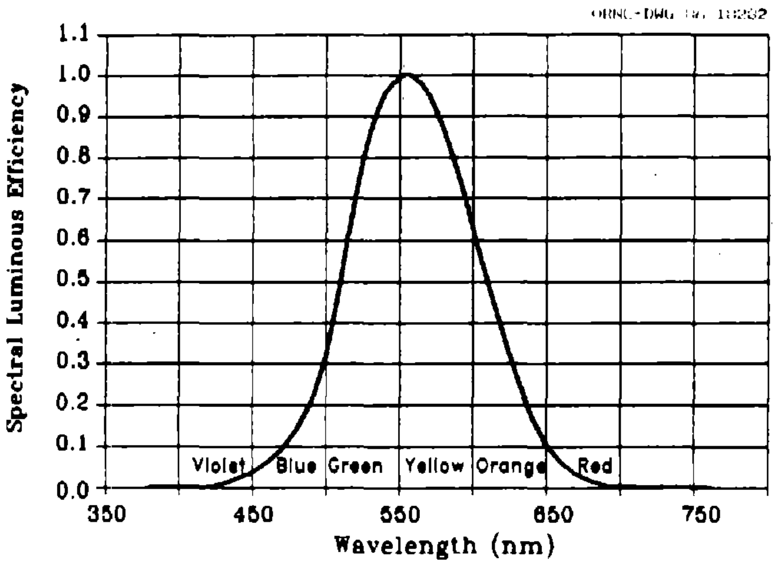

Figure 1.1. Photopic curve. Peak value (555 nm) = 680 lm/W. (Commission International De L'Eclairage, 1924, as referenced in IES Lighting Handbook, Illuminating Engineering Society of North America,1984).

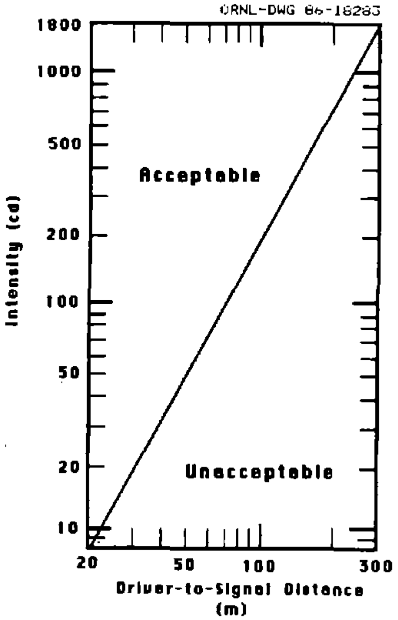

Figure 1.2. Intensity required for recognition as a function of viewing distance (Background luminaces = 10,000 ft-L) (Cole, B.L. and Brown, B., "Specification of Road Traffic Signal Light Intensity,"Human Factors, June 1968).

The time required for a driver to recognize a clearly visible signal and react to it (apply brakes) varies from subject to subject, as do braking distances for different driver/vehicle combinations. To determine visibility distance requirements, the Federal Highway Administration (FHWA) uses the data graphed in figure 1.3, corrected for road surface conditions.(4)

Data in figures 1.2 and 1.3 are sufficient for calculating signal intensity specifications for the signal configurations used for various crossing geometries.

An overly bright signal's glare can cause the driver enough discomfort so that he diverts his eyes and risks missing other important indications. Glare also can saturate the rods and cones in his retina, requiring recovery time before effective vision returns, especially at night when the driver's pupils are dilated to admit the maximum amount of light. While glare is seldom a problem with red signals, a signal visible in bright daylight can be dimmed by 70 percent between dusk and dawn without sacrificing visibility (assuming a nondistracting background).(5) Automatic dimming devices, whether controlled by timers or by ambient light measurements, should be overridden in the presence of dense fog.

Given steadily and brightly illuminated objects of similar color and finish, viewers can discern differences in luminance as small as 3 percent.(6) Brightness variation among flashing lights is harder to detect, but it would be unrealistic to require that signal lights on the same mast be near enough equal in brightness so that differences would be undetectable. Even new, well-adjusted signals from the same manufacturer vary more than 50 percent in output intensity.

Conspicuity, the attention-getting effectiveness of a signal, is the product of visibility and a factor that takes into account color

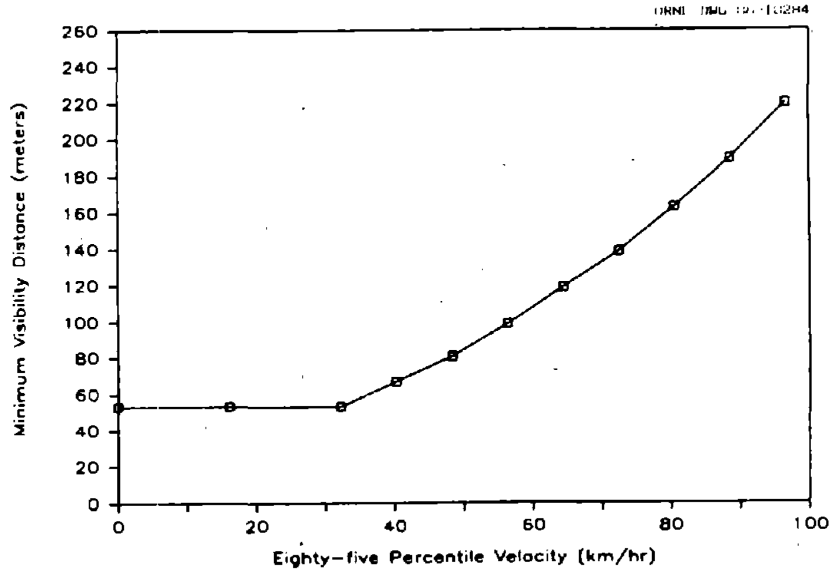

Figure 1.3. Required visibility distance as a function of approach velocity. [Manual on Uniform Traffic Control Devices for Street and Highways, Federal Highway Administration, Washington, D.C., 1978 (revised 1986)] (1 km/h = 0.62 mi/h, 1 m = 3.28 ft).

contrast, novelty, modulation, animation, background composition, size, and placement.

1.2 THE SIGNAL LIGHT UNIT

The standard crossing signal light has three optical components: the lamp, the reflector, and the roundel (fig. 1.4). Other components give mechanical support, provide electrical power, and shelter internal components from the elements. The lamp (light source) is positioned with its filament at the focal point of the parabolic reflector, which captures the light, collimates it, and directs it to the roundel, where it is filtered and distributed in the desired output pattern.

Despite the apparent simplicity of this system, numerous conditions can (and do) degrade signal performance: roundels can be dirty, loose and out of position, damaged, or improperly applied; reflectors can be dirty, damaged, loose, or warped; lamp envelopes can be dirty or age-blackened; units can be out of focus (lamp improperly

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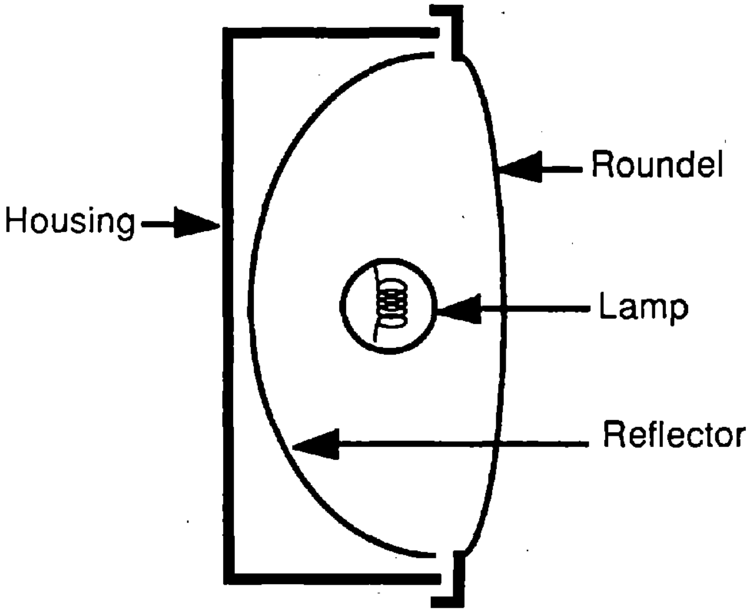

Figure 1.4. Optical components of a crossing signal.

positioned with respect to reflector); units can be misaligned (aimed improperly); or units can be operating below recommended voltage.

Many variations are found in signal designs available from different vendors (enumerated in sect. 3). There are, however, design principles common to all units.

Roundels are designed to provide specified output patterns when light from the source is perfectly collimated. The degree to which collimation is achieved in a crossing signal depends on (1) the position of the light source, (2) the shape and surface quality of the reflector, and (3) the degree to which the source approximates an ideal point source. In an ideal paraboloidal reflector, light rays captured from a point source at the focal point would be directed in a uniform beam parallel to the axis of symmetry. Real lamps, however, have filaments of finite size, so, at best, only one point of the filament can be at the focal point. Because light from other parts of the filament is not perfectly collimated a spreading, nonuniform beam profile results. Mispositioning the filament by as little as 1 mm (0.04 in) from a typical 12-inch deep-dish reflector's focal point can reduce the beam's on-axis intensity by one-half. Signal maintainers cannot be expected to adjust focus to this precision without a special-purpose instrument. Although misfocus will have a smaller effect on the beam profile when a lamp with a larger filament is used, the beam will always have more spread than those produced by small filaments.

The importance of misalignment varies with the roundel beam pattern, but in the worst case--a long-range roundel designed for straight approaches--a 3° misalignment can reduce beam intensity at the target location by one-half. This accuracy is not as difficult to achieve as is the focusing requirement, but it is still unreasonable to expect a signal installer or maintainer to achieve consistent alignment unaided. One signal manufacturer has built into its signals a small peepsight for this purpose.

Current research in signal visibility improvement does not appear to address the problems affecting conventional signals. The research is, instead, directed toward increased conspicuity through "innovative" designs incorporating strobe lights or other hardware involving radically different appearance or operation. While some of these new signals may gradually be adopted by the industry, the familiar pair of alternately flashing round red lights will be with us for some time and can benefit from further development.

2. SIGNAL SPECIFICATIONS

An examination of the crossing signal environment is discussed and suggested specifications for environmental testing are presented. Signal intensity specifications based on stopping distances and visibility criteria also are presented.

2.1 CROSSING SIGNAL ENVIRONMENT

2.1.1 Temperature

The typical low temperature for a January morning in northeastern North Dakota is -23°C (-10°F), with temperatures dipping below -31°C (-25°F) on some mornings. By contrast, temperatures on a typical August afternoon in a substantial portion of southeastern California and southwestern Arizona will peak over 41°C (105°F), with highs each year over 46°C (115°F). In direct sunlight on a hot day, the temperature of a metal enclosure can rise 22°C (40°F) above ambient. [The temperature inside the Signal Cycling Test Stand cabinet used in this study exceeded 60°C (140°F) during the summer.] A signal should be designed to survive the elements anywhere in the 48 contiguous United States, but it need not meet specifications when weather conditions bring highway and/or rail traffic to a halt. [Few automobiles are equipped to operate outside the -37°C to 46°C (-35°F to 115°F) range].

2.1.2 Humidity

Humidity varies from 15 percent to condensing (100 percent) under fairly common conditions. Thus, although signal lights probably do not meet intensity specifications with condensation on the reflector or roundel, moisture should evaporate shortly after the lamp begins flashing as the signal warms to above-ambient temperature.

2.1.3 Shock

An empty aluminum beverage can striking a signal at 18 m/s (40 mi/h) would impart a 10-ms shock of about 5 g (49 m/s^2). A glass bottle moving at the same speed would yield a shock an order of magnitude higher. The shock from a deer-rifle slug moving at or near muzzle velocity would be on the order of 2,000 g (20 km/s^2) in peak value. Yet signals with metal reflectors have continued to operate after sustaining damage from deer rifles, albeit with reduced (approximately 80 percent of normal) output.

2.1.4 Vibration

Signal mast vibration levels associated with train and vehicle traffic are low--1 or 2 g at frequencies below 10 Hz. The highest vibrations measured, however, came from the clanging bell on top of the mast and from gate operation. Setting specifications higher than these levels to include vibration experienced during transport would be desirable.

2.1.5 Wind

Because supporting structures are more susceptible to wind damage than are the light units, the specifications for signal units should be set equal to or higher than those for masts, crossarms and cantilevers [160 km/h (100 mi/h) steady load with 30 percent gusts(7)]. Hoods and backgrounds are inexpensive and easily replaced, and damage to them should not interfere with signal operation, so wind-load specifications for them could be less stringent. Designing them to break away when wind speed reaches a certain threshold--for instance, 120 km/h (75 mi/h)--could reduce stress on the remainder of the signal structure during severe storms.

2.1.6 Background Luminance

Luminance of the western sky in the afternoon can be as high as 51,000 cd/m^2 (15,000 ft-L), so signals that compete with bright conditions should always be fitted with large backgrounds. Luminance at night approaches zero.

2.1.7 Particulate Contaminants

Concentrations of up to 100,000 particles/cm^3 and 1 mg/cm^3 have been observed in urban environments on singularly bad days, but levels on a typical steamy August afternoon are an order of magnitude smaller. Crossing signals near construction sites or steam plant ash dumps may receive even higher exposure and require more frequent cleaning.

2.2 SUGGESTED SIGNAL TEST SPECIFICATIONS

2.2.1 Unacceptable Results

When the signals are tested, none of the following effects shall be observable:

- Broken, cracked, warped, or loosened components,
- Defocusing,
- Wrinkled, softened, tarnished, or flaking finishes,
- Inoperative lamps,
- Reduced dielectric standoff voltages, or
- Substandard output.

2.2.2 Test Preparation

Lamps shall be cycled from off (between 0 percent and 30 percent of rated voltage) to their full rated voltage 42 times per minute for a 100-h burn-in period.

2.2.3 Temperature Cycling Test

Ambient temperature shall be cycled from -40°F to 160°F (-40°C to 70°C) and back five times, pausing 30 min at each extreme.

2.2.4 Elevated Temperature Test

Lights shall be operated at 160°F (70°C) for 250 h, flashing continuously at 42 cycles/min.

2.2.5 Vibration Test

Signal units shall be vibrated at an amplitude of 0.8 mm (0.03 in) peak displacement, sweeping vibration frequency linearly from 5 to 50 Hz at 1 cycle/min. The only coupling to the vibration should be through the conduit fitting threads.

2.2.6 Shock Test

Three 50-g shocks 11 ms in duration should be administered along each major axis. The only coupling to the shock should be through the conduit fitting threads.

2.3 INTENSITY SPECIFICATIONS

Specification tables were derived using two criteria: minimum visibility distance for traffic lights from the Manual on Uniform Traffic Control Devices(4) and minimum intensity for positive recognition of a red traffic light against a bright (34,000 cd or 10,000 ft-L) sky background as determined by Cole and Brown.(3) Computer-assisted calculations were used to verify the adequacy of these values for a wide variety of crossing geometries including straight, angled, and curved approaches and mast- and cantilever-mounted signals. The velocity of approaching traffic was assumed to be 45 mi/h for the standard roundel tables and 60 mi/h for the long-range roundel tables. In computer models, lights were aimed at a point 1.7 m (5 ft 6 in)(7) above the center of the approach lane at minimum visibility distance from the signal. Mast-mounted signals were mounted 5 m (16 ft 5 in) to the right of the center of the approach lane and centered 3 m (9 ft 10 in) above road level. Cantilevered signals were centered over the approach lane at a distance of 6 m (19 ft 8 in) above the road.

