IDEA

Innovations Deserving
Exploratory Analysis Programs

NCHRP IDEA Program

Self-de-icing LED Signals for Railroads and Highway Intersections

Final Report for
NCHRP IDEA Project 190

Prepared by:
Hongyi Cai
The University of Kansas

September 2022

NATIONAL ACADEMIES Sciences Engineering Medicine

TRB TRANSPORTATION RESEARCH BOARD

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IDEA Project NCHRP-190

Prepared for

The NCHRP IDEA Program
Transportation Research Board
National Academies of Sciences, Engineering, and Medicine

by

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September 8, 2022

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EXECUTIVE SUMMARY

This project was aimed at developing and demonstrating a new type of self-de-icing LED signals for highway and railroad intersections as a replacement for existing LED signal lights that remain too cold to deice or melt snow and could cause accidents in snowy conditions.

Stage 1 work focused on laboratory development and testing. Needed equipment, components and materials were procured to develop and build the prototypes. The innovative "Integrated Light and Heat Arrangement of Low Profile Light-Emitting Diode Fixture" (Patent No. US 10,215,441 B2) was adopted for the architecture of the new LED signals and tested in the laboratory to enhance the heating and lighting performance while reducing costs. Appropriate color LED modules using the new architecture were designed in-house and custom-made through the industrial partner (Sunlite Science & Technology). Five generations of prototype signals (Red, Yellow, and Green) were developed and tested in the laboratory for further improvements. The prototype signals (R, Y, G) use new light engines in low profile using 96 medium-power LEDs, two custom-made LED drivers (one for red light and the other for green/yellow light) integrated with a remote temperature sensor for controlling the power output in ambient air temperature and an on/off switch for winter and summer modes, new signal housing, and new signal lens integrated with 96 small Fresnel lenses (diameter: 15 mm, focal length: 11.5 mm, thickness: 1.5-2.0 mm) for light collimation of individual LEDs. Laboratory testing of all heating and lighting parameters of the prototypes with the desired specifications was completed. The industrial partner assisted in the production of finalized LED light engines while several other contracted companies produced all other metal, glass, and plastic parts needed for assembling the final porotypes for field tests. The prototypes were tested in a controlled cold room for the performance of the ambient temperature sensor connected to the LED driver, and the power output of the LED drivers was adjusted. The signal housing was also revised for quick assembly.

The fully functional prototypes have been under continuous testing on the university's engineering building roof and powered by a traffic control cabinet for closed-course performance and reliability evaluation. Issues with second-generation LED drivers were resolved with needed changes, and the ambient temperature sensor of the drivers was improved for switching power output at 4°C with acceptable tolerances. Second generation LED driver samples were tested thoroughly in the cold room and on the rooftop and, based on the test results, improvements were made to develop the third generation LED drivers. New Fresnel lenses made by another manufacturer with lower price and higher quality control were procured and tested in the laboratory with satisfactory results. Additional 5000 units of new Fresnel lenses were procured for the upcoming field tests. A total of 21 new third generation LED drivers were tested for field performance and further improvements needed for the control of the yield rate were made. New fully functional prototypes for field tests were assembled and continuously tested in the laboratory in preparation for field tests. In addition, a field monitoring system consisting of a Raspberry PI computer, three cable cameras, four temperature sensors, USB flash drivers, power supplies, and mounting accessories, was built in-house and continuously tested in the laboratory and on the rooftop in preparation for field installation. The system would be mounted at all field test sites for year-around real-time monitoring and data recording of the new signals.

The first field test site was set up in Kansas at the intersection of County Road 458 /US-59. All new equipment including the performance monitoring system for data recording, installed on side signals facing north, has already survived three winters and three summers. Based on the test results, the third-generation LED

drivers needed further improvement, which led to the development of fourth generation drivers. Collaborations continue with the LED driver company to produce fourth generation drivers compatible with UL certificate whose power consumption in warm weather would be minimized. To correct the defective concaved lens surface of the plastic housing in mass production, the molding technique was revised by increasing the runner diameter size from 4 mm to 6 mm, which solved the problem of housing lens' unevenness with a maximum tolerance of 1.5 mm. Meanwhile, the PC material was changed to Markrolon 2807 for UL certificate. Samples of the new housings made in the factory were tested with passing quality. The field remote monitoring system with added mobile communication information device and data plan to remotely send signal performance data back to the laboratory on daily basis for real-time performance monitoring was continuously tested on the roof and installed at a field test site in Kansas.

A new Fresnel disc was custom-made with 96 small Fresnel lenses to replace the old system design of 96 separate Fresnel lenses. Twenty samples of the first-generation Fresnel lens disc were tested for lighting and thermal performance in the laboratory. The mold of the Fresnel lens disc was revised to improve its fitting in the final product installation. A total of 40 samples of the improved second-generation Fresnel lens disc were tested with satisfactory thermal performance but the lighting performance was not optimized due to increased focal length of 12.5-13.0 mm (> 11.5 mm). With improvement on injection technology, a sample of third generation Fresnel lens disc was tested with shortened focal length of 11.9 mm, but still > 11.5 mm. Several laboratory tests were also conducted to help revise the mold for fourth generation Fresnel lens disc with optimized focal length of 11.5 mm or less in mass production. This problem could be solved by revising the mold with adjusted focal length of 10.5 mm. The lens surface luminance uniformity was tested to meet the code.

