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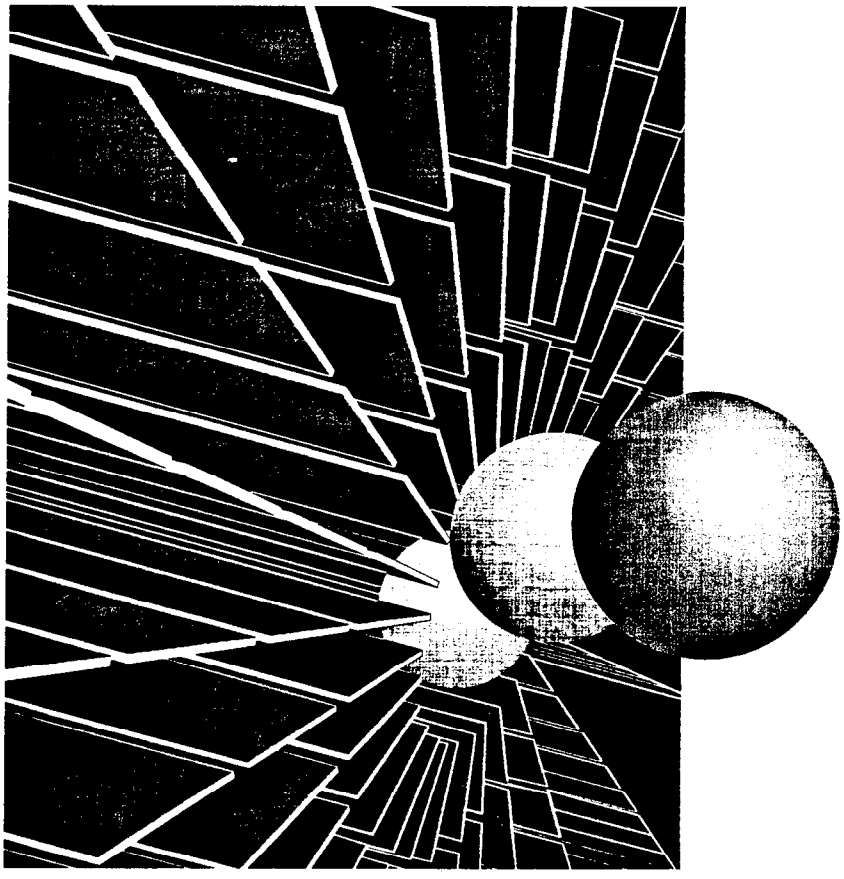
MoDOT

Research, Development and Technology

RDT 99-010
Final Report

Light Emitting Diode (LED) Signal Installation



February, 2000

RESEARCH INVESTIGATION 96-023

LIGHT EMITTING DIODE (LED) SIGNAL INSTALLATION

PREPARED BY
MISSOURI DEPARTMENT OF TRANSPORTATION
RESEARCH, DEVELOPMENT AND TECHNOLOGY

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The investigation was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract

Red, green and yellow light emitting diode signals were compared to incandescent bulbs of the same color. Using the life cycle cost analysis approach, LED signals were more cost effective than incandescent bulbs and comments were favorable that they were brighter. Red LED signals have already been implemented into MoDOT operations. Green LED signals will soon be used within the department as well. Yellow LED signals should be considered for use after ITE (Instutute of Traffic Engineers) approval although the cost savings for yellow will be less since it is not as active as red and green.

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Mr. Daryl Woodruff, District 5 Signal Assistant
Mr. Jerry Budnik, District 5 Signing Crew Leader

I especially wish to acknowledge Mr. Vince Imhoff, P.E., currently Engineer of Contract Controls for Construction, but formerly a Research and Development Engineer, for his work in instigating and implementing this study and his continued assistance with completing the study.

EXECUTIVE SUMMARY

The Light Emitting Diode (LED) Signal Installation study consists of a partnering between the Missouri Department of Transportation (MoDOT), the Federal Highway Administration (FHWA) and the Dialight Corporation. The FHWA Priority Technologies Program (PTP) funded $18,000 for the study, 51 percent of the $35,400 total budgeted cost. MoDOT and the Dialight Corporation divided the remaining portion of the budget.

The objectives of the study were to develop an evaluation methodology that would provide data comparing LED signal heads to incandescent signal heads and to accelerate the implementation of LED signal head technology within the State of Missouri. The data shows the LED signal heads are cost beneficial as compared to incandescent signal heads.

Data was provided to ascertain that LED signal heads are more beneficial to incandescent bulbs by showing:

1. Greater energy efficiency
2. Longer signal life
3. Less maintenance
4. Increased signal intensity
5. Improved motorist awareness
6. Actual dollar amount of benefits

The greater energy efficiency was documented with a 75 percent reduction at the intersection test location. Longer signal life and less maintenance have already been seen in the last 2 years. The expected life of an LED signal head is projected to be seven years or more compared to one year for an incandescent bulb. Maintenance costs have been reduced by more than 90 percent from less outages and yearly relampings. From comments received, motorist awareness and signal intensity have increased. The most expensive aspect of the LED signal heads is the initial cost but the savings in maintenance and repair costs appear to justify the initial costs.

The Life Cycle Cost Analysis (LCCA) gave an Incandescent Bulb/LED ratio of 0.97. This ratio would have been even higher if the intersection had been located farther from the signal shop. The greater the distance the maintenance crews have to travel for repairs and relamping, the more expensive incandescent bulb indications become compared to LED indications. In addition, the ratio will continue to increase as the price of LED signal heads is reduced. Using a price estimate at 1999 costs, the ratio increases to 1.36. The 1999 ratio, using present day costs, is more appropriate than the 1997 ratio, when LED technology was still considered very new and expensive.

Overall, the study was considered a success. Based on the results of this study, MoDOT recommends using LED signal indications in lieu of incandescent bulb indications. Red LED signal heads have been implemented elsewhere in the state and are currently in the Standard Specifications. After this study, MoDOT will recommend the use of green LED signal heads and will include green in Missouri Standard Specifications. The Department will consider the use of amber LED signal heads in some locations after Institute of Traffic Engineers (ITE) approval.