Roundel designations (e.g. 30°/15) indicate the approximate horizontal/vertical beam spread (see tables 2.1 and 2.2). Not all of these roundels are available in both 8-in and the 12-in sizes.

Table 2.1. Roundels for use in mast-mounted signals.

Roundel	Intended application (approach)
30°/15°	Straight and angled
30°/15° LR	High-speed straight and angled
70°/0°	Curved
70°/0° LR	High-speed curved

Table 2.2. Roundels for use in cantilever-mounted signals.

Roundel	Intended application (approach)
20°/32°	Curved and strait (including high-speed)

Table 2.3. Minimum intensity specification for 30°/15° roundel (intensity in kcd).

Vertical angle	Horizontal Angle Off-Axis				
	0°	1°	5°	10°	15°
-1.0°	250	75	50	15	10
0.0°	475	200	75	50	10
1.0°	150	100	50	20	10
2.5°	110	75	35	10	10
5.0°	75	50	20	10	10
10.0°	20	10	10	10	10
15.0°	10	10	10	10	10

Zonal (asymmetric) roundels were not considered because those listed adequately address all realistic approaches.

Intensity specifications in the tables that follow are conservative in that the visibility distance used allows adequate time to stop on wet roads, while intensity criteria are applied assuming a bright sky background. Although these conditions do not often occur simultaneously, they certainly can. On the other hand, the specifications represent minimum requirements; and therefore, sufficient margin should be allowed for performance degradation caused by aging, minor misadjustments, dirt accumulation, and atmospheric conditions (fog and haze) that restrict visibility.

The following requirements are recommended for all signal installations:

- The signal axis shall be aligned to a point 1.7 m (5 ft 6 in)(7) above the center of the approaching lane(s) at the minimum visibility distance (as measured along the center of the lane) (fig. 1.3).

- Roundel selection must ensure that intensity at all points along the approach between the alignment point and a point 10 m (33 ft) from the signal exceeds that shown in figure 1.2. These intensity levels may be reduced by as much as 70 percent for nighttime operation if the backdrop is free of distracting lights.(5)

- Intensity, as measured at the alignment point, shall not vary more than 40 percent between lights in a signal pair.

- Exitance at any point of the outside roundel surface shall not vary more than +100 percent or -50 percent from the roundel average. This measurement must be made with a photodetector having an active area of 7 cm^2 (1 in^2) or less. Roundel hot spots introduced intentionally are excluded from this restriction.

Specifications are furnished for horizontal and vertical angular displacements with respect to the beam axis (tables 2.3 through 2.7). Current industry-standard specifications(7) (for horizontal spread only), are slightly higher than these figures in most cases. Values from the table for the 70° roundel are compared in figure 2.1 with current specifications of the Association of American Railroads (AAR) for the same roundel and the specifications of the Institute of

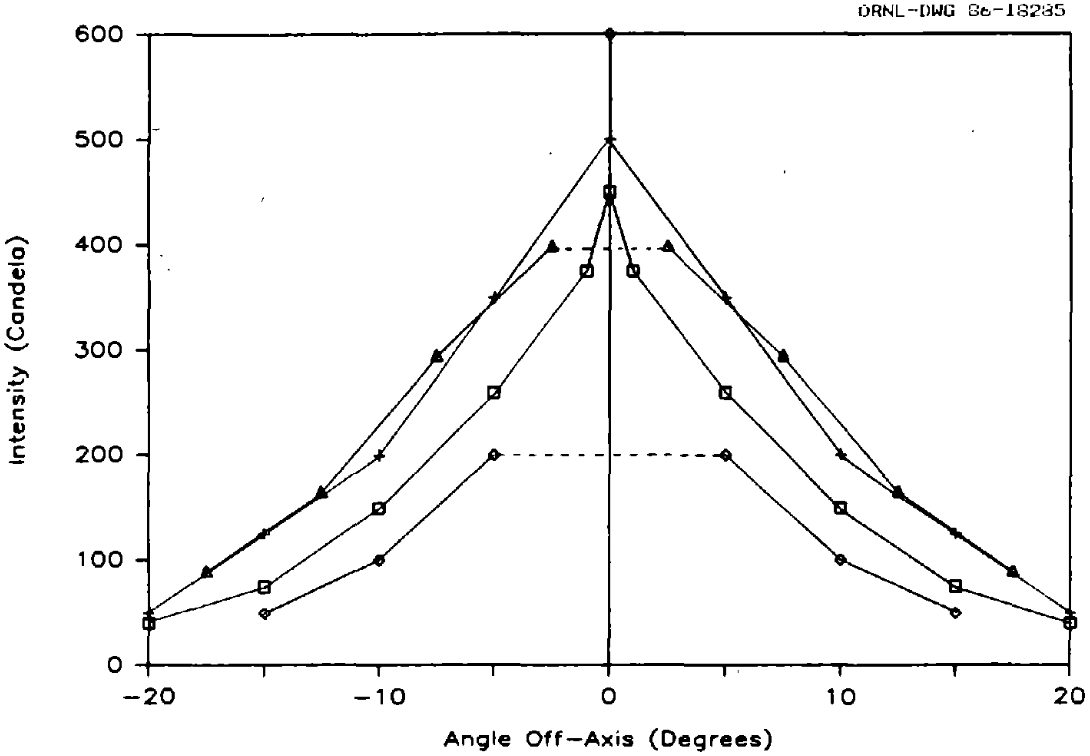

Figure 2.1. Comparison of the minimum intensity criterion for a 70° roundel in the horizontal plane with that of AAR and those from ITE and CIE for red traffic light (Signal Manual, Section 3, Association of American Railroads, 1984; A Standard or Adjustable Face Vehicular Traffic Control Signal Heads, Technical Report #1, Institute of Traffic Engineers, Washington, D.C., 1970; Light Signals for Road Traffic Control, Publication CIE#48, International Commission of Illumination, Paris, France, 1980) (ITE values are for 2½°downward deflection.)

Table 2.4. Minimum intensity specification for 30°/15° long-range roundel (Intensity in kcd).

Vertical angle	Horizontal angle off-axis				
	0°	1°	5°	10°	15°
-1.0°	400	150	50	15	10
0.0°	1000	300	100	30	10
1.0°	300	150	50	10	10
2.5°	100	30	20	10	10
5.0°	50	15	10	10	10
10.0°	10	10	10	10	10
15.0°	10	10	10	10	10

Table 2.5. Minimum intensity specification for 70° roundel (intensity in kcd).

Vertical angle	Horizontal angle off-axis							
	0°	1°	5°	10°	15°	20°	30°	35°
-1.0°	250	150	100	70	50	30	20	10
0.0°	450	375	260	150	75	40	20	10
1.0°	250	150	100	70	50	30	20	10
2.5°	60	40	30	25	20	20	20	10
5.0°	20	10	10	10	10	10	10	10

Table 2.6. Minimum intensity specification for 70° long-range roundel (intensity in kcd).

Vertical angle	Horizontal angle off-axis							
	0°	1°	5°	10°	15°	20°	25°	35°
-1.0°	500	350	250	150	110	60	30	10
0.0°	875	795	550	275	125	100	40	10
1.0°	500	350	250	150	110	60	30	10
2.5°	100	75	40	25	20	20	20	10
5.0°	30	20	15	10	10	10	10	10

Table 2.7. Minimum intensity specification for 20°/32° roundel (intensity in kcd)

Vertical angle	Horizontal angle off-axis					
	0°	1°	5°	10°	15°	20°
-1.0°	350	325	300	275	125	75
0.0°	975	775	525	300	150	100
1.0°	350	325	300	275	125	75
2.5°	175	130	125	110	100	60
5.0°	100	80	60	45	35	20
10.0°	50	40	30	30	30	20
15.0°	25	25	20	20	20	20
20.0°	15	10	10	10	10	10
30.0°	10	10	10	10	10	10

Traffic Engineers (ITE) and the Commission Internationale de l'Eclairage (CIE) for red traffic signal lights.

Because measurements used in this study have shown that a properly adjusted 12-in signal fitted with a 20°/32° roundel and a 10-V, 25-W lamp provides sufficient light, the specifications for this roundel have been written to cover high-speed approaches.

3. HARDWARE OPTIONS

This section details alternative configurations for grade crossing signal lights and examines instrumentation of potential use to signal maintainers and inspectors. Advantages and disadvantages of each are discussed, and the reasons are given for selecting approaches for further investigation in this study.

3.1 SIGNAL HARDWARE OPTIONS

3.1.1 Size

Twelve- and eight-in units are in use. Although the visibility criteria presented earlier are stated in units of intensity and are independent of signal size, recent literature suggests that larger units have a better target value and produce less glare at close range.(8)

3.1.2 Lamps

In size and appearance standard crossing signal lamps are similar to automobile turn signal and brake light lamps, but they differ in two important respects: crossing signal lamps operate from 10-V power and their filaments are precisely centered ± 0.4 mm (0.016 in) around a point on the lamp's axis of symmetry and 31.7 mm (1.25 in) from the base locator pins.

Incandescent lamps have the lowest initial cost of all lamp types. Their luminous efficacy range is from ~12 lm/W for a 120-V, 100-W lamp and a filament temperature of ~2400°C to ~22 lm/W for a 10-V, 25-W lamp having a filament temperature of ~2600°C. Their lifetimes are marginal (about one year in moderately heavy service, i.e., twenty trains per day). Quartz-halogen lamps offer higher efficacy (~32 lm/W), as a result of increased filament temperature (over 3000°C). Halogen lamps have longer lifetime ratings (at least 50 percent longer for continuous duty), and their envelopes blacken less than those of incandescent lamps, resulting in a more uniform output over lamp life.

Compact filament structures, such as the C-6 and CC-6 helical and double-helical coils, permit tight beam patterns and increased efficiencies (more lumens per watt) and offer greater shock resistance. Long filaments make beam profiles dependent on filament orientation, and higher voltage ratings usually dictate greater filament lengths.

Reflectorized globe lamps have been available in the past and have the potential of almost doubling the amount of light collimated by the reflector but are no longer commercially available, reportedly because of limited lifetimes, quality control problems, and incompatibility with many available crossing signal lights.

Sealed-beam construction offers several attractive features, including permanent focusing and a reflector that stays clean. The cost of a precision 12-in unit would be more than $100 per unit in volume production. Using conventional sidelights would be precluded with a sealed-beam lamp, and the lamp would be more vulnerable to vandalism than standard lamps.

Incandescent lamps with 18-W and 25-W power ratings and quartz-iodide lamps with 16-W and 36-W ratings are available for 10-V operation. The 10-V, 16-W halogen lamp has visible output approximately equal to the 10-V, 25-W incandescent lamp. Older signal installations may be restricted to low-powered lamps because of limited current capacity in the control hardware and power cables.

A 120-V, 25-W lamp is available for crossing signals, but 120-V traffic signal lamps could conceivably be adapted for this duty. Because back-up power for 120-V systems would be nonstandard and very expensive, maintainers would have to use extra caution when working around exposed terminals in a signal control cabinet.

Flashing signals lamp life may be extended by 50 to 100 percent when a reduced voltage, typically 30 percent of the rated voltage, is applied to the lamp during the "off" portion of the flashing cycle. This small voltage reduces temperature cycling by keeping the filament warm enough to glow faintly during a time when it would otherwise cool to near-ambient temperature. This feature can be added to existing controllers by a simple circuit modification involving placement of two rugged zener diodes across each flasher relay contact.

Mounting a lamp in the base-up position reduces the effect of envelope blackening from filament evaporation on its output (not an issue with quartz-iodide lamps). Mountings with bases away from the reflector allow more direct illumination of the reflector and higher collimated light output, but the bases cast shadows on the hot-spots of long-range roundels. Base-to-the-side and diagonal-base orientations also are available.

3.1.3 <u>Reflectors</u>

Deep-dish reflectors capture and collimate more of the lamp's output. While metal and plastic reflectors are more vandal resistant, glass units have traditionally been made to the closest tolerances and have the best surface quality, giving the most uniform beam profile. Surfaces on front-silvered reflectors are usually protected by a thin plastic film to prevent scratching. Rear-silvering is subject to damage when reflectors are handled outside the light unit and requires closer control of glass forming during manufacture.

3.1.4 <u>Lamp Supports</u>

Current signal designs provide adjustable lamp supports but vary widely in implementation. Most brackets fix lamp position with respect to the signal housing instead of the reflector. None of the designs allows independent x-, y-, and z-direction adjustments, and this greatly complicates focusing. In some units, lamp sockets are mounted on long arms secured only by a friction clamp at one end, making it difficult to relamp without disturbing focus.

3.1.5 Prefocused Lamp-Reflector Assemblies

In prefocused assemblies, lamp supports are attached to the reflector, rather than to the signal housing, so that the assembly can be focused in the signal shop. When a signal in the field needs relamping, the entire assembly is exchanged. If signals from different vendors are used, a supply of assemblies compatible with each brand would have to be maintained. A very sturdy lamp support would be required to prevent defocusing during handling and installation, and the maintainer would have to disconnect and reconnect electrical wiring during changeout.

3.1.6 Targets

Targets (backgrounds) are available in 20- and 24-in diameters. The slight premium in cost and wind load of the larger units is justified wherever bright or distracting backgrounds indicate increased conspicuity may be needed.

3.1.7 Roundels

All "old railroad red" roundels should be taken out of service because of the low optical transmittance they provide (half the 20- to 25-percent value of the newer color) and because some color-blind drivers have trouble detecting the deeper color. A technique is needed to prevent rotation of the roundel when shock or vibration loosens the hold-down clamps and to ensure proper orientation when installed.

An antireflective coating on each surface of the roundel could improve light transmission by up to 10 percent (e.g., from 20 to 22 percent). This technique is used on quality camera lenses to reduce reflection from more than 5 percent at each glass-air interface to less than 0.2 percent across most of the visible spectrum.

Roundels are available with a variety of horizontal/vertical angular deflections (see tables 3.1 and 3.2), but not all are available in both the 8- and the 12-in sizes:

Table 3.1. Roundels available for mast-mounted signals.

Roundel (horizontal/vertical angle)	Intended application (approach)
20°/15°	Straight and angled
30°/0°	Straight and angled
30°/15°	Straight and angled
30°/15° LR	High-Speed straight and angled
70°/0°	Curved with backlights
70°/0° LR	High-speed curved
15°-5°/10° (zonal)	High-speed straight and angled

Table 3.2. Roundels available for cantilever-mounted signals.

Roundel horizontal/vertical angle)	Intended application (approach)
20°/32°	Curved and straight (including high-speed)
30°-70°/32° (zonal)	Curved and straight (including high-speed)

3.1.8. Choices for Further Investigation

Eight modifications to standard signal hardware were selected for further development and evaluation:

- Two permanently focused lamp mount brackets.
- Two quartz-iodide lamps.
- A 120-V lamp compatible with standard light units.
- An anitreflective roundel coating.
- A roundel retainer clip.
- A filament warming current.

Because lamp support technique and its effect on focus were judged to be the most critical problems in signal light design, five of the six modifications directly address this problem.

Lamp position can be disturbed during handling or relamping, and no practical field-focusing method exists to make appropriate adjustments should this occur. Two permanently focused lamp mounts were selected for development: a variation on a tripod mounting bracket suggested by the Allard, Inc., study preliminary to this investigation;(1) and an integral reflector/socket assembly. The tripod bracket fixes lamp position with respect to the signal housing, so use of this hardware presumes proper reflector positioning. Because neither of these fixtures is adjustable, proper positioning of the filament inside the lamp envelope is essential.

Both 16-W and 36-W quartz-iodide lamps were evaluated because of conflicting views held by associates on the benefits of halogen lamps. Antireflective roundel coatings were chosen because of the promise of a significant gain in output with no penalty in either power consumption or recurring costs.

A simple clip was devised to aid in proper roundel orientation and to prevent rotation of the roundel should its clamps become loosened.

The 120-V signal lamp was evaluated in response to controversy concerning the use of 120-V power at crossings. In addition, standard crossing signals and red traffic lights were characterized to provide a dual basis of comparison for our prototype units.

3.2 MAINTENANCE AIDS

Based on our survey of industry needs, several instruments potentially of use to signal maintenance crews were selected for further development and evaluation.

3.2.1 Photometers

Except for a few special-purpose instruments, photometers measure either illuminance or luminance or both. Verifying proper signal operation in the field with available illuminance meters would be difficult because light from all extraneous sources would have to be excluded; yet the probe would have to be located several feet from the signal to get a reading that averaged output across the entire roundel.

Five photometers, representing a cross section of commercially available instruments, were considered for further evaluation. Features and performance correlated directly with price. Based on a comparison of published information on features and performance, two systems, each having a 1° active aperture, were selected for evaluation as maintenance aids. Published specifications for the less expensive of the two instruments, a Minolta Spotmeter intended for photographic use, claim an accuracy of 4 percent of reading. The other system, a Tektronix model J16 photometer with a model J6523 luminance probe which had a specified accuracy of 5 percent of reading was subsequently used in signal characterizations. This instrument has the minimum features and performance deemed necessary for field use, but its $3,000 price is at the upper limit of what most railroads would probably be willing to invest for this purpose.

Selected for further development was a special-purpose photometer design described in the Allard study.(1) This photometer measured exitance at 42 points on the surface of the roundel, performed an averaging function, and gave an indication proportional to the total light flux from the signal. This flux is given by

$$\varnothing = \varnothing_f \times T_g \times [(R_r \times F_r) + F_l] \times T_l,$$

where

$\varnothing_f$ = total luminous flux from lamp filament,
T_g = average transmittance of lamp globe,
R_r = average reflectivity of reflector,
F_r = fraction of lamp output captured by reflector,
F_l = fraction of lamp output radiated directly to lens,
T_l = average transmittance of lens (roundel).

A low reading from the flux meter would indicate: (1) a high-resistance lamp filament or low lamp voltage, (2) a darkened or dirty lamp envelope, (3) a damaged or dirty reflector, or (4) a dark-colored or dirty roundel. Mispositioning of signal components would not be detected unless it were severe. Flux is not affected by different roundel output patterns; so for roundels of equal color and transmittance, the flux meter reading would not be dependent on the type spread and deflection of the signal's roundel. Accordingly, signals giving similar readings on the flux meter may vary widely in on-axis intensity and vice versa.

3.2.2 Focusing Tool

Based on information gathered from signal vendors and the railroads, techniques used to focus signals, even in well-equipped laboratories, seem tedious and subjective. There is a critical need for a tool that would help manufacturers focus signals before shipping and would help railroad crews inspect and optimize signal focus after reflector replacement or movement of the lamp support for whatever reason. An effort was made to develop an inexpensive, easy-to-use, instrument that would give a positive indication of focus condition.

3.2.3 Alignment Tool

Especially when long-range roundels are used, a device that would allow precise aiming of the signal could significantly improve visibility at the approach point where the driver first needs to see the signal. The tool should be inexpensive and easy to use.

4. PROTOTYPE HARDWARE

Design considerations and details for this study's prototype hardware are presented in this section.

4.1 SIGNAL HARDWARE

Prototype signal designs address the greatest problems with existing signals--optimizing and maintaining signal focus. Two permanently focused lamp mounts were devised: the first, a rigid tripod mounting bracket that attaches to the signal housing, and the second, a stud mount that attaches to and penetrates the apex of the paraboloidal reflector as do lamp mounts in traffic signals. A variation on the standard signal, using a 120-V lamp, was evaluated in response to speculation that its large filament might obviate the strict focusing requirements altogether.

4.1.1 Tripod Lamp Mount

The tripod lamp mount shown in figure 4.1 uses plastic screws to secure the welded structure to the signal housing. Insulating tabs under the tripod feet hold the reflector in place and allow one of the legs to serve as an electrical conductor for lamp power. The base-out orientation of the lamp provides full illumination of the reflector. This configuration was evaluated using several different types of lamps. A 10-V, 16-W quartz-iodide lamp used in the environmental and reliability tests, with its small, bright filament, was expected (and proven) to provide a bright, well-collimated beam. Also evaluated with this configuration were antireflective (subwavelength) roundel coatings that could theoretically give an increase of up to a 10 percent in light transmittance (e.g., from a transmittance of 20 percent to a transmittance of 22 percent). Vapor-deposited layers of magnesium fluoride (MgF_2) 130 nm thick were used for the coating.

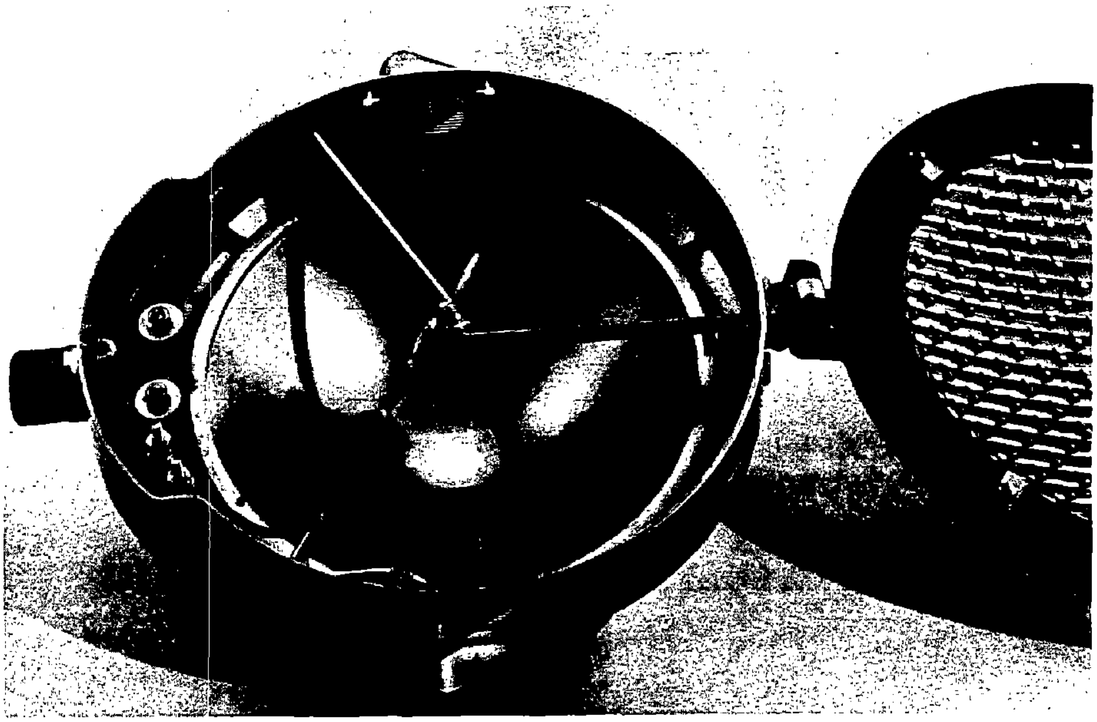

Figure 4.1. Tripod lamp mount bracket.

A clip designed to replace one of the clamps used to secure a roundel in a signal housing cover (fig. 4.2) prevents rotation of the roundel should the clamps become loosened, is compatible with any combination of roundels and signal housings currently available, and does not require modification of signal components.

4.1.2 Integral Socket/Reflector Assembly

The stud lamp mount (fig. 4.3.) threads into a plastic insulating spacer that provides crucial positioning of the lamp with respect to the metal reflector. The metal reflector is part of a retrofit kit purchased from a signal vendor (not the same vendor from which the signals used in this study were purchased). The lamp support attached to the reflector was removed for this modification. This assembly was characterized using a variety of lamps, but a 10-V, 36-W quartz-iodide lamp was used in environmental and reliability testing.

figures 4.2 & 4.3

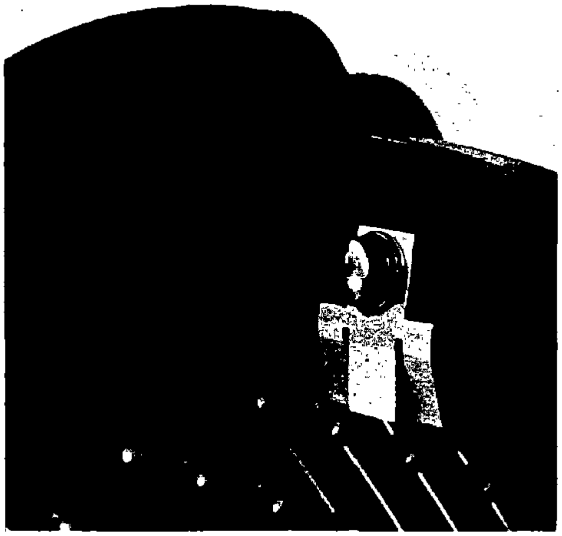

Figure 4.2. Roundel retaining clip.

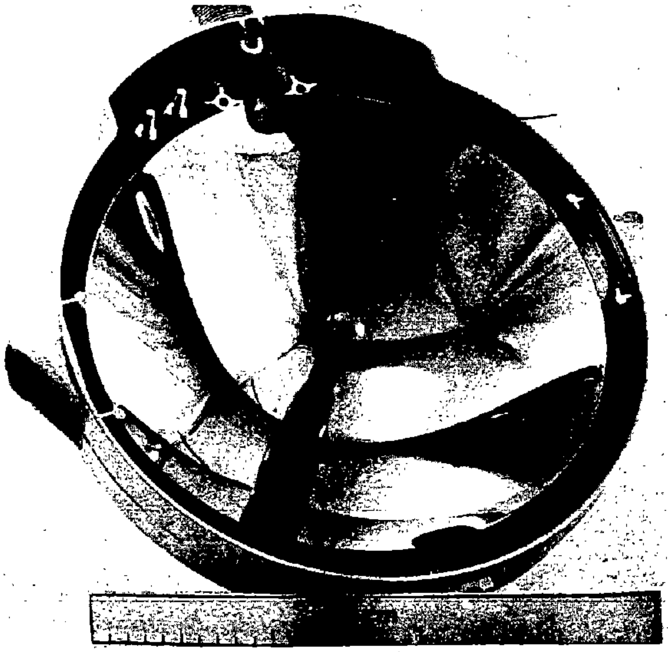

Figure 4.3. Integral socket/reflector assembly.

The fixtures were designed specifically to be used in the signals purchased for this study but would have to be redesigned to accommodate signals from different manufacturers. As with any permanently focused signal, precision placement of the filament within the lamp is presumed, as are close tolerances in the shape of the reflector. The tripod mount, in addition, presumes repeatably accurate positioning of the reflector in the signal housing.

4.1.3 120-V Operation

No modifications were made to the signal used in the 120-V lamp evaluation. The lamp used has a type C-5 filament, a type G-16 envelope, and a single-conductor bayonet (type BA15S) base.

4.2 MAINTENANCE AID HARDWARE

Two tools were developed to aid in adjusting a crossing signal for optimum visibility: a signal alignment scope and a signal focusing tool. A third aid, the signal flux meter, measures light output of crossing or traffic signals and can alert the maintainer to problems that reduce light flux.

4.2.1 Signal Alignment Scope

The signal alignment tool adapts the rifle scope principal to a crossing signal (see fig. 4.4) via a telescope mounted on three legs that rest against the rim of the reflector. The user, looking into the telescope through a right-angle prism, on the side of the signal, sees down the road along the signal beam axis to the point where the signal is aimed. Cross hairs give a positive indication of beam center. The tool is to be used when the signal housing is open and would probably be used only when some other maintenance (such as relamping) is being performed or when the signal is obviously in need of alignment. Prototype instruments indicate beam direction with an accuracy better than 10 arc-minutes (0.15°).

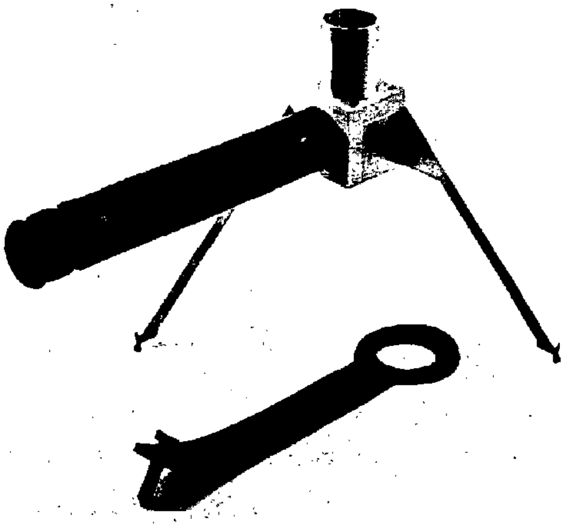

Figure 4.4. Alignment scope.

4.2.2 Signal Focusing Tool

The focusing tool (fig. 4.5) measures the position of the lamp with respect to the reflector indirectly by showing how well reflected light is collimated. Its simple principle of operation is illustrated in figure 4.6. The focal point of a convex lens is, by definition, that point where rays of light parallel to the lens's axis and reaching the lens from one side converge on the other side. The focal point of a paraboloidal reflector is that point where light rays parallel to the reflector's axis converge after being reflected. Conversely, a reflector capturing light from a point source located at its focal point will collimate the light into a beam parallel to its axis of symmetry. The axis of the simple convex lens in the focusing tool is aligned with the beam axis, and a focusing screen, similar in function to the ground-glass screen in a view camera, is oriented perpendicular to the lens axis and centered around the lens's focal point. An opaque mask passes light only through three small areas around the perimeter of the lens. (A large-diameter lens is required for high sensitivity.) The user sees three images of the lamp figures 4.5 & 4.6

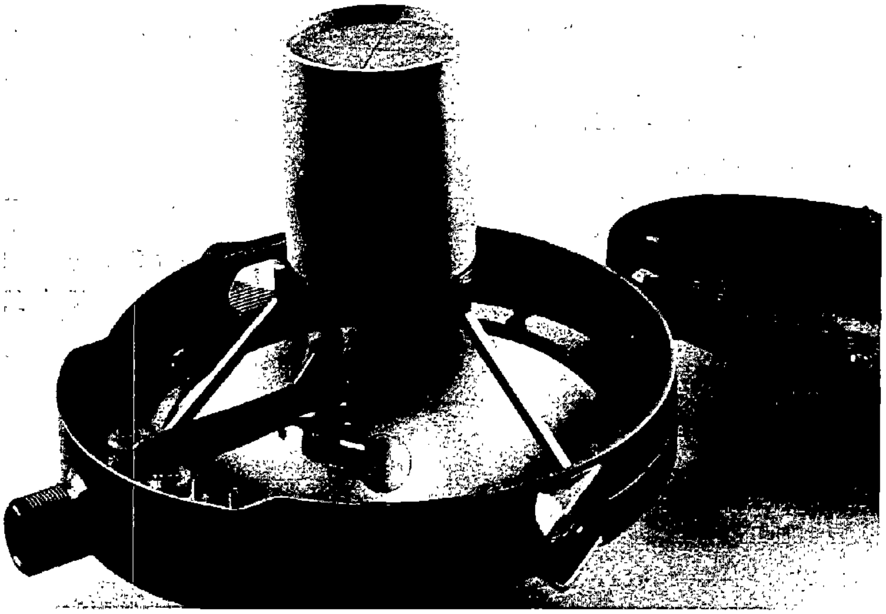

Figure 4.5. Focusing tool.