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INTRODUCTION

Light Emitting Diode (LED) technology is currently being used in items such as changeable message signs, but only recently has the Missouri Department of Transportation (MoDOT) discussed LED signals. MoDOT had not initiated implementing and evaluating the technology until the Federal Highway Administration (FHWA) Priority Technologies Program (PTP) program provided the mechanism for MoDOT to do so because of funding. The LED Signal Installation study consists of a partnering between MoDOT, FHWA and the Dialight Corporation. The PTP funded $18,000 for the study, 51 percent of the $35,400 total budgeted cost. MoDOT and the Dialight Corporation divided the remaining portion of the budget. The breakdown of the proposed budget can be found in the workplan located in Appendix A.

LEDs are small semiconductor chips that emit light. Measuring just 1/100th of an inch long, they are encased in epoxy to protect them from shock, vibration and environmental contaminants. Vast amounts of research have been developed by the industry in LED applications in the area of signalized intersections. Green and red LEDs have been approved by the ITE, but the yellow or amber LED has not yet been ITE approved at the time of this study. For an LED to receive ITE approval, it has to meet lumen and color requirements. There is still research being conducted toward the development of an ITE approved yellow or amber LED signal indication. One of the major contributors towards this research and development of LED signal indications is the Dialight Corporation of Manasquain, New Jersey. Dialight Corporation is an active partner in this study. The supplier for the study was Brown Traffic out of Davenport, Iowa. MoDOT put this existing research and technology into a "real world" location to evaluate it.

The LED signal indications utilize a combination of Light Emitting Diodes to provide the green, green arrow, red ball and amber indications. The LED indications reportedly draw less power than incandescent indications. In addition, if the incandescent bulbs burn out the entire indication is lost whereas with LED signal heads, the loss of individual LEDs will not lead to a total loss of the indication. The LEDs do not burn out like incandescent bulbs. The light output degrades over time in a fairly predictable manner. The LEDs result in increased reliability of indications. The average life cycle for an LED is approximately seven to eight years. Maintenance costs and power costs result in financial savings to DOT's, cities and municipalities. Converting to red, green, and amber LEDs should provide for virtually maintenance free signals.

OBJECTIVES

The objectives of the study are to develop an evaluation methodology that will provide data comparing LED signal heads to incandescent signal heads and to accelerate the implementation of LED signal head technology within the State of Missouri. The data will show whether the LED signal heads are cost beneficial as compared to incandescent signal heads.

The above evaluation methodology provided data to ascertain that LED signal heads are more beneficial to incandescent bulbs by showing:

1. Greater energy efficiency
2. Longer signal life
3. Less maintenance
4. Increased signal intensity
5. Improved motorist awareness
6. Actual dollar amount of benefits

DISCUSSION OF PRESENT CONDITIONS

The use of incandescent bulbs in signal heads is currently the most common practice in Missouri. Generally, incandescent bulbs do not last more than 1 to 1 1/2 years. Attempts have been made to increase this life expectancy by using a higher wattage bulb and running it at a fraction of its capacity. Unfortunately, this extended life comes at the expense of other needs. This practice reduces the efficiency of the bulb, meaning that fewer lumens are output per watt of energy. It is not an option to go below ITE standards on the lumen output. ITE specifies minimum initial lumens 1650 bulb output and rated average lumens 1750. To increase the efficiency, the filament can be made thinner but this also makes the filament much easier to break. To make a bulb more intense, a higher voltage filament is used but the heat factor increases.

Heat is another problem with incandescent bulbs because it damages the reflector, sockets, and lenses. Problems arise in order to keep bulb wattage low enough to prevent damage to the head, yet high enough to get sufficient lumen output to meet ITE standards. There are some variations of the quality of the heads. Some have glass lenses, metal reflectors and porcelain sockets. Other heads may have plastic lenses, reflectors and sockets. Some withstand more heat and dissipate it better than others. Heat buildup is mostly caused by insufficient clearance between bulb and lens, and by arrow masks.

A MoDOT Signal Lamp Task Force group determined that incandescent bulb failure is a function of the duty cycle of the bulb and the voltage that is applied. LED indications could solve most of the problems that arise with incandescent bulbs such as short life expectancy, possible insufficient lumen output, inability to handle voltage variations and heat problems. If the indications that dwell red and those that dwell green were replaced with a long life alternative, such as LED signal heads, power usage and relamping costs would greatly decrease. The non-dwelling indications are much less critical, and a conventional traffic signal bulb could be more than adequate in them. Controlling the voltage at the intersection is probably not going to be feasible but LEDs handle voltage changes much better than incandescent bulbs.

TECHNICAL APPROACH

District 5 signal personnel installed the Light Emitting Diode signal indications on September 10, 1997. The LED signal indications were purchased through a partnering agreement with Dialight Corporation. The signal crew set up traffic control. The location chosen for the study is the intersection of Rex Whitten Expressway (US Route 50-63) and Missouri Boulevard in Jefferson City, MO. This location was chosen because it is a relatively new intersection with state of the art non-LED signal heads. There are 51 indications in the interchange, of which, 41 were changed to LED indications. It is also the busiest intersection in Jefferson City with traffic volumes in excess of 54,000 ADT. In addition, this intersection is in close proximity to the Central Materials and Research Lab, MoDOT Headquarters and the Central District Office, which makes installation and evaluation much easier.

The evaluation consisted of a total reinstallation of red and green, including straight and left green arrow, LED signal heads in both directions of Missouri Boulevard and east bound lanes of Route 50-63. For the west bound lanes of Route 50-63, all of the indications were changed to LED except the signal head for the center west bound lane was left incandescent for comparison purposes. The yellow arrow of the far-left lane was not changed to LED for comparison and liability reasons. Most of the yellow indications were left as incandescent bulbs because the amber LED signals did not meet ITE specifications. However, the yellow indications are only on for a short time, therefore, they require minimal power consumption and the bulbs should have a longer life. A location sketch of the intersection can be found in Appendix B.

The installation went smoothly and was comparable to existing procedures. The wiring attachments for the LED indications required no modifications or alterations for proper operation. There were no problems installing the LED indications in the newer plastic signal heads or with the existing signal control equipment operating with the LED signal indications. The installation took about twice as long as a normal relamping. For this particular intersection, the most time consuming portion was the traffic control.