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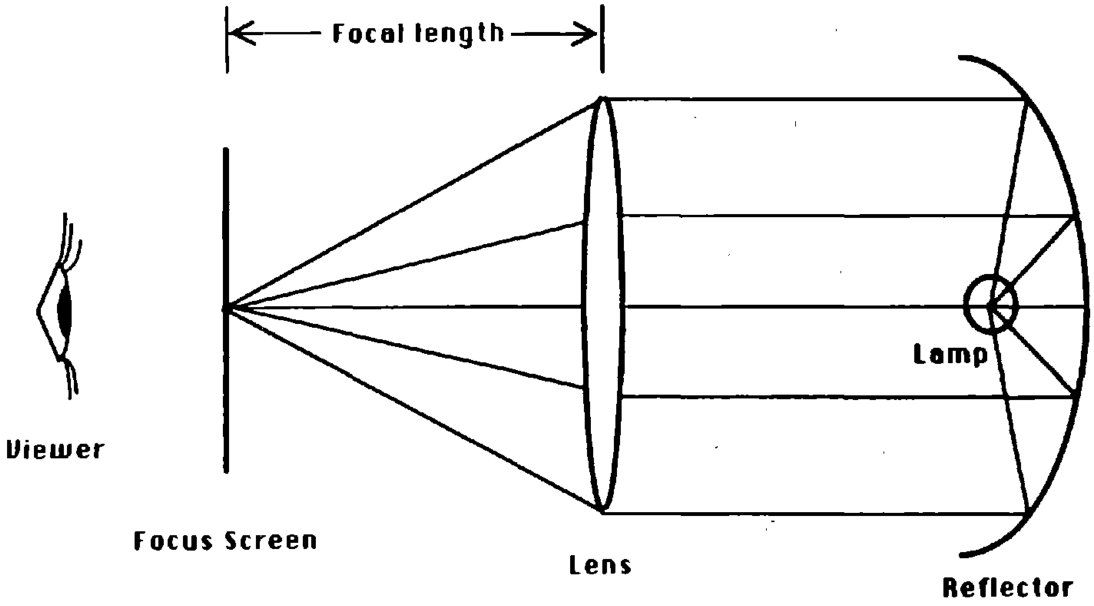

Figure 4.6. Focusing tool principle.

filament on the focusing screen. When the images converge at the center of the screen, the filament is at its optimum location. If the images converge at a point above and to the left of center, for instance, the lamp is positioned too low and too far to the right. If the images are separated, the lamp needs to be moved in or out until the images overlap.

This device provides a much clearer indication of signal focus than can be obtained through techniques used in signal shops and could improve and expedite focusing operations there. The tool could be used in the field to diagnose focus problems and, in some instances, to focus signals.

4.2.3 Signal Flux Meter

The flux meter (fig. 4.7) samples light output from 42 small areas on the face of the roundel and gives an output indication proportional to the amount of light collected. Instead of using 42 separate light sensors, fiber-optic cables gather the light samples and deliver them to an optical integrating sphere that scrambles the light from the fibers and presents it to a single photodetector. Thus, a high-quality sensor (in this case a sensitive, stable photoresistor) can be used without major impact on the cost of the instrument and without encountering problems inherent with low-cost sensors: high temperature sensitivity, drift, and high dark-currents. A simple electronic resistance-measuring circuit is used to drive an analog meter, which most often will be used to indicate either that the signal is functioning satisfactorily or that servicing is required. Signal conditions that can cause low outputs are discussed in section 3.2.1.

To quantify the human eye's perception of the brightness of a signal accurately, a photometer must have a spectral response that closely matches that of the eye. An inaccurate response, for example, can result in an unfair comparison of the output of a signal

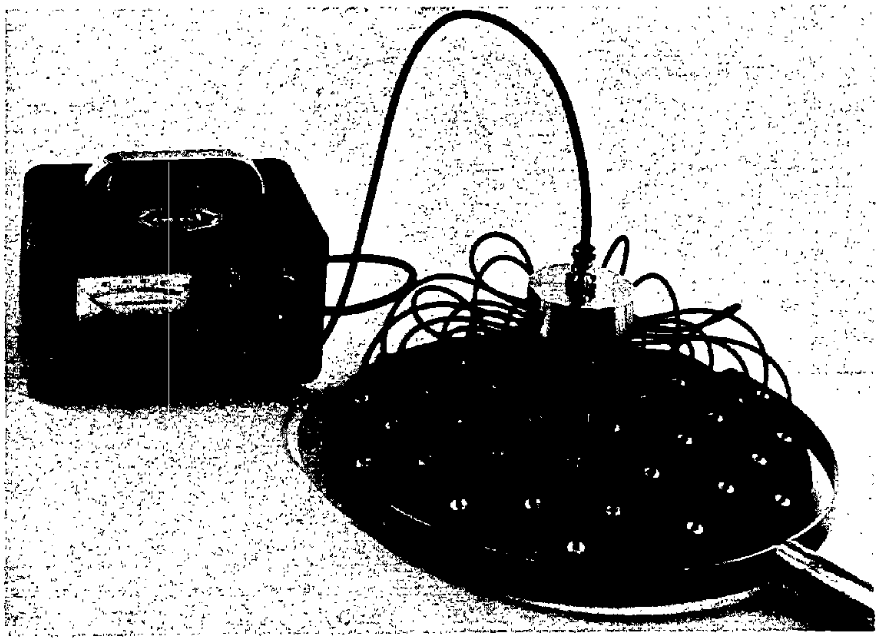

Figure 4.7. Flux meter.

illuminated by an incandescent lamp with one using a quartz-iodide lamp. Sensitivity to infrared energy will unfairly bias the comparison in favor of the incandescent lamp because of its greater infrared output. (Over 90 percent of an incandescent lamp's output is infrared.) In the flux meter, color correction and infrared filtering are accomplished with a single glass filter. The resulting spectral response is shown in figure 4.8.

Since total flux from a signal does not depend on the output pattern of its roundel, and in order to make readings independent of this dispersion pattern, no attempt was made to exclude light not parallel to the beam axis. Light from roundel hot spots was excluded, however. If an on-axis intensity measurement had been desired, the receiving ends of the fiber-optic cables could have been aligned with the beam axis and given "tunnel vision" by recessing them in tubes that blocked all light except that parallel to the axis.

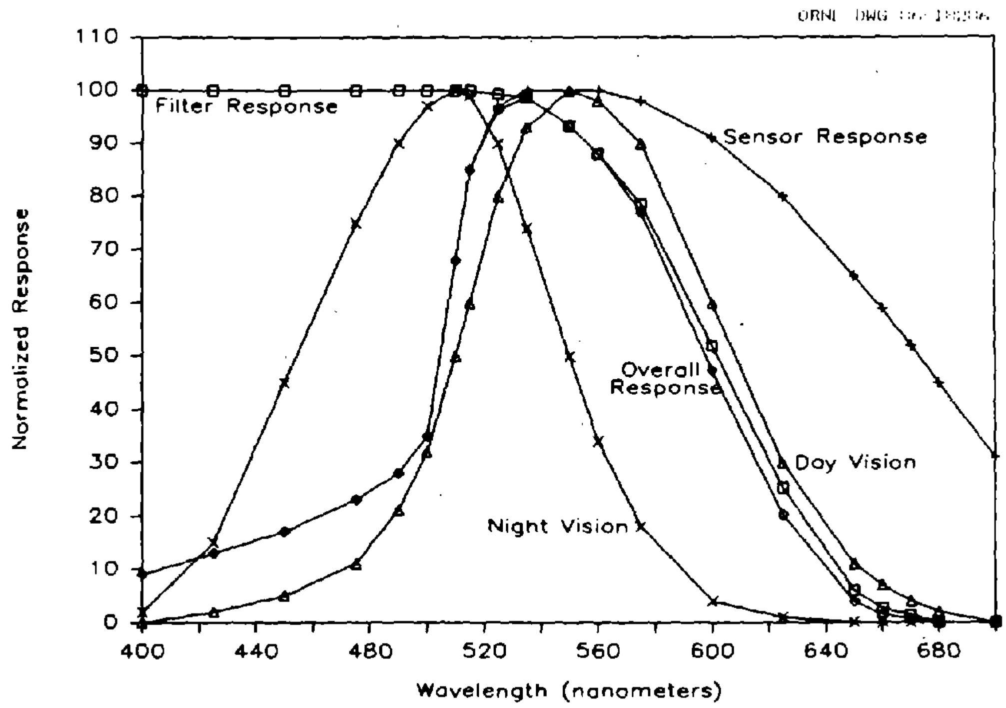

Figure 4.8. Spectral response of flux meter.

The fiber-optic cables used in this instrument were chosen for their large cross section and flexibility, resulting from the bundling of 32 plastic fibers in the core of the cable.

The sensor head is designed to be mounted at the end of a long handle so that a mast-mounted signal can be measured without a ladder. It is connected to the small electronics package by a flexible coaxial cable. A voltage output is provided for connection to an external meter or to a data collection system if desired.

5. LABORATORY TESTING

Extensive laboratory measurements were performed to (1) characterize standard signals as a basis for comparison, (2) characterize performance of the prototype signal hardware, (3) exercise and evaluate functionality of the prototype maintenance aids in actual use, and (4) characterize performance of the maintenance aids quantitatively.

5.1 SIGNAL CHARACTERIZATION

5.1.1 Test Procedure

A Tektronix Model J16 photometer and Model J6523 luminance probe were set up 14.5 m (47 ft 6 in) from the signal to be evaluated. At this distance, the signal lens filled the active aperture of the photometer when the signal was rotated by angles up to 15°. The usable luminance range of the photometer was extended, when necessary, by using neutral-density filters over the lens of the probe, allowing direct measurement of the luminance of a signal with its roundel removed.

The test signal was installed in a fixture (fig. 5.1) having provisions for precise adjustment of angular displacement around horizontal and vertical axes passing through the focal point of the signal's reflector. Lamps were operated at their rated voltage (± 1 percent).

The photometer was aligned for the highest reading on an illuminated signal. The cover of the signal was opened and the signal was aimed to give the highest photometer reading. In this relative orientation, the photometer was assumed to be on the axis of the signal's reflector, and succeeding signal orientations were referenced to this one. When 120-V signals were evaluated, the broad spread in figure 5.1

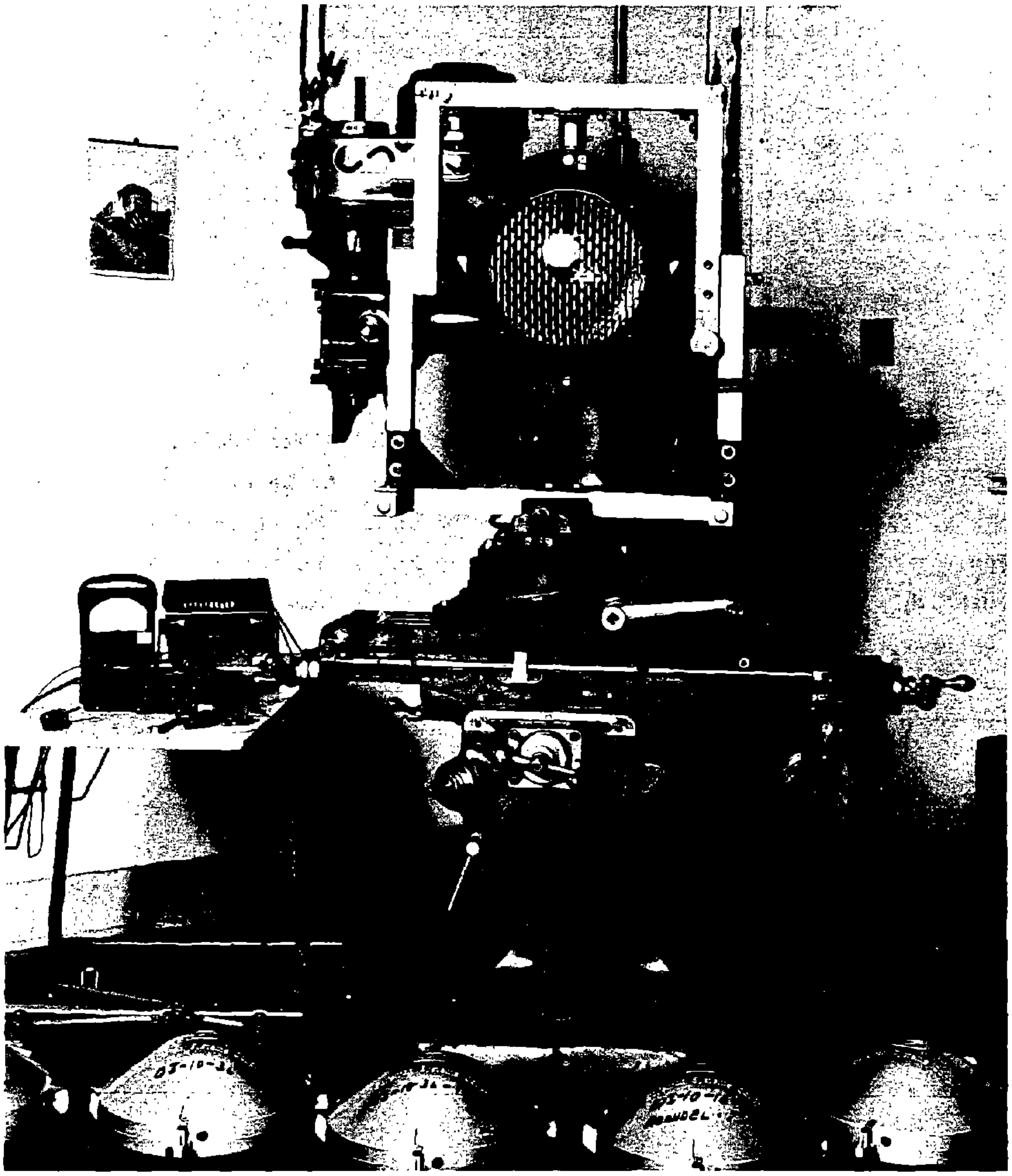

Figure 5.1. Test fixture fashioned from milling machine with rotary table.

the light output pattern made it difficult to find the axis. The alignment scope was used in these cases.

Unless otherwise specified, 30°/15° long-range roundels were used on the signals evaluated.

The terms "beam" and "beam profile," as used in this study, refer to the variation of signal output intensity with angular displacement (usually in the horizontal direction) with no roundel in place. The terms "output pattern" or "output distribution" refer to the intensity distribution after the light passes through the roundel.

The illuminated portion of the roundel in the signals was 27.7 cm (10.9 in) in diameter. Assuming that the photometer reading represented the average luminance over the face of the roundel, the conversion factor used to calculate intensity from this luminance figure can be derived as shown:

$$3.426 \text{ cd}/(\text{m}^2 \text{ ft-l})[3.142(0.138 \text{ m})^2] = .204 \text{ cd/ft-L} \quad . \qquad (2)$$

Had a full 30.5-cm- (12.0-in)-diameter illuminated surface been assumed, the conversion factor would have been 25 percent greater than the value shown in equation 2. For angles very far off-axis, this value should be reduced by an additional amount proportional to the reduction in the apparent area of the signal.

On the signals used in this study, the roundel gaskets obscured a significant amount of the illuminated roundel, reducing the effective diameter by 9.5 mm (0.375 in) and this conversion factor by 10 percent. The effect on the on-axis intensities is even greater because the flat area around the perimeter of the roundel serves as additional "hot spot" area.

5.1.2 Standard Crossing Signal

Twenty-five new signals from three procurements were received directly from the same manufacturer over a five-month period. Each bore a sticker inside the housing advising that the signals were factory focused and that the user should be careful not to disturb focusing adjustments. Each was fitted with a 10-V, 18-W incandescent lamp. On-axis intensities ranged from a high of 3.77 kcd to a low of 2.24 kcd, with an average value of 3.28 kcd.

Table 5.1 shows a test data matrix for a well-focused 12-in signal with a 10-V, 25-W incandescent lamp. These figures demonstrate an output well in excess (at some points by a factor of 25) of the minimum intensity specifications presented in section 2.3. A plot of the intensity of this signal's output in the horizontal plane is compared with our minimum visibility specifications in figure 5.2. Presentation of these data should in no way be construed as a suggestion that signal design standards be relaxed. A substantial safety margin must be maintained to allow for degradation in light output resulting from component aging and environmental exposure and for reduced visibility resulting from fog and haze.

The beam produced by a well-focused lamp/reflector system (no roundel) has a beam width slightly over 1° (as measured between half-intensity points). The horizontal beam profile for a standard fixture is shown in figure 5.3. This data was taken with the lamp filament oriented diagonally in the vertical plane. A vertical profile should show a slightly broader peak.

Mispositioning the lamp by as little as 1.4 mm (0.055 in) reduced the on-axis intensity of a standard fixture by one-half. Sensitivity to misfocus along the reflector axis is shown in figure 5.4.

Table 5.1. Beam distribution for a standard crossing signal light unit.[a]

Verticle angle	Horizontal angle off-axis								
	Left					Right			
	15.0°	10.0°	5.0°	2.5°	0.0°	2.5°	5.0°	10.0°	15.0°
-2.5°	86	100	116	149	226	153	131	133	141
0.0°	1550	2100	2630	2900	5200	2820	2630	1960	1610
2.5°	57	76	81	102	353	108	82	78	53
5.0°	65	92	97	98	98	105	96	96	67
10.0°	67	78	84	78	78	90	88	79	68
15.0°	55	59	48	44	45	47	51	61	60

[a] Intensities are given in candelas (cd).

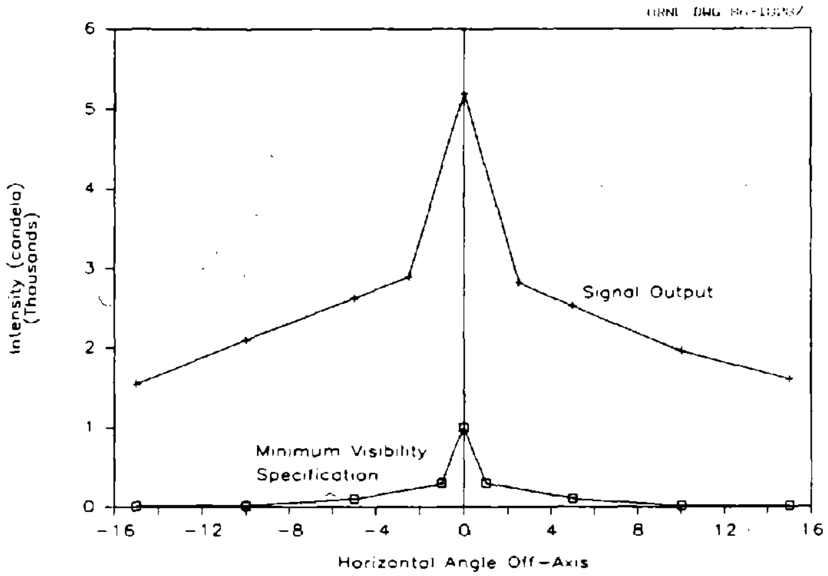

Figure 5.2. Typical output pattern (25-W incandescent lamp).

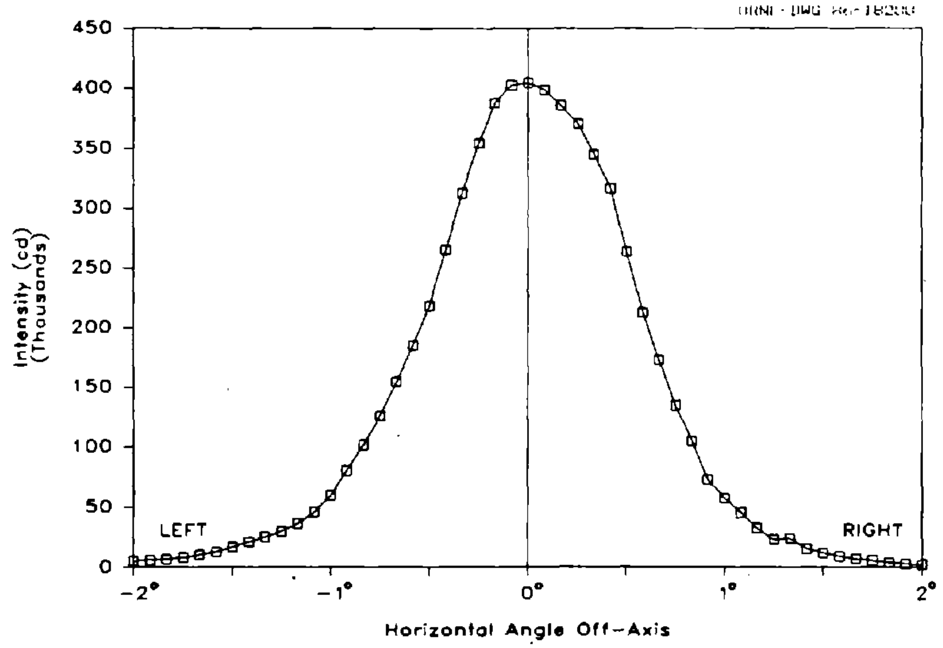

Figure 5.3. Typical beam profile (25-W incandescent lamp).

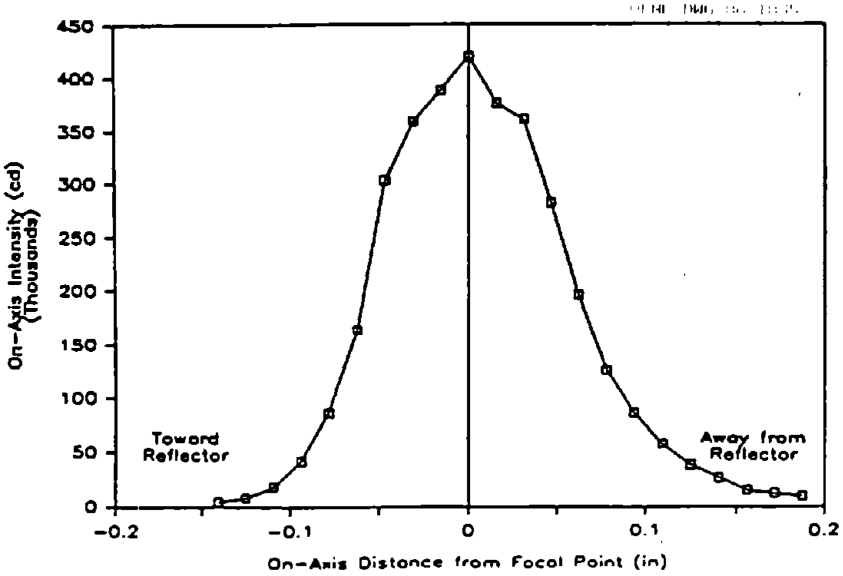

Figure 5.4. On-axis sensitivity to lamp position for standard (10-V, 25-W) lamp (1 mm = 0.039 in).

5.1.3 Incandescent Lamps vs Halogen Lamps

The 10-V, 16-W quartz-iodide crossing signal lamp has a flux rating of 502 lm, nearly equal to the 528-lm rating of the standard 10-V, 25-W incandescent lamp. Because the filament in the halogen lamp appears to be about half the length of that in the incandescent lamp, the halogen lamp was expected to produce an on-axis intensity approximately equal to that of the incandescent lamp and a beam width slightly less spread in the direction in which the filament is oriented. The data in figure 5.5 show the horizontal beam spreads for both lamps when their filaments are oriented diagonally in the vertical plane and show a remarkable similarity. With a roundel in place, however, the incandescent lamp yielded a slightly higher on-axis intensity (5.0 kcd vs. 4.6 kcd). The red roundel color apparently filters out a significantly larger percentage of the whiter light from the halogen lamp. (The difference would be even greater if an "old railroad red" roundel were used.) This value for the 10-V, 16-W halogen lamp, however, is about 40 percent higher than any

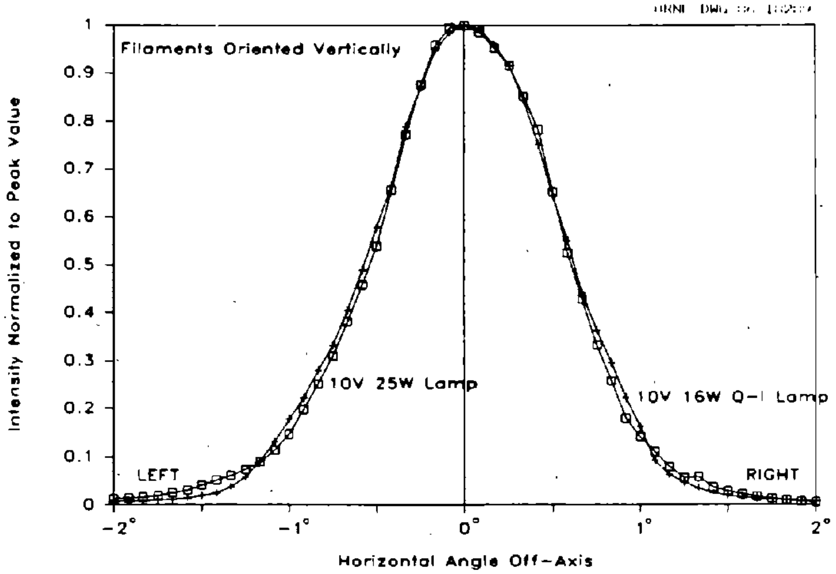

Figure 5.5. Beam profiles for 10-V, 25-W incandescent lamp and 10-V, 16-W quartz-iodide lamp.

intensity achieved with 10-V, 18-W incandescent lamps and demonstrates the higher efficiency of the halogen units.

Data plotted in figure 5.6 verify that beam quality produced by the 16-W halogen lamp is (as it should be) more sensitive to focus than that produced by the incandescent lamps as a result of its smaller filament.

The 36-W quartz-iodide lamp has a flux rating more than twice that of the 25-W incandescent lamp or the 16-W quartz-iodide lamp. Its filament is much larger and is oriented along the lamp axis. As expected, beam profile measurements showed that most of this additional light flux was uncollimated, (i.e., outside of the half-intensity beam width). In fact, on-axis intensities for 36-W halogen lamps were usually about 15 percent lower than for 16-W units.

Lamp-center length (the distance along the lamp axis from the locator pins on the lamp base to the center of the filament) for the 36-W halogen units tested seemed to be poorly controlled. Drastic

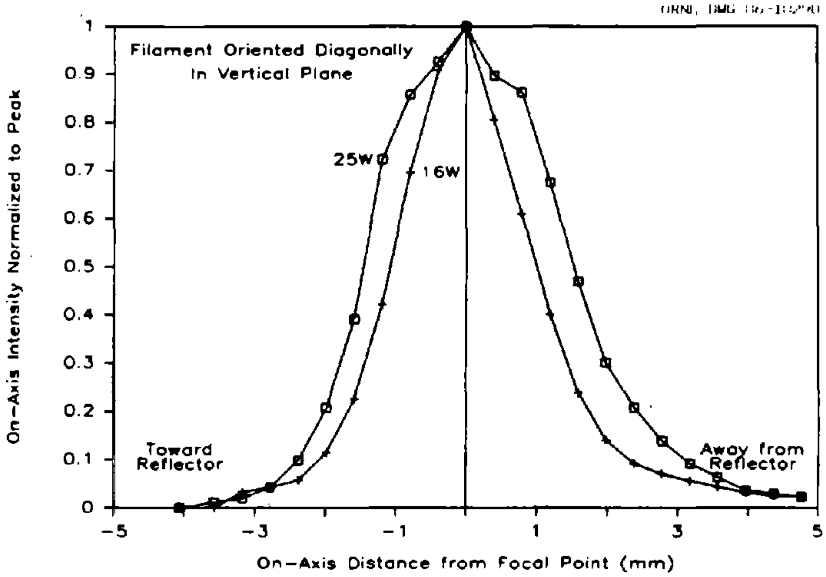

Figure 5.6. On-axis intensity as a function of misfocusing along reflector axis for 10-V, 25-W incandescent lamp and 10-V, 16-W quartz-iodide lamp.

refocusing was necessary to optimize the beam pattern when these lamps were used. Figure 5.7 shows the beam profile resulting when a 36-W halogen lamp was installed in a signal that had been factory-focused (which we verified to be very close to the optimum adjustment) with an 18-W incandescent lamp and the profile after focus has been optimized for the 36-W halogen lamp, which required moving the lamp socket approximately 7 mm (0.27 in). This was typical of our experience with 36-W units. Even if this lamp could provide a brighter signal (which we were unable to verify), this focusing problem by itself is sufficient argument against the use of the currently available 36-W halogen lamps in most circumstances.

5.1.4 120-V Power

Two approaches to the use of commercial 120-V ac power were evaluated using a 120-V, 25-W lamp compatible with standard crossing signal hardware, and using a crossing signal modified to accept the reflector, lens, and 150-W lamp from a traffic signal.

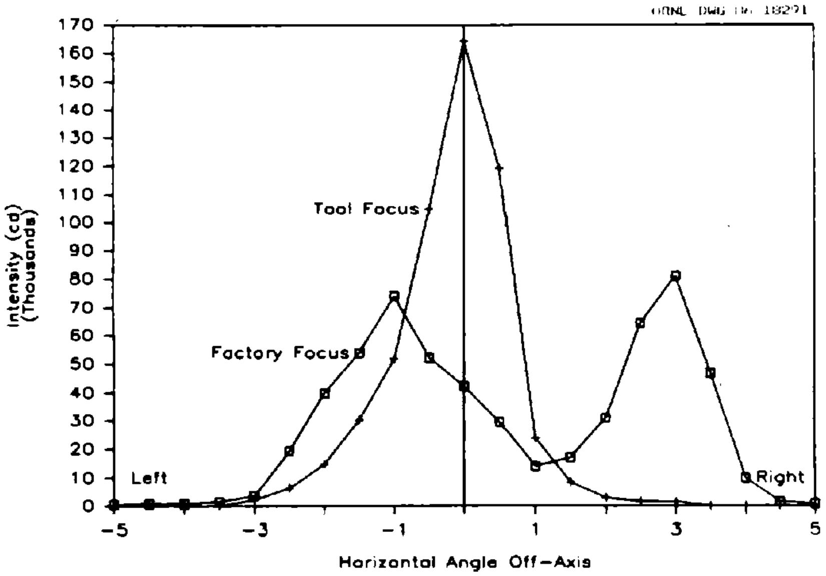

Figure 5.7. Beam profile of signal fitted with 10-V, 36-W quartz-iodide lamp when signal was focused for a standard lamp and after refocusing.