The evaluation procedure consisted of collecting data that included installation and material costs for the LED as compared to similar incandescent bulb installations, energy usage and cost comparisons of each type of installation, and maintenance and repair costs of the LED installation compared to the previous incandescent installation. From this data, signal life cycle costs and dollar amount of benefits were calculated. Comments on the performance of the LED signal heads were also collected from those associated with the study. Originally, it was planned to measure the LED signal intensity while the installation was taking place, but upon checking with the Dialight Corporation, it was found that there is no field intensity measuring devices available. The technology is new enough that only laboratory intensity measurements can be made. However, the lab measuring equipment is very expensive. The total compiled data was then compared to the previous year's data for this location's incandescent signal heads. A benefit cost study was conducted by Research, Development and Technology engineers to ascertain if future implementation of LED signals was warranted.

RESULTS AND DISCUSSION

From the results of the study, the electrical power savings alone will almost completely pay for the retrofit of red LED indications. Red LED indications have already gained popularity with many municipalities and local governments. In addition, savings in relamping costs, maintenance costs, and potential liability exposure adds to the return on the investment. The primary items that affect cost analysis are the initial material, retrofit and power costs. The LED signal indications used in this study are said to have a life expectancy of at least 7 years, some now even carry 10-year warranties. This means less power consumption and less relamping. Less relamping results in fewer traffic interruptions. From available data, the average LED life expectancy appears to be 7 to 8 years. For calculation purposes, we chose to use a life cycle length of 7 years. All of the cost calculations are included in Appendix C.

Installation

The most expensive aspect of LED life cycle costs is the cost of the LED indications. Initial material costs account for approximately 75 percent of the total life cycle cost. Green LED signals are significantly higher in cost than red LED signals. As LED signals become more widely accepted, the competition between LED manufacturers will continue to increase, forcing prices to decrease even more. As can be seen in Table 1, the prices of LED signals have already dropped significantly in the past two years. For this particular intersection, the total installed material price would be decreased by more than a third.

Table 1 - Price Comparison

Type	Purchase Price 1997	Price Estimate 1999	Percent Reduction
Red Ball	$190	$135	28.95%
Yellow Ball	$200	$175	12.50%
Green Ball	$690	$275	60.14%
Green Arrow	$220	$144	34.55%
Yellow Arrow	$112	$94	16.07%

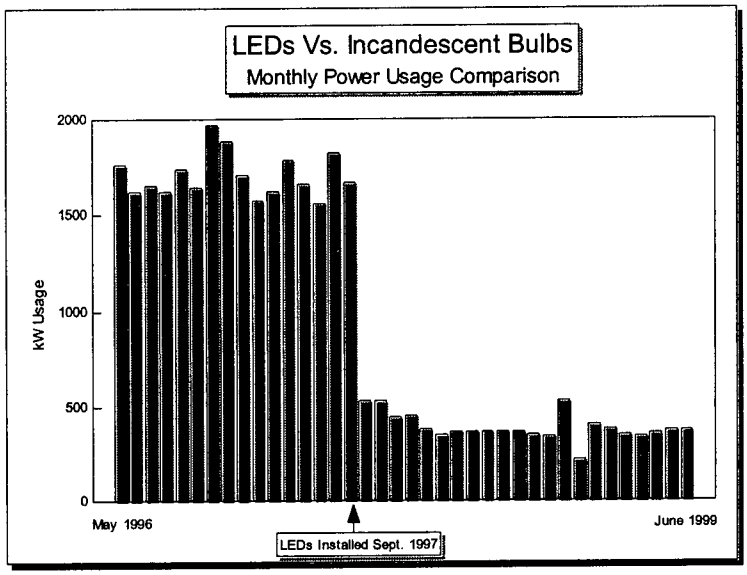
The intersection is in close proximity to the MoDOT Central District Headquarters which saved money in transportation expense and equipment rental for the installation.

Energy

After the LED signal indications were installed, kilowatt usage and power costs dropped approximately 75 percent at this intersection. To determine the energy usage at the intersection, Ameren UE was contacted and a request was made for the billing records of meter # 16280622. The power usage is paid for by the City of Jefferson. Ameren UE required permission from the

city to release the information to MoDOT. The Director of Public Works for the city was contacted and permission was granted. Figure 1 shows the monthly kilowatt usage from May of 1996 to June of 1999. The LED indications were installed in September of 1997. When the incandescent bulbs were in place, the average monthly kilowatt usage at this intersection was 1700 kilowatts. After the LED signals were installed, the average kilowatt usage dropped to 400 kilowatts.

Figure 1 - Monthly Power Usage Comparison



Various LED signal indications use 5 - 25 percent the power of equivalent incandescent indications and produce considerably less heat. The amperage draw on the intersection is around 18 amps with incandescent bulbs but with the LED signals, has dropped to only 5 amps. LED technology generally uses only an average of 22 Watts of power for an indication compared to 135 Watts of power for an incandescent bulb.

Using LED arrow indications can result in even more energy and cost savings because light and energy are not wasted on the non-illuminated portion. Red LED indications generally use less than 1/3 of the energy as incandescent bulbs and arrow LED indications generally use only 1/5 of the energy.

Maintenance

Very little maintenance has been needed at the intersection since installation. Shortly after installation, two of the indications had a string of LEDs go out in them. However, the problem was considered minor since it did not dramatically affect the intensity or visibility of the indications. A picture of an indication with a string of LEDs out is included in Appendix D. A left turn signal had a serious failure when it was damaged in a lightning storm. The indication stayed fully on after power was removed for 15 seconds, after which it began to lose intensity. It took 2 or 3 minutes to darken completely. At the intersection, this caused the indication to appear to be on nearly all of the time and it caused conflicts with other phases. The MoDOT

Traffic unit contacted Brown Traffic, the supplier, to resolve the problem. The problem was corrected internally and Brown Traffic replaced the LED indication.

There have not been any other outages so far and the light intensity of the LEDs has not diminished. On average, this intersection usually had at least one outage a year with incandescent bulbs. The chance of an outage occurring during business hours is only one in four. Therefore, most outage repairs require overtime pay for employees, which makes outages even more expensive to repair. This was taken into account in the calculations. Unlike incandescent indications, yearly relamping of the intersection does not appear to be necessary with the LED signals. On average, the LED signals have saved 4 to 5 maintenance trips, including those for relamping, since 1997. The reduction in maintenance repairs has saved in time, travel and equipment costs. This particular intersection requires less time and travel expense for maintenance and repairs than other intersections because of the close proximity to the MoDOT Central District Headquarters. For intersections further away from a signal shop, the cost savings on maintenance and repairs makes LED signals even more cost effective.

Comments

Comments were collected from those associated with the study. Occasionally, calls were received from the public that the green arrows were not as visible resulting in difficulty picking out the arrows in certain locations. The reds are considered very impressive, bold and bright. The yellows had the intensity of optically limited yellows, definitely less impressive than the reds. Another thing noticed was the "snappieness" of the changing indications. When watching both types, you could see a small, but noticeable, difference in advancing to the next colors between the two types, with LED signals being the faster.

Others made comments that overall, the LED indications look great. They have great visual impact compared to the incandescent indications. The difference in the color of the yellows does not seem as great during nighttime. However, the red ball indications do not seem to work very well when louvered. The red ball indication can be seen, at all distances, from the adjacent through lanes. The red bleeds through the louvers because of the increased intensity. In addition, the green ball indications located on the upright appear to be very distracting as you approach them, due to their intensity. This may be caused by the high directionality of the emitting light and the height of installation. Activities #7 and #8 on page 3 of the workplan were not conducted. These activities consisted of preparing and conducting a motorist awareness survey. As a result of ITE approval and positive internal comments, no motorist awareness surveys were taken.

Photographs comparing LED indications to incandescent bulb indications are in Appendix D.

CONCLUSIONS

Overall, the study was considered a success. Until this study was undertaken, no LED signals had been used on a statewide basis. The increased energy efficiency was documented with a 75 percent reduction. Increased signal life and decreased maintenance have already been seen in the last 2 years. Maintenance costs have been reduced by more than 90percent. From comments received, motorist awareness and signal intensity have increased. The most expensive aspect of the LED indications is the initial cost but the savings in maintenance and repair costs appear to justify the initial costs.

The Life Cycle Cost Analysis (LCCA) gave an Incandescent Bulb/LED ratio of 0.97. This ratio would have been even higher if the intersection had been located farther from the signal shop. The greater the distance the maintenance crews have to travel for repairs and relamping, the more expensive incandescent bulb indications become compared to LED indications. In addition, the ratio will continue to increase as the price of LED signals is reduced. Using a price estimate at 1999 costs, the ratio increases to 1.36. The 1999 ratio, using present day costs, is more appropriate than the 1997 ratio, when LED technology was still considered very new and expensive. The factors used in calculating the benefit to cost ratio included the life cycle, power usage, installation, materials, maintenance and repair costs.

RECOMMENDATIONS

Overall, the study is considered a success. Based on the results of this study, MoDOT recommends the consideration of using LED signal indications in lieu of incandescent bulb indications. Red LED signals have been implemented statewide and provisions for their use can be found in the Standard Specifications. The specification is Section 902.4.1 of the Missouri Standard Specifications for Highway Construction, 1999 Edition. This specification is attached as Appendix E. After this study, MoDOT will recommend the use of green LED signals and will include green in the Standard Specifications. The Department may consider the use of amber LED indications in some locations after ITE approval.

The red LED indications are extremely cost effective. The red indication is illuminated for the greatest length of time during an average cycle length. The yellow indications are usually illuminated for only approximately four seconds during an average cycle. Replacing the red indication with an LED results in considerable power savings and replacing the green indication will result in additional power savings. A detailed investigation of green LED power savings should be coordinated with the MoDOT Traffic unit. If only the red indication are replaced, yearly relamping of the green indications at each intersection will still be required. However, with red and green LED indications installed, perhaps the yellow incandescent bulbs could be replaced every two to three years. By reducing yearly relamping and possible outage repairs, the initial cost difference between the red and green LED signals may be justified. Additional maintenance savings will be realized as the distance from the intersection to the signal shop increases.

For semi-actuated control, if the indications that "dwell" red and green are replaced with LED signals, power usage costs would greatly decrease. Relamping and outage repair costs will be greatly reduced if both the red and green "dwelling" indications are replaced at an intersection.

IMPLEMENTATION PLAN

This report was shared with the Traffic unit of the department. Currently, red LED indications are being used throughout the state and required by the Missouri Standard Specifications. After this study, MoDOT will use the green LED indications (both green ball and green arrow indications) and will include green in the Standard Specifications book. RDT will assist the Traffic unit in writing and incorporating new specifications into the Missouri Standard Specifications book.

Assuming ITE approval in the future and the MoDOT's acceptance of yellow LED signals, a similar specification to the green and red specifications would be written for the yellow LED indications. RDT would also assist the Traffic unit in that endeavor. The Traffic unit should remain close to ITE to know if and when they do approve yellow LEDs.

This report will be shared with other states, cities and counties through our technology transfer program.

PRIORITY TECHNOLOGIES PROGRAM
Fiscal Year 1997

WORK PLAN

PROJECT TITLE:	Light Emitting Diode (LED) Signal Installation
PROJECT DESCRIPTION:	This project consists of a partnering agreement between the Missouri Department of Transportation, Federal Highway Administration and Dialight Corporation to install a light emitting diode signalized intersection. This project evaluation will develop and accelerate implementation of LED signal head technology and research. This project will consist of total changeout of new incandescent signal indications to LED signal indications.
PROJECT LOCATION:	The project location is US Route 50-63 intersection with Missouri Boulevard in Jefferson City, Missouri
RESEARCH AGENCY:	Missouri Department of Transportation Division of Research, Development and Technology
PRINCIPLE INVESTIGATOR:	Vince Imhoff Sr. Research and Development Engineer Research, Development and Technology Division
Telephone:	573-751-9252
RESEARCH PERIOD:	Following installation during the summer of 1997 the signal installation will be evaluated for a period of twelve months.
FUNDING AMOUNT:	The total funding for this project is $35,405.00.
FUNDING SOURCES:	This is a joint funding project with Missouri Department of Transportation, Dialight Corporation and Federal Highway Administration (FHWA). The funding amounts and sources are shown in the following table.