The first evaluation of these two configurations compared their output patterns to that of the standard crossing signal. The surprising results are shown in figure 5.8. The 120-V outputs are compared with the minimum intensity requirements in figure 5.9.

A severely defocused beam resulting from the large filaments in these lamps seems to be the primary cause of poor showing of the 120-V units. A lesser cause would be the lower luminous efficiency of the relatively cool 120-V filaments. The beam profiles shown in figure 5.10 support the defocusing hypothesis.

A traffic signal lamp and reflector may meet minimum intensity specifications when used with 30°/15° or 70°/0° (not long-range) roundels. (Roundel chromaticity and output pattern were not variables in hardware evaluations.) Still, visibility would be much lower than if standard hardware and lamps were used. The advantage of reduced focus sensitivity in 120-V lamps is not worth the penalty paid in visibility. Additional penalties would be exacted in the cost of

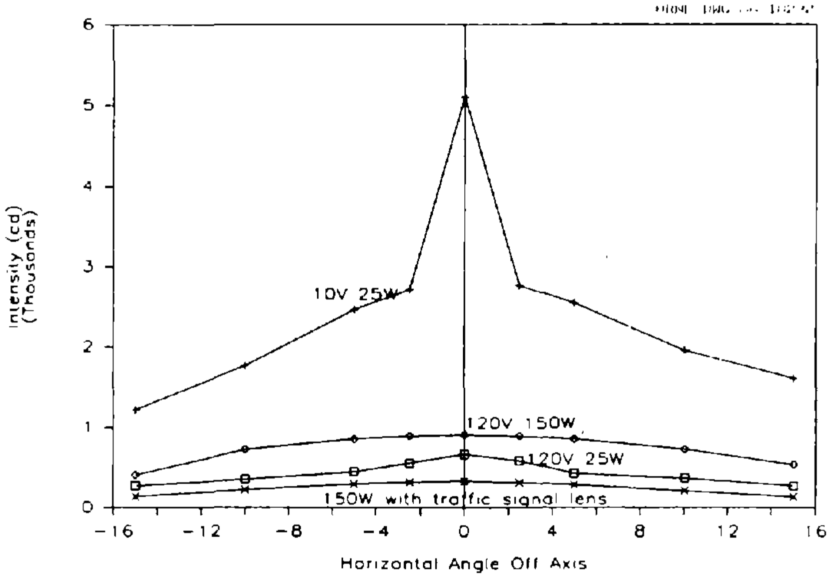

Figure 5.8. Output patterns obtained using standard (10-V, 25-W) lamp, using 120-V, 150-W, traffic signal lamp, and using 120-V, 25-W crossing signal lamp.

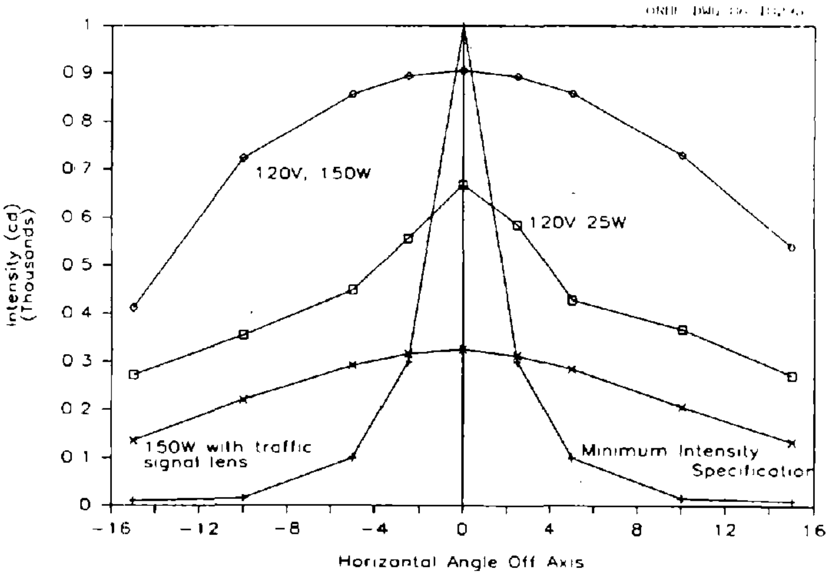

Figure 5.9. 120-V lamp output patterns compared to minimum intensity specifications (30°/15° roundel).

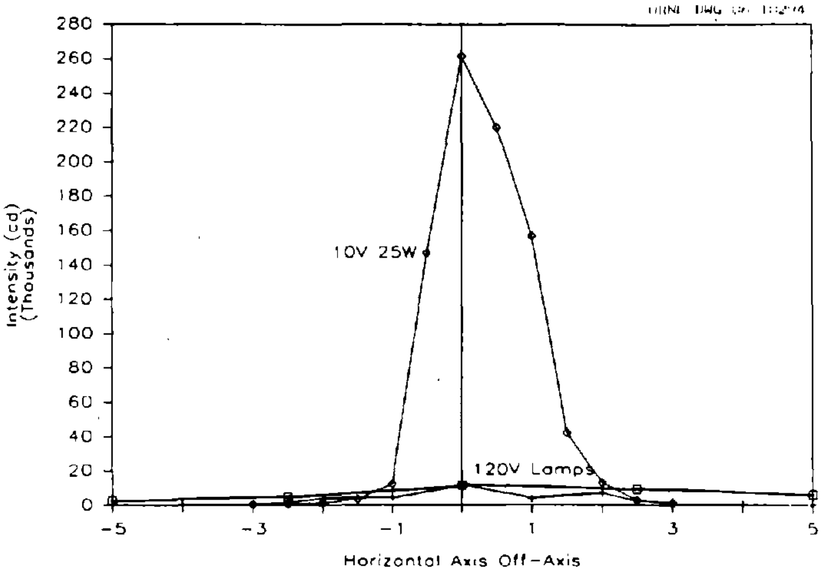

Figure 5.10. Beam profiles of 120-V (25-W and 150-W) lamps compared to standard (10-V, 25-W) lamp.

providing and maintaining backup power. Batteries capable of providing power for the same length of time would cost about 50 percent more than 10-V units, with 12 times as many battery cells requiring water-level monitoring and 12 times the chance of a faulty cell or cell interconnection disabling backup power altogether.

Conventional traffic signal hardware does not show the same attention to details affecting light output as is seen in crossing signal hardware. Even if the hardware were thoroughly redesigned for crossing signals and could boost output of these signals enough to meet the minimum output requirements, it is doubtful there would be much margin for degradation caused by lamp aging and dirt accumulation. Even less chance exists for an adequate 120-V lamp to be developed for use in standard crossing hardware. Without an unanticipated breakthrough in lamp or signal design, the use of 120-V signal power at public crossings where better-than-marginal visibility is required [where approach speeds are greater than 72 km/h (45 mi/h) or where bright or distracting backgrounds are present] cannot be recommended.

5.1.5 Prototype Signal Hardware

5.1.5.1 Tripod lamp mount. The data plotted in figure 5.11 show that substitution of the tripod mount for a well-focused standard lamp made little difference in the beam profile when either 16-W halogen or 25-W incandescent lamps were used. When the 16-W halogen lamp was used with a roundel in place, the tripod mount decreased on-axis intensity significantly (although it still exceeded minimum visibility specifications by more than a factor of three) but increased off-axis values slightly. When a 25-W incandescent lamp was used, the tripod had almost no impact on the output distribution, as shown in figure 5.12. It is not surprising that the tripod mount reduced on-axis intensity when the halogen lamp was used because it partially shadows the roundel hot-spot, but why the same effect was not observed for the incandescent lamp is a mystery.

Relamping the tripod fixture is more difficult than for a standard fixture, especially with halogen lamps, the glass globes of which are not supposed to be touched by fingers.

5.1.5.2 Antireflective roundel coating. The increase in on-axis intensity achieved by applying an antireflective layer of 130 nm (51 μin) of magnesium fluoride (MgF_2) to each surface of four roundels is shown in figure 5.13. Because the improvement being measured was on the same order of magnitude as the repeatability of the instruments, measurements were compared to a fifth uncoated "reference" roundel (designated "REF" in the plot). This procedure was used to reduce common-mode measurement errors. In addition, each measurement sequence was repeated several times to ensure reliable values.

The average improvement obtained was 2.9 percent. With careful optimization of the coating parameters (thickness and index of refraction) and additional experience in applying the coating, we

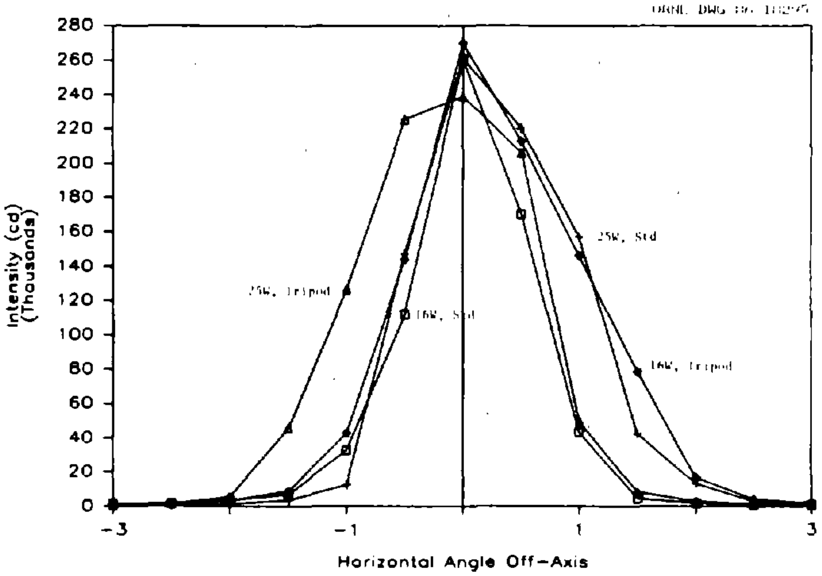

Figure 5.11. Effect of tripod on beam profile when using 10-V, 25-W incandescent and 16-W quartz iodide lamps.

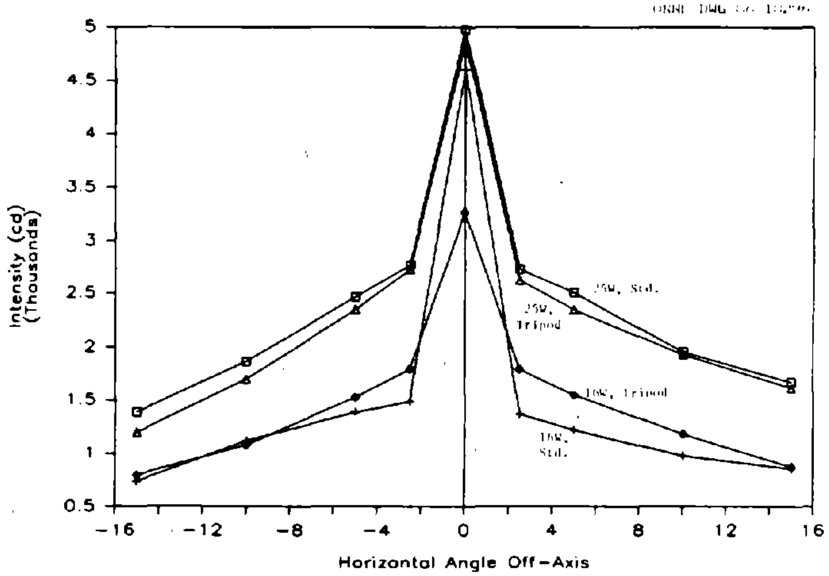

Figure 5.12. Effect of tripod on output pattern (incandescent and quartz-iodide lamps, 30°/15° roundel).

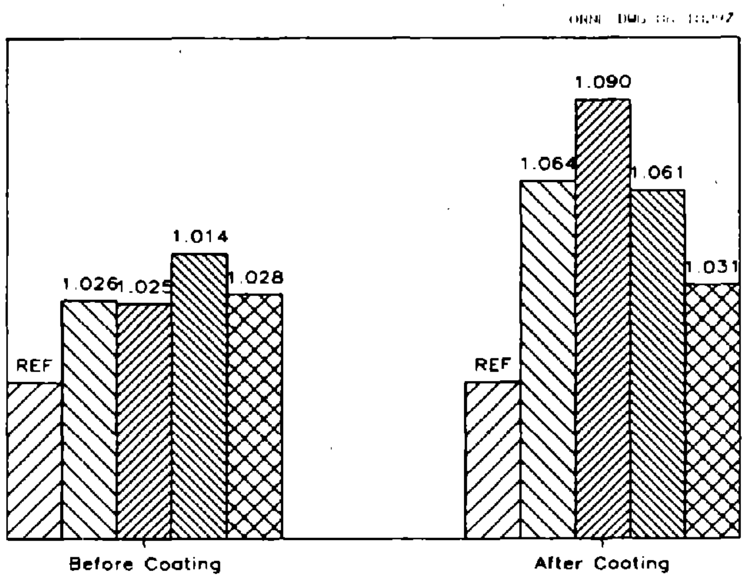

Figure 5.13. On-axis intensity relative to reference roundel before and after application of antireflective coating.

believe this improvement could consistently be doubled. The time and expense involved, however, could be better applied in other areas of development.

5.1.5.3 <u>Integral socket/reflector assembly</u>. Deep-dish metal reflectors used in the integral lamp mount/reflector assembly came from the manufacturer with their own lamp mounting brackets. When the unit was characterized "as received," it was found to be badly out of focus. (There was no indication on the units that they had been factory-focused, but prefocusing was specified in the purchase requisition, and specifications in the AAR <u>Signal Manual</u>(7) require that they be shipped that way.) Trying to focus the units, even using the new focusing tool, impressed upon us the value of permanently focused signals. There were four screws that had to be loosened before focus could be adjusted, and it was a difficult, time-consuming process to retighten them without moving the lamp enough to defocus the assembly.

Output patterns obtained before and after focusing are compared in figure 5.14 with the pattern for one of the new stud-mount prototypes. The broad, dull peak on the stud-mount curve is attributed to the base-in position of the lamp.

5.2 ENVIRONMENTAL TESTS

Two each of the following prototype signals were subjected to environmental testing:

- Signal with original lamp mount assembly removed, tripod lamp mount added, roundel coated, 10-V, 16-W halogen lamp.
- Signal with original lamp mount assembly removed, original reflector removed, stud-mount socket/reflector assembly added, 10-V, 36-W halogen lamp.
- Signal with 120-V, 25-W lamp.

5.2.1 Preparation

Lamps used in the prototype signals were flashed at their rated voltage with a 50 percent duty cycle and a frequency of 42 cycles/min for 100 h. Signal performance was characterized before testing began.

5.2.2 Elevated Temperature Test

This test was performed in a Standard Environmental Systems, Inc., Model LHH/64S temperature chamber. Signals were flashed continuously at an ambient temperature of 50°C (122°F) for 250 h. On-axis intensity measurements made after this test showed no degradation of signal performance.