TASK	TOTAL COST	MODOT CONTRIBUTION (CASH)	DIALIGHT/ BROWN TRAFFIC	FHWA SHARE
Installation Manpower	$ 1,500	-	-	$ 1,500
Signal Head System (No.) (Average Retail Value)	$26,605	$ 8,540	$8,865	$ 9,200
5 Yellow Lt. Arrow @$340 10 Yellow St. Arrow @$340 10 Green St. Arrow @$1,000 5 Green Lt. Arrow @$1,000 2 Green Ball @$1,000 17 Red Ball @ $265	$ 1,700 $ 3,400 $10,000 $ 5,000 $ 2,000 $ 4,505			
Evaluation	$ 4,100	-	-	$ 4,100
Contingencies @ 10%	$ 3,200	-	-	$ 3,200
TOTALS	$35,405	$ 8,540 24%	$ 8,865 25%	$18,000 51%

Project Objectives: The objective of this project is to accelerate the implementation of LED signal head technology within the State of Missouri and develop an evaluation methodology that will provide data comparing LED signal heads to incandescent signal heads. The data will show whether the LED signal heads are cost beneficial as compared to incandescent signal heads.

The above evaluation methodology could provide data to ascertain that LED signal heads are more beneficial to incandescent bulbs by showing an:

1. Increased energy efficiency
2. Increased signal life
3. Decreased maintenance
4. Increased signal intensity
5. Increased motorist awareness
6. Actual dollar amount of benefits
7. Decrease red violations

Project Background: Vast amounts of research has been developed by the industry in light emitting diode (LED) applications in the area of signalized intersections. Green and red LED has been ITE approved, but the yellow or amber LED has not yet been ITE approved. There is still research being conducted toward the development of an ITE approved yellow or amber LED signal indication. One of the major contributors toward this research and development of LED signal indications is Dialight Corporation of Manasquain, New Jersey. Dialight Corporation is an active partner in this project. MoDOT will put this existing research and technology into a "real world" location to evaluate it.

Project Procedure: MoDOT is responsible for site selection, installation including traffic control and maintenance of the system. MoDOT will rely on technical assistance from its partners during the installation, maintenance and evaluation phases of the project.

An RDT staff engineer will be assigned to supervise the project. The actual installation and traffic control will be handled by MoDOT's central district traffic personnel. Data collection will be a joint exercise between MoDOT's research and traffic engineers. This data will be compiled for a period of twelve months. This data will then be compared to the previous twelve months data for incandescent bulbs. The data collected will consist of:

1. Installation costs, including material costs
2. Energy requirements and costs
3. Maintenance costs and frequency
4. Motorist awareness
5. Signal intensity measurements
6. Signal life cycle costs and dollar amount of benefits

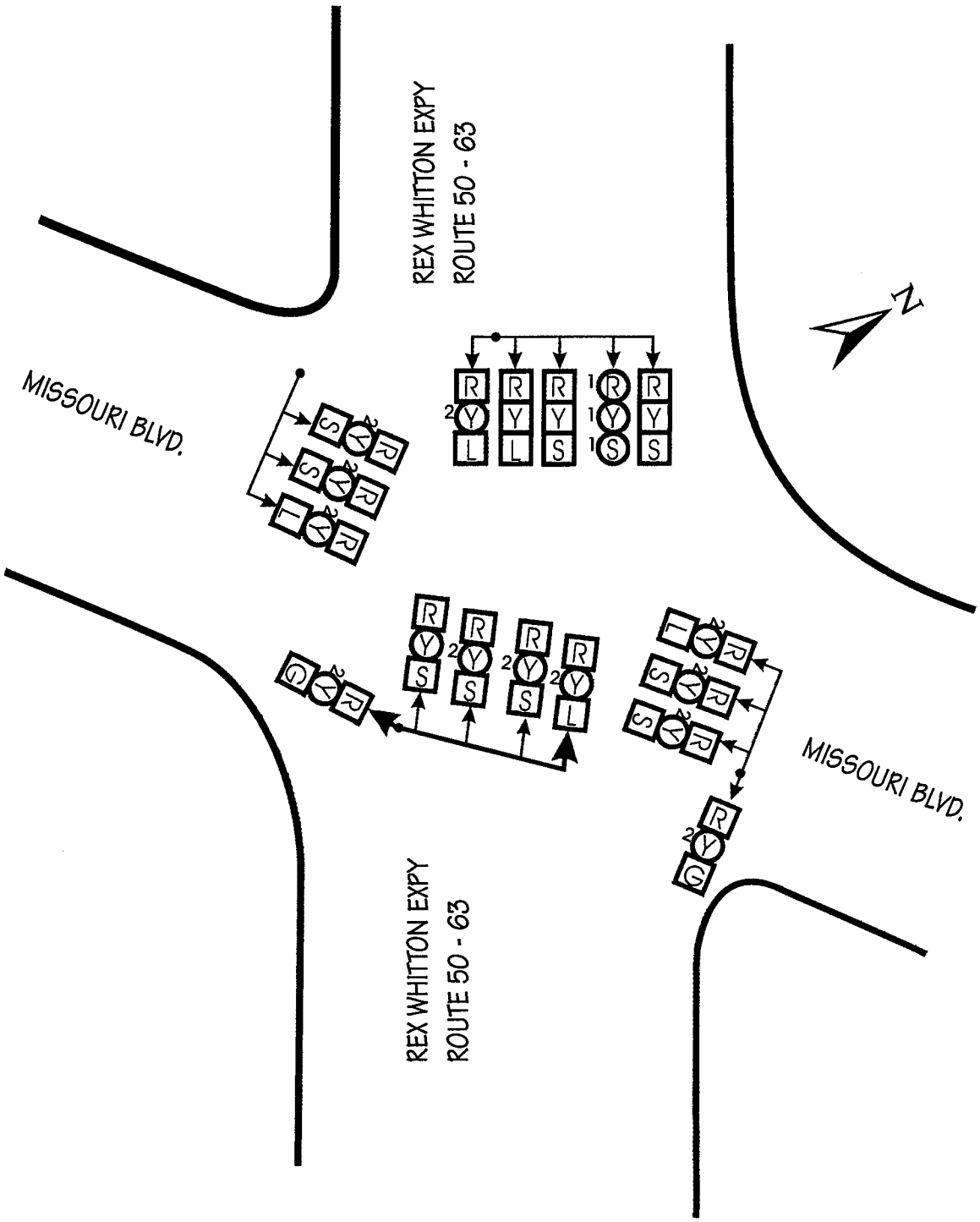
The final evaluation report will be completed by August 1, 1998.

Energy requirements and costs and maintenance costs and frequency will be documented on a monthly basis. This data will be provided to RDT by district traffic engineers.

Schedule of Activities: The following is a listing of activities associated with this project.

1. Order and receive material (Central District Traffic)
2. Prepare traffic control plan (video and still pictures of traffic control)
3. Determine time frame for installation (Target Date June 1, 1997)
4. Remove existing incandescent signals and install LED signals (one week)
5. Monitor monthly data collection (power and maintenance)
6. Initial Intensity check and at six month intervals (Dialight Corp)
7. Prepare a motorist awareness survey (RDT to prepare survey)
8. Conduct motorist awareness survey (District traffic data collectors to take)
9. Prepare interim evaluation reports (Six month intervals)
10. Prepare final evaluation report

Implementation of Evaluation Results: Four copies of the draft report and fifteen copies of the final report will be provided to the Federal Highway Administration. The final report will be shared with any state DOT requesting it. The evaluation report will also be shared with industry partners of this project. If it is determined by cost benefit studies to be cost efficient, the Traffic Division will be approached to incorporate this technology into future contracts.



○ - Incandescent (U.I.P.)
□ - LED (Replace)

1. To provide side-by-side comparison of indications
2. To assure conformance with MUTCD and ITE

Power Usage and Cost Comparison

Incandescent Bulbs

Read Date	*Usage (kW)*	*Bill Amount*
06/04/96	1758	$150.08
07/03/96	1620	$138.91
08/01/96	1650	$141.38
08/29/96	1619	$138.83
09/27/96	1737	$109.56
10/29/96	1640	$106.13
12/03/96	1970	$117.81
01/06/97	1884	$114.76
02/04/97	1702	$108.32
03/05/97	1566	$101.75
04/03/97	1620	$105.06
05/05/97	1784	$111.22
06/03/97	1653	$141.63
07/02/97	1550	$133.16
08/04/97	1818	$155.27
09/02/97	1663	$142.45
16 Months	***27234***	***$2,016.32***
Monthly Avg.	***1702***	***$126.02***
Yearly Avg.	**20426**	**$1,512.24**

LEDs

Read Date	*Usage (kW)*	*Bill Amount*
10/01/97	532	$38.36
10/30/97	532	$38.36
12/03/97	445	$32.96
01/06/98	452	$33.48
02/05/98	381	$29.11
03/06/98	350	$27.21
04/07/98	367	$29.22
05/05/98	367	$29.22
06/05/98	366	$35.81
07/06/98	366	$35.81
08/05/98	366	$35.81
09/01/98	350	$34.52
10/02/98	347	$27.02
11/02/98	532	$38.38
12/03/98	218	$18.36
01/06/99	411	$30.94
02/04/99	382	$29.17
03/08/99	350	$27.21
04/06/99	344	$26.84
05/06/99	357	$27.83
06/07/99	380	$36.99
07/07/99	377	$36.74
22 Months	***8570***	***$699.33***
Monthly Avg.	***390***	***$31.79***
Yearly Avg.	**4675**	**$381.45**

Percentage Saved Yearly	**77.11%**	**74.78%**

Appendix C

Installation and Material Costs

Incandescent Bulbs

Installation

Time	2.5	hours
Labor	2	people
Cost	$20	/ person / hr
Equipment	$17	/ vehicle / hr
Total	**$143**	**/ installation**

Installed Materials

Number	51	bulbs
Cost	$3	for each
Total	**$153**	**/ installation**

LEDs

Installation

Time	4	hours
Labor	2	people
Cost	$20	/ person / hr
Equipment	$17	/ vehicle / hr
Total	**$228**	**/ installation**

Installed Materials

	Number	*Cost for each*
Red Balls	17	$190
Amber Balls	4	$200
Green Balls	3	$690
Green Arrow	15	$220
Amber Arrow	2	$112
Total	**$9,624**	**/ installation**

Materials at 1999 Prices

	% Reduced	*Cost for each in 1999*
Red Balls	28.95%	$135
Amber Balls	12.50%	$175
Green Balls	60.14%	$275
Green Arrow	34.55%	$144
Amber Arrow	16.07%	$94
Total	**$6,168**	**/ installation**

According to Bob Lehman from the Central District Signal Shop, this intersection is less expensive for installation because of the close proximity to the Central District Headquarters.

Maintenance and Repair Costs

Incandescent Bulbs

Maintenance
(Relamping)

# per year	1 / year
Time	2.5 hours
Labor	2 people
Cost	$20 / person / hr
Equipment	$17 / vehicle / hr
Materials	$153 / installation
Total	**$296 / relamping**

Repairs

Outages	1 / year (avg.)
Time	2 hours
Labor	2 people
Overtime	$30 / person / hr
Equipment	$17 / vehicle / hr
Materials	$3 / bulb
Total	**$157 / outage / yr**

LEDs

Maintenance
(Relamping)

# per year	0 for life cycle
Time	4 hours
Labor	2 people
Cost	$20 / person / hr
Equipment	$17 / vehicle / hr
Materials	$9,624 / installation
Total	**$0 / relamping**

Repairs

Outages	1 (lightning)
Time	0.25 hours
Labor	2 people
Overtime	$30 / person / hr
Equipment	$17 / vehicle / hr
Materials	$0 (warrantee)
Total	**$19 / outage**

According to Bob Lehman from the Central District Signal Shop, this intersection is less expensive for maintenance and repairs because of the close proximity to the Central District Headquarters.