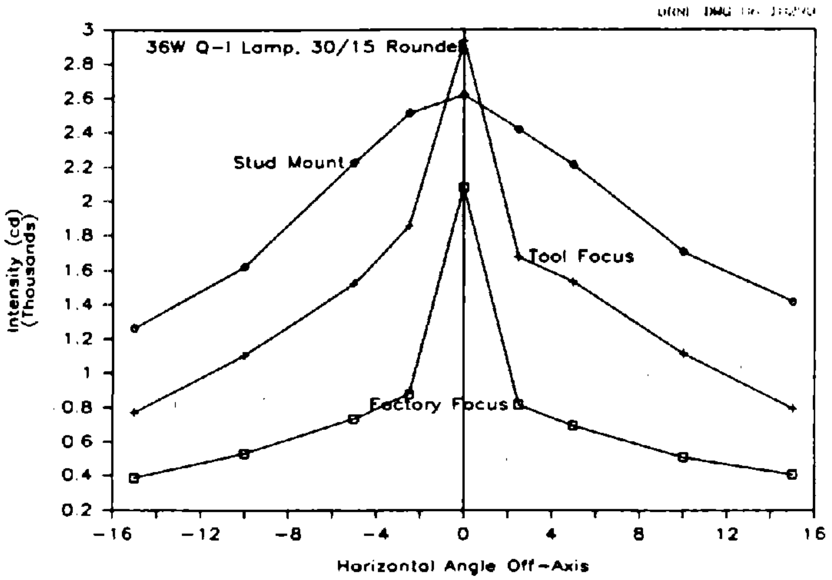

Figure 5.14. Output pattern for metal reflector assembly as received from factory, as refocused using tool, and as modified to make integral socket/reflector assembly.

5.2.3 Vibration Test

A vibration test system consisting of an MB Electronics, Inc., Model C60 exciter (shaker table), a Bruel & Kjaer Type 1025 exciter controller, and an MB Electronics Model T-452 power amplifier was used for this test. Test jigs were fabricated for mounting the signals on the shaker in three orthogonal orientations. The signals were vibrated along each major axis at an amplitude of 0.75 mm (0.03 in) at a frequency linearly swept from 5 Hz to 50 Hz and back once each minute for 60 min. On-axis intensity measurements made after this test showed no degradation in signal performance. In addition to the six prototype signals, two standard signals were tested.

5.2.4 Temperature Cycling Test

The temperature cycling test was performed in a Thermotron, Inc., Model F2-CH-075-075 environmental temperature chamber. Prototype signals were cycled five times from -30°C to +50°C (-22°F to +122°F) and back, pausing for 30 min at each extreme. On-axis intensity measurements showed no degradation of signal performance as a result of this test.

5.2.5 Shock Test

An L.A.B., Inc., Model SDB-16-66-150 shock test machine was used with an Endveco, Inc., Model 2272 accelerometer, an Umholtz-Dickie Model 1610M vibration monitor, and a Tektronix Model 7633 storage oscilloscope to monitor shock. Test jigs were fabricated for mounting the signal on the tester carriage in three orthogonal orientations. Three 50-g half-sine-wave shocks, each 11 ms in duration, were delivered along each major signal axis. In addition to the six prototype signals, two standard signals with 10-V, 25-W lamps were tested. On-axis intensity measurements following the test showed no degradation in performance of the 120-V signals or the signals with the stud-mount/reflector assemblies, but the two signals with the tripod mounts showed losses of 5 percent and 18 percent. Because the tripod mounts are rigid and are held securely in position, this result was unexpected. Investigation revealed that the tripod mounts had not yielded but that the reflectors in each unit had shifted position slightly. After refocusing by adjusting reflector position, the on-axis intensity measurements were within 2 percent and 3 percent, respectively, of their original values.

5.3 MAINTENANCE AIDS

5.3.1 Focusing Tool

The ideal measure of focusing tool accuracy is the distance between the true focal point of the reflector and the lamp filament center after application of the tool. Locating the true focal point of a reflector for such an evaluation, however, would be tedious and, given the manufacturing tolerances in the shape of the reflector, might be impossible. Instead, the instrument was evaluated using it to refocus several factory-focused signals and measuring the resulting improvement in on-axis beam intensity. The data (fig. 5.15) show that focus was improved in each case.

5.3.2 Alignment Scope

The prototype alignment tools are accurate to better than 10 min of arc--far better than necessary for their intended purpose. The limiting factor on their performance in use will probably be the degree to which the rim of the reflector against which the alignment tool rests is perpendicular to its own axis of symmetry. The peephole sights in the signal housings were about as effective (in laboratory testing) as the scope for distances up to 15 m (49 ft), the distance over which the narrow-angle luminance meter was usable. The alignment scope probably would prove more effective at long distances by virtue of its nine-power magnification. In addition, the peepsights are difficult to use in the field because there is usually insufficient clearance between signals to permit convenient access to the rear of the unit.

5.3.3 Flux Meter

Flux meter readings varied linearly (fig. 5.16) with signal flux as lamp output was modulated by adjusting the applied voltage. (Lamp flux was assumed to vary proportionally with $V^{3.4}$.)(9) The slope of the curve of data taken with the red roundel in place decreases slightly as lamp flux increases because of the change in filament color temperature.

Signal-to-signal consistency is harder to demonstrate because of variations in lamp filaments, reflector shapes and finishes, and roundel transmittances. The data shown in figure 5.17 were taken using several different signals over the course of 15 months. In spite of the obvious data scattering, the meter serves as a valuable diagnostic tool. For example, the low reading of 40 percent for the 10-V signals corresponded to an on-axis intensity of 4.6 kcd, or more than four times the minimum intensity criteria for that roundel. Any

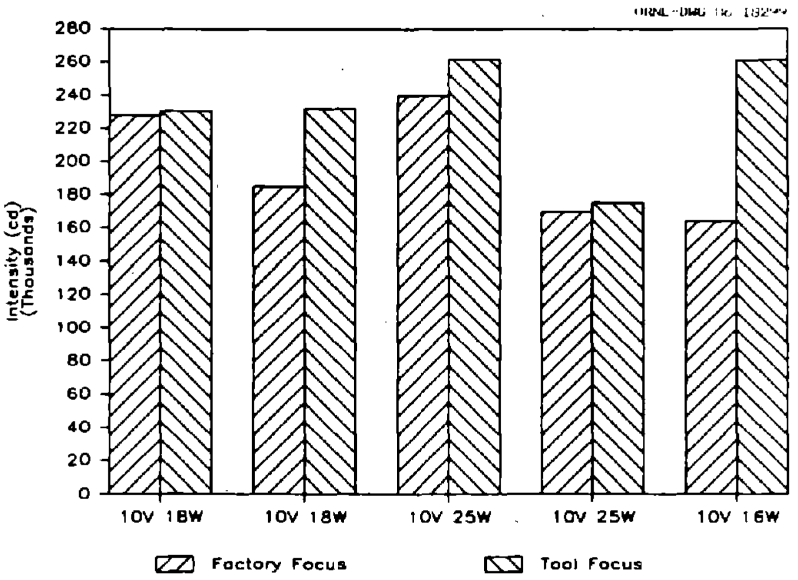

Figure 5.15. On-axis intensities for five factory signals and after optimization using focusing tool.

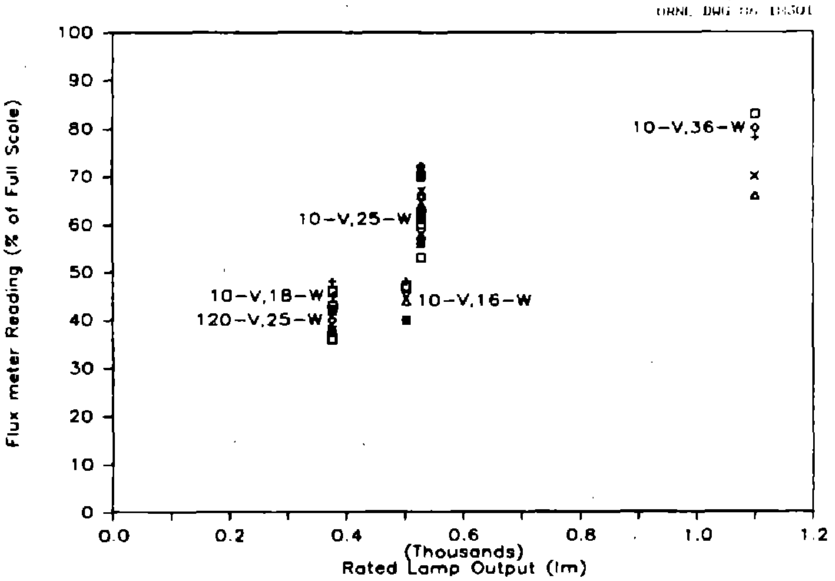

Figure 5.16. Flux meter reading as a function of signal lamp flux with and without roundel installed. Readings normalized to reading obtained when lamp was operated at rated voltage.

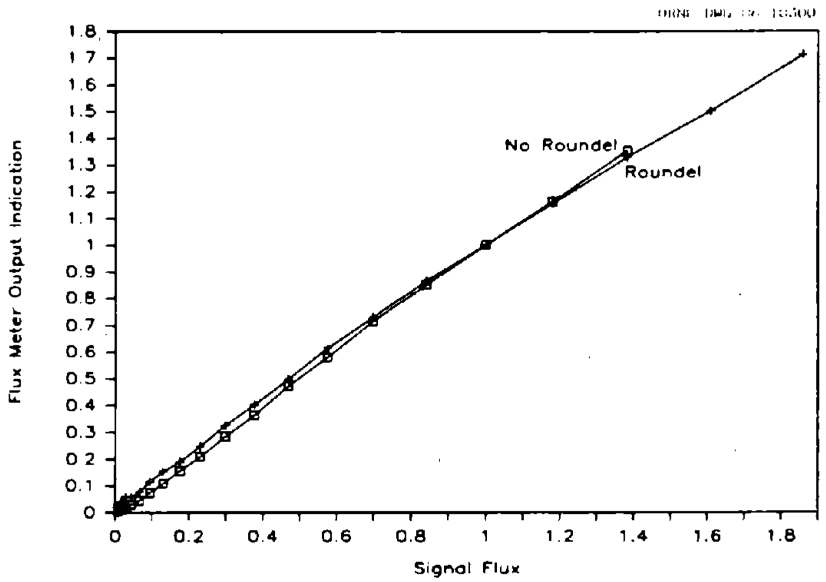

Figure 5.17. Flux meter readings as a function of lamp flux for approximately 50 different signal/lamp combinations.

signal in the field that produces a reading of 20 percent, although it would meet minimum specifications if properly focused, requires servicing as soon as possible.

5.3.4 Roundel Clip

The roundel clip that replaces one of the roundel hold-down clamps furnished with the signal is effective at preventing the roundel from rotating unless the screw holding it in place is loosened by at least two full turns.

5.3.5 Commercial Photometers

The Tektronix J16/J6523 photometer did not meet its published 5 percent (of reading) accuracy or 2 percent linearity specifications. During calibrations, its readings were usually 5 to 8 percent higher than our calibration standard (a LabSphere, Inc., Model CLS-6000 luminance calibration source), when measuring white or red light. However, the uncertainty in our calibration system can be up to 3 percent, so the Tektronix unit may have come very close to meeting its accuracy specification. We did not apply a calibration factor to the readings reported in this document.

The Minolta Spotmeter registered 10 to 15 percent low when measuring white light, but only 1 to 2 percent low when measuring red light. (Its published specifications claim a 4 percent-of-reading accuracy.) Such color-dependent errors make it impossible to compensate readings by applying a simple calibration factor. These accuracies are quite acceptable in photography, its intended field of application.

The Tektronix unit proved a valuable laboratory tool, but it would not be practical for field use by a maintenance crew. The most meaningful measurement it can provide, on-axis luminance, would be extremely difficult and time-consuming to obtain. In many cases, stopping or diverting automobile traffic would be necessary to allow the user to locate himself safely on-axis. In addition, the flasher relay in the signal controller would have to be defeated to provide a steady signal, which could prove confusing to motorists. A signal inspector may occasionally find use for this instrument in the field, but no commercially available photometer was deemed useful for signal crews.

6. FIELD TESTS

At the beginning of this study two field tests were planned. The simulated crossing test was intended to expose six prototype and two standard signals to field conditions by installing them on masts near an active rail line and to monitor changes in performance for the period of one year. The signal cycling test would determine if any of the design modifications in the prototypes compromise reliability when the signals are operated continuously in an outdoor environment for one year.

6.1 SIGNAL CYCLING TEST

Ten signals were mounted on a test stand (fig. 6.1) at a convenient outdoor location. Two each of the following signals were used:

- Signal with original lamp mount assembly removed, tripod lamp mount added, roundel coated, 10-V, 16-W halogen lamp, 10-V dc power.
- Signal with original lamp mount assembly removed, original reflector removed, stud-mount socket/reflector assembly added, 10-V, 36-W halogen lamp, 10-V dc power.
- Signal with 120-V, 25-W lamp, 120-V ac power.
- Signal with 10-V, 25-W lamp, 10-V ac power.
- Signal with 10-V, 25-W lamp, 10-V dc power, and 3.0-V dc power applied during half-cycle when signal would normally be without power.

figure 6.1

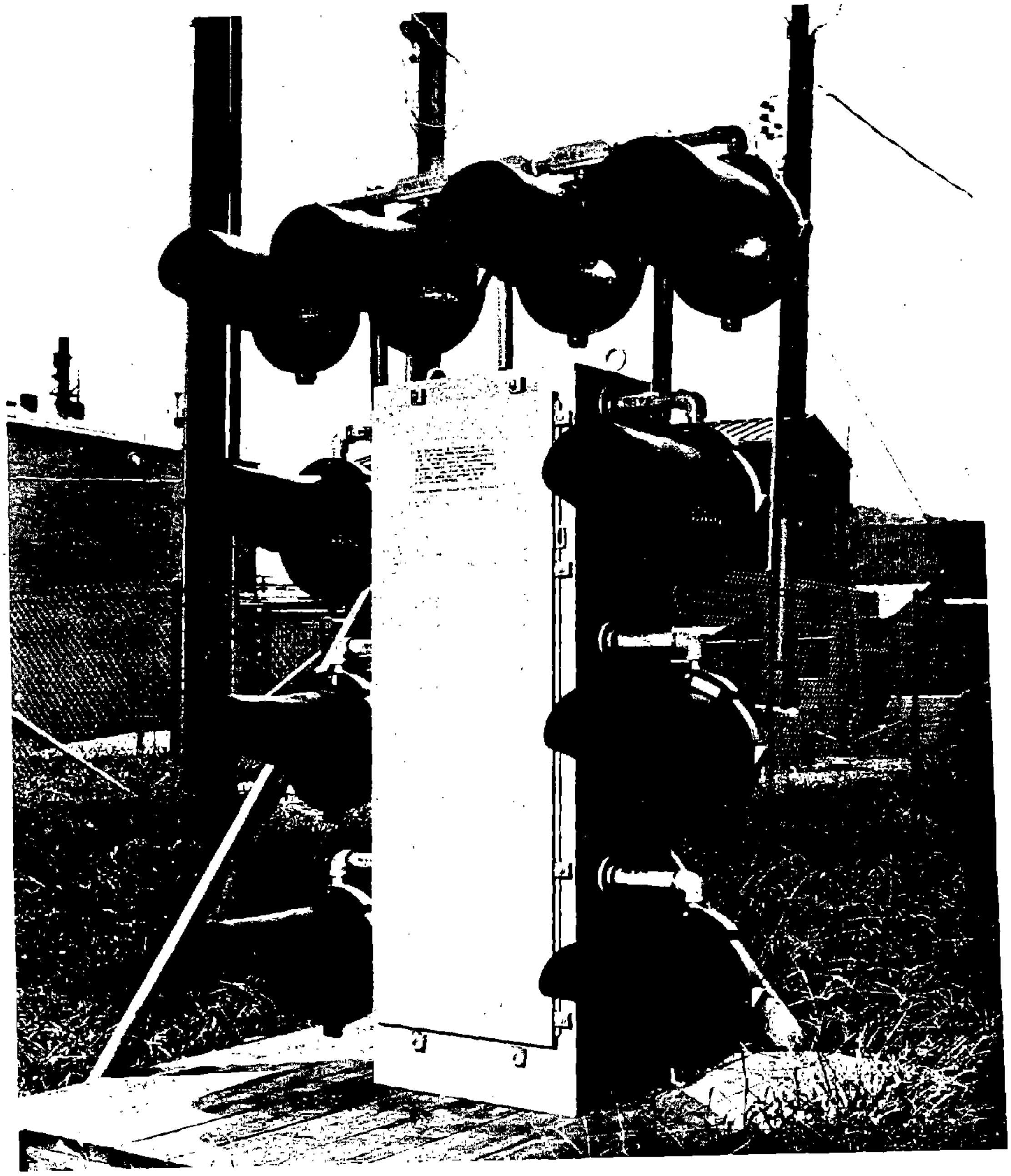

Figure 6.1. Signal cycling test stand.