Life Cycle Cost Analysis

Incandescent Bulbs

Total Cost for Life Cycle

Life Cycle	1 year
Power Usage	$1,512 / year (avg)
Installation	$143 / life cycle
Materials	$153 / life cycle
Maintenance	NA, same as install
Repair	$157 / life cycle

1512+143+153+157=1965

LEDs

Total Cost for Life Cycle

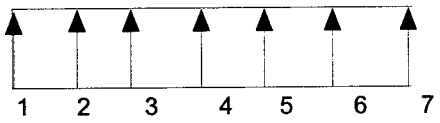
Life Cycle	7 years
Power Usage	$381 / year (avg)
Installation	$228 / life cycle
Materials (97)	$9,624 / life cycle
(99)	$6,168 / life cycle
Maintenance	$0 / life cycle
Repair	$19 / life cycle

(1997) 228+9624+19 = 9871
(1999) 228+6168+19 = 6415

I. Incandescent Bulbs

Installation, Materials, Repairs, Power Usage

$1,965

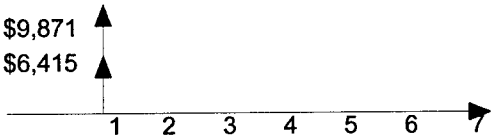


(F/A 4%, 7 years) $1,965 x 7.8983=$15,520

II. LED's

Installation, Materials, Repairs

(1997) $9,871
(1999) $6,415



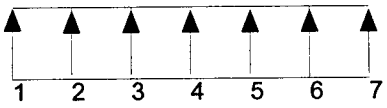
(F/P, 4%, 7 years)

(1997 Prices) 9871 x 1.3159=$ 12,989
(1999 Prices) 6415 x 1.3159 =$ 8,441

1997 Prices = 12989+3009 = $15,998
1999 Prices = 8441+3009 = $11,450

Power Usage

$381



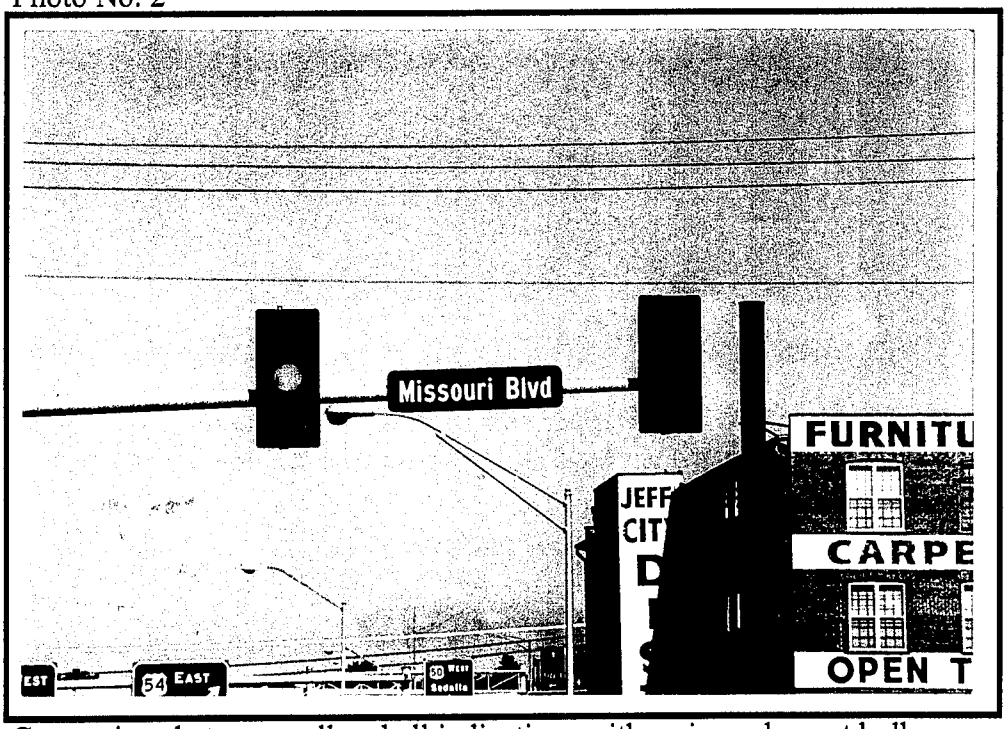
(F/A, 4%, 7 years)
$381 x 7.8983 = $3,009

Incandescent Bulbs/ LED Ratio
(1997) 15520/15998= 0.97
(1999) 15520/11450 = 1.36

Photo No. 1

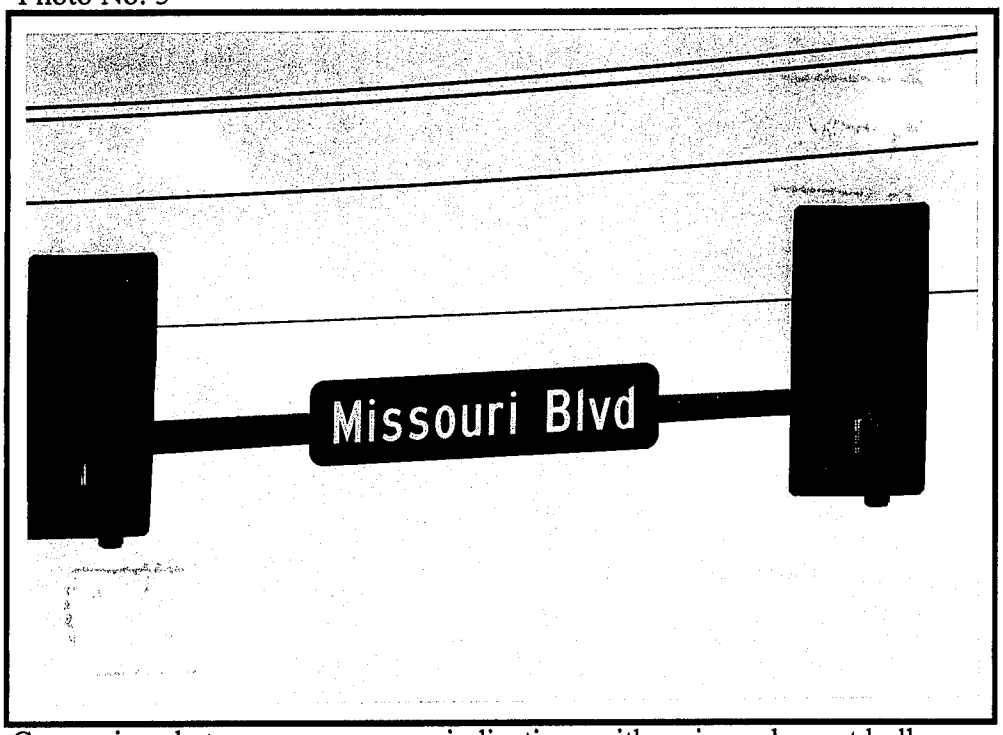
Comparison between red ball indications with an incandescent bulb indication on the left and a LED signal indication on the right.

Photo No. 2



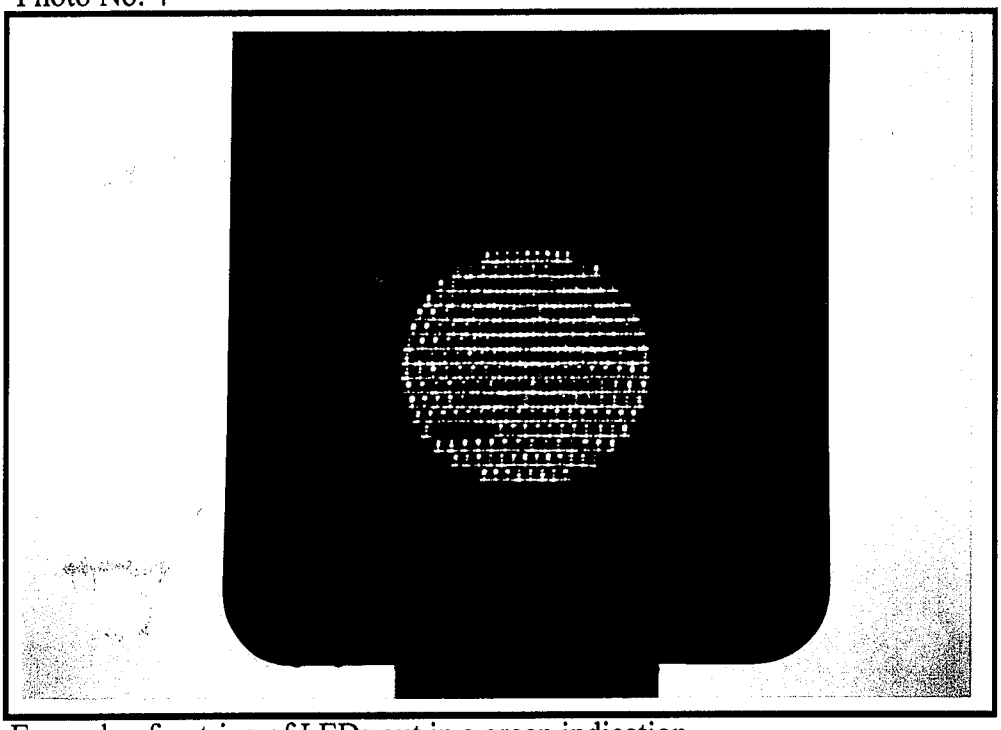
Comparison between yellow ball indications with an incandescent bulb indication on the left and a LED signal indication on the right.

Photo No. 3



Comparison between green arrow indications with an incandescent bulb indication on the left and a LED signal indication on the right.

Photo No. 4



Example of a string of LEDs out in a green indication.

902.4.1 Signal Heads. Each signal head of one or more signal faces shall be conventional or, if designated on the plans, optically limiting. The contractor has the option to furnish aluminum or polycarbonate signal heads. All signal heads shall be weatherproof and meet the following requirements:

(a) All signal heads shall be black in color in accordance with Sec 902.5.10. All indications shall be 12 inches (300 mm) unless otherwise specified.

(b) All red signal indications in conventional signal heads shall be illuminated with light emitting diode (LED) modules. LED modules shall conform to ITE specifications and standards for LED vehicle traffic signal modules and the following:

(1) The lens of each indication shall be tinted with a wavelength-matched color to reduce sun phantom effect and enhance on/off contrast. The tinting shall be uniform across the lens face. If a polymeric lens is supplied, a surface coating shall be applied to provide abrasion resistance.

(2) LED modules shall not contain Aluminum Gallium Arsenide (AlGaAs) LEDs.

(3) LED modules shall provide constant light output under power. Modules with dimming capabilities shall have the option disabled or set on a non-dimming operation.

(4) In the event of a power outage, light output from the LED modules shall cease instantaneously.

(c) Incandescent signal indications in conventional and optically limiting signal heads and walk indications in pedestrian signal heads shall be certified by the manufacturer.

(d) Each signal face shall be furnished with a terminal block with circuit capacity as required but not less than four terminals. If single sections are specified, each section shall be furnished with a terminal block. All terminal blocks shall be rigidly secured to the section housing.

(e) A tunnel visor shall be supplied with each signal section unless otherwise specified.

(f) The position of signal indications shall be as specified in the contract.

(g) The lamp receptacle shall be designed so that it will be impossible for the lamp to loosen due to thermal expansion or vibration. The lamp receptacle shall be of heat resistant material and shall be of the fixed-focus type. The receptacle shall be designed to hold a 67, 100, 135 or 150-watt, Type A-21, traffic signal lamp with the light center at 2 7/16 inches (62 mm) for 8-inch (200 mm) diameter signals and to hold a medium screw base lamp having a 3-inch (75 mm) light center for 12-inch (300 mm) diameter signals. The receptacle shall have a grip to hold the lamp securely. Rotation of the receptacle for positioning the lamp filament shall be possible without using tools.

(h) Wiring for each lamp receptacle shall be provided by color coded No. 18 AWG (1 mm^2) insulated stranded copper conductors of sufficient length to extend, without splicing, to the terminal block located within each signal face with the reflector and holder in a fully open position.