The signals were flashed continuously for one year except for brief interruptions when light output was being measured with the flux meter or when signals were being relamped. No degradation in signal performance or condition could be detected during the course of the test.

Data on lamp life are presented in figure 6.2. Even with the limited number of lamps tested in this portion of the study, two conclusions can be drawn: (1) application of a small "warming voltage" during the lamp's power-off cycle can significantly extend its lifetime, and (2) the longer lifetime promised by the halogen lamps' continuous-duty ratings (in this case, 2,500 h) cannot be realized in flashing service.

More than half of the halogen lamps used in this test failed upon reapplication of power after a brief (2- to 5-min) interruption during the monthly light output checks. This effect was never observed with the incandescent lamps. This suggests that a better way to perform flashing-service lifetime tests on halogen lamps may be to remove power intentionally and frequently (hourly or at least daily) long enough to let the lamps cool to near-ambient temperatures.

6.2 SIMULATED CROSSING TEST

The simulated crossing test was not performed, because a satisfactory agreement could not be reached with a local railroad to permit erecting two signal masts, each bearing four signals, on the railroad's right-of-way.

An ideal test area was found on a busy line (15 to 25 trains per day) where the signals would not be visible from any public crossing or road. The area around the site is fenced, so unauthorized persons at the site would clearly be trespassing. It was proposed that the signals would be actuated only during a monthly signal inspection and then only for a few minutes. Electric power was to be provided by a

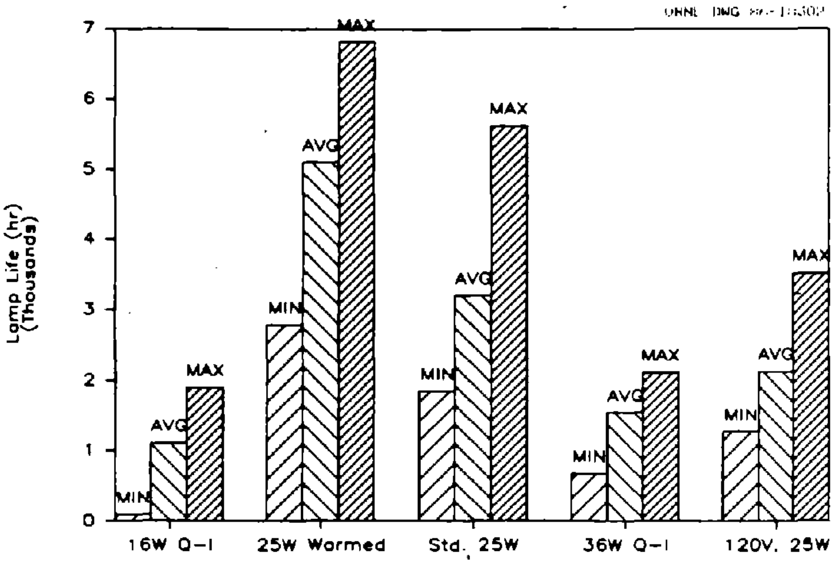

Figure 6.2. Lamp life statistics obtained in signal cycling test stand.

portable gasoline-powered generator and no connection would be made to the tracks or to any railroad equipment. No test gear except the signals themselves would be left at the site between monthly evaluations. Signal masts and concrete foundations were to be removed at the end of the test.

In spite of these attempts to minimize both interference with railroad operations and liability concerns, the railroad asked for indemnification in an amount we and the sponsor felt was inappropriate, given the size and scope of the project and the realistic risks involved. After months of tedious but unsuccessful negotiations, this portion of the field test was dropped.

7. SUMMARY AND CONCLUSIONS

7.1 PROTOTYPE SIGNAL PERFORMANCE

Both the integral reflector/socket assembly and the tripod lamp mount provide reliable performance far in excess of existing minimum government or industry requirements, assuming the rest of the signal is in good condition. While they cannot consistently outperform a precisely adjusted standard signal, standard signals are rarely precisely adjusted. The prototypes would provide superior performance after only a short time in the field. Signal focus ceases to be a concern when either assembly is used. Either of these design concepts could be incorporated into the design of a new signal without major impact on its cost. Of the two, the integral reflector/socket assembly may be preferable because it is more readily adaptable to a variety of signals, it allows easier access to the lamp than is found in commercially available crossing signals, and it can survive malicious mischief, especially gunshot damage, that would disable signals of other designs.

The prototype design incorporating the 120-V lamp could not meet specifications for crossings where vehicle traffic approaches at speeds greater than 72 km/h (45 mi/h), and its adequacy for other crossings is marginal.

7.2 PERFORMANCE OF PROTOTYPE MAINTENANCE AIDS

The alignment scope gives an accurate indication of the direction of the signal axis and could be a valuable tool for a maintenance crew in signal alignment. It can be used to best advantage when the signal housing is open for other maintenance. Units of acceptable quality could be manufactured in quantity for sale in the $75 to $100 price range.

The flux meter fills a real need in the industry by providing meaningful information about the total light output of a signal. No commercially available instrument can provide this function. A low meter reading alerts maintenance personnel to a developing problem before it may be noticeable to the eye. Signal conditions responsible for low readings include low voltage, dirty reflectors or roundels, "old railroad red" roundels, darkened lamp envelopes, weak filaments, and damage to internal components. Built in quantity, this instrument could be sold for about $300 to $500.

Of the three systems the focusing tool is the most promising for commercial development. It could be made in quantity for less than $50 and would pay for itself in the first few hours of use. Its simple design, ease of operation, and informative display are significant features.

Permanently focused signals are the most desirable of the alternatives considered. Never having to worry about focusing is better than having to monitor focus and occasionally refocus, even with a tool that makes doing so relatively easy. Because instant conversion to prefocused signals is unrealistic, the need for the focusing tool will exist for the foreseeable future.

7.3 SUGGESTIONS FOR FURTHER DEVELOPMENT

None of these instruments is ready to market. Their designs are intended for proof-of-principle. In particular, fieldworthiness and suitability for large-scale manufacture were not major design issues. We are convinced, however, that the principles lend themselves to practical, durable implementation. Extensive tests have been performed on signals from only one manufacturer, but the operating principles apply to all signals (including 8-in units). Further design will probably be required to produce "universal" instruments.

The prototype flux meter lacks a peak-hold circuit consisting of a single integrated circuit and a few resistors and capacitors (less than $1 in additional component cost) to "freeze" the peak reading during flashing operation. This feature was not required in our testing but would be needed for field use. After the measurement has been taken, pushing the reset button (the only control or adjustment on the instrument except for the power switch) readies the instrument for the next measurement.

For quantitative measurement of flux level rather than a simple "go/no go" indication, a logarithmic amplifier in the light measurement circuit may be preferred to a linear amplifier so that meaningful measurements over several orders of magnitude in flux level could be obtained without the addition of range-changing controls and circuitry.

7.4 CONCLUSIONS

The following results were achieved through this study:

- Two permanently focused lamp supports were developed. Each ensures near-optimum beam collimation and can stand up to rough handling, aging, and repeated lamp changes. Signal performance incorporating these devices compares favorably with the performance of properly adjusted conventional signals.

- Two implementations of 120-V hardware were evaluated and judged inadequate for most public crossings.

- The two commercially available narrow-angle photometers evaluated were found to be worthwhile for laboratory and for signal shop use, but their utility for field maintenance and inspection applications was judged to be limited.

- An alignment scope was designed to facilitate accurate aiming of signals.

- A special-purpose photometer was developed for evaluating performance of crossing signals and traffic lights. Its reading is an indication of signal flux and can be used to screen signals for servicing.

- Although an improvement of nearly 3 percent in roundel light transmission was achieved by coating both surfaces with an antireflective film, in most instances, the small gain would not justify added costs.

- Maintaining 30 percent of rated voltage between flashes extends lamp life by over 50 percent.

- A practical tool developed to aid maintainers in inspecting and adjusting focus of crossing signal lights has outstanding potential for commercial development.

- A new set of two-dimensional signal intensity specifications based on widely accepted human-factors criteria was developed.

- It was found that available signals are capable of exceeding minimum visibility requirements if properly maintained.

- Application of the developments from this study can result in uniformly brighter signals and reduced maintenance costs.

APPENDIX A - Photometry

Photometry, the measurement of light as perceived by humans, is related to radiometry by the photopic curve (figure 1.1). The basic unit of photometry is the lumen (lm), which is used to quantify light flux (the rate of flow of light energy from a source or to a surface). At a wavelength of 555 nm (the peak of the photopic curve), 1 W of radiant power equals 680 lm. The flux per unit area passing through or reflected from a surface in any direction is called the exitance and is expressed in lumens per unit area. The flux per unit area reaching a surface is called illuminance (if light from all angles is considered) or incidence (if light only from a certain direction is included) and is also expressed in lumens per unit area, most often in lux (abbreviated lx and equal to 1 lm/m^2) or foot-candles (ft-c, equalling 1 lm/ft^2 or 10.7 lx). Illuminance and exitance, as applied to an opaque surface, are related by a dimensionless factor called surface reflectivity, which is a function of wavelength. Intensity is a measurement of the luminous flux from a source (which can be an illuminated surface) in a particular direction and is expressed in flux per unit solid angle. The most often used unit of intensity is the candela (cd), which is equal to 1 lm per steradian (sr). Apparent surface brightness is also a function of viewing angle and is called luminance or luminous sterance, expressed in flux per unit solid angle per unit surface area, usually cd/m^2 or foot-lamberts (ft-L, equalling 0.318 cd/ft^2).

A "point source" is an infinitely small source that radiates equally in all directions. Real sources can only approximate this ideal. As rule of thumb, if an observer is at least ten source diameters away, the source will "behave" like a point source and the observer is said to be in the "far field."[10]

The efficacy of a source is a measure of its efficiency in producing visible light. It is defined as the ratio of the source's lumen output to the amount of power used in producing the light and is usually expressed in lm/W.

The following points are important to the understanding of signal visibility issues.

- The intensity of a light source is the integral of its luminance over its entire visible surface.
- Neither the luminance nor the intensity of a source varies with viewing distance.
- Illumination varies inversely with the square of the distance to the source.
- The curve in figure 1.3 is a square-law relationship, so the distance for which a signal has adequate visibility is equal to the distance for which its illumination exceeds a threshold of approximately .01 lm/m^2.

Instruments for measuring visible light are called photometers. Most measure light flux directly and infer illumination using the surface area over which the light was collected. Some can calculate luminance using optical systems with well-known apertures, but if the user desires to know intensity, he usually has to perform a calculation based on one of these measurements and either the distance to the source or the size of the source.

Most laboratory-grade photometers claim absolute accuracies in the range of 3 percent to 5 percent. Light meters intended for field use (the most common of which are meters in cameras) frequently have errors on the order of -50 percent to +100 percent. The National Bureau of Standards claims only 4 percent repeatability for its photometric calibration systems.(11) These accuracies seem crude to researchers in other branches of measurement science but reflect the extreme difficulty of making a precise light measurement and of building a stable, repeatable calibration source. Major sources of error in inexpensive instruments include poor matching of spectral response to the photopic curve (many are overly sensitive to red and infrared energy) and high temperature sensitivity.

APPENDIX B - Traffic Signals vs Crossing Signals

A comparison of the design, function, and operation of grade crossing signals with traffic signals highlights several of the human-factors issues that arise in their application. Both signals control automobile traffic, flow and in each case, motorist safety depends on the devices' visibility and reliability. Their control strategies and implementations, however, differ widely.

Traffic signals control traffic flow through intersections, granting and denying right-of-way to motorists approaching from different directions and having different destinations. A red traffic signal is an instruction to stop; it does not warn that other vehicles are expected at the intersection. Drivers know that the law requires them to obey this instruction and many have witnessed accidents or near-accidents resulting from failure to do so. An actuated railroad crossing signal, in contrast, sends a warning that a train is approaching the crossing and that the driver should stop. (The train never stops for automobile traffic.) This function is impaired, however, in that many drivers have encountered signals that flash for no apparent reason. Many drivers are unaware that the law requires motorists to stop for flashing crossing signals and to wait until they have made sure that it is safe to proceed. Few drivers have heard of these statutes being enforced or witnessed a collision involving a train.

Installation techniques for the two types of signals also are different. Traffic signals usually are suspended over the traffic lanes; crossing signals most often are located on masts near the shoulder of the road. Lights in a traffic signal are close together and are mounted in a body that may be painted any of several different colors; crossing signal lights are separated by several signal diameters and always are surrounded by circular black backgrounds. While crossbucks accompany crossing signal lights and crossings usually are marked by advance-warning signs, such signs are used at traffic intersections only when the signals may be unexpected or when there is excessive competition for drivers' attention. Traffic signals hang with faces vertical (although they typically are free to sway in the breeze); crossing signals can be aimed independently up or down and side-to-side and are fixed rigidly to crossarms or cantilevers.

Actuated crossing signals may be accompanied by ringing bells, and train operators usually sound their horns when approaching grade crossings. Traffic signals operate silently and, although drivers sometimes blow their horns at intersections, such action certainly is not standard operating procedure. Automobiles often are allowed to turn at an intersection but never at a rail crossing.

Traffic signals are maintained by State or local governments; crossing signals are maintained by the railroads.

Yet another important difference in the two implementations is the handling of power outages. Drivers expect to see at least one lens of a traffic signal illuminated and are alerted (especially at familiar intersections) to use extra caution when all lenses are dark. The opposite is true for a crossing signal: its appearance during a power outage is exactly the same as for the safe-to-proceed state. This ambiguity is eliminated by providing reliable battery back-up power for crossing signals. Because back-up power is expensive, low-power lamps (typically 25-W in new installations) are used. Thus, care must be taken in crossing signal design and maintenance to ensure that (1) lamps are efficient, (2) lenses (called "roundels" in railroad parlance) have high optical transmittance, and (3) light is directed to where it is needed most. The traffic signal designer, by comparison, has the luxury of flooding a darker, more distinctively colored lens with light from a 150-W lamp and has traditionally been pleased with a widely dispersed output pattern. (The need for better control of traffic signal light distribution has recently been investigated.)(12)

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