Fifth generation prototypes of the final product and the associated field remote monitoring systems were prepared and fully tested for field tests in other states. Three prototypes were shipped to Maryland Department of Transportation for compatibility tests. Two additional field tests were conducted in Wisconsin (location: STH 100 & Center Street, Milwaukee County, Wauwatosa, Wisconsin) and Michigan (location: MDOT OFS Operations Field Services, 6333 Lansing Rd, Lansing, MI 48917). The field installation and testing at those two new sites were successfully and the test data have been remotely retrieved on daily basis since then. More prototypes of the final products were prepared for other possible test sites in the future. Seven states (Kansas, California, Michigan, New Jersey, Wisconsin, Pennsylvania, and Maryland) participated in field-testing and evaluation of the prototypes.

IDEA PRODUCT

This project has developed a new type of self-de-icing LED signal for highway signalized intersections and railroad signaling applications to solve a well-known problem of the existing LED signal light with lens too cool to melt snow and deice in wintery conditions. The existing "cool" LED signal light does not generate sufficient heat in the forward direction towards the lens of the signal. As a result, as shown in Figure 1, snow and ice can easily accumulate on the lens within the signal hood in wintery conditions and block light to the drivers of vehicles or locomotive engineers. The snow-clogged signal lights can decrease the performance of signalized intersections and railroads and may result in collisions in inclement weather conditions.

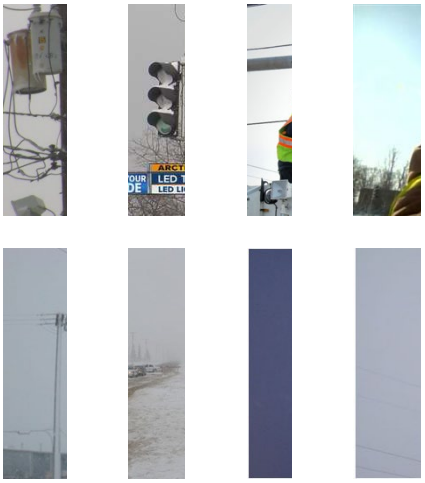


Figure 1 Snow-clogged "cool" LED traffic lights and their cleaning off by hand [1, 2], and snow-clogged railroad signals [3, 4]

This problem of snow-clogged LED traffic signal could be prevented by the new type of self-de-icing LED signal where the heat generated by the LEDs is harvested by the passive heat exchanger and stored there to continuously heat the signal lens in wintery conditions. Figure 2 illustrates the prototypes of self-de-icing LED signals (Red, Yellow, Green) for highway signalized intersections.

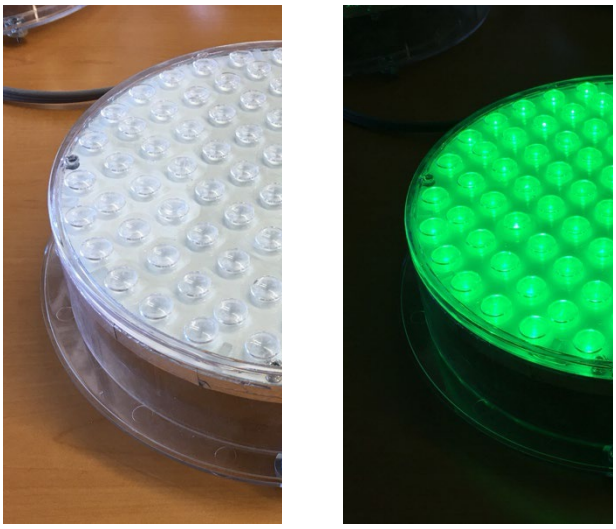


Figure 2 Prototypes of the new type of self-de-icing LED signals (Red, Yellow, Green) for highway signalized intersections.

The self-de-icing LED signal modules (R, G, Y) were designed to be swappable with the existing "cool" LED signal modules of the same color, without altering the function and sizes of the existing signal modules. No additional wiring inside and outside of the existing signal controller cabinets is necessary, no need to change anything outside of the signal housing. The self-de-icing LED signal is expected to transform the use and operation of the existing signal lights in snowy regions in North America with significant benefits in safety and performance efficiency and overall user cost savings. As validated in the field tests, the self-de-icing LED signal can be a viable retrofit to the existing "cool" LED signal lights (also the obsolete incandescent signal lights as well) installed at the highway signalized intersections.

CONCEPT AND INNOVATION

The self-de-icing LED signal light employs the innovative system architecture of "Integrated Light and Heat Arrangement of LEDs in Low Profile" (Figure 3) to harvest both the light and the heat generated by the same LEDs for illumination and heating of the signal lens. Approximately 70-80% of the electricity consumed by LEDs is converted to heat rather than light [5]. The harnessed great deal of LED heat enables the self-de-icing LED signal for prevention of the buildup and accumulation of ice, sleet, and snow on the lens of the signals during wintery conditions. As validated in the field tests, there is no need of additional heat generators (e.g., resistance wires or infrared LEDs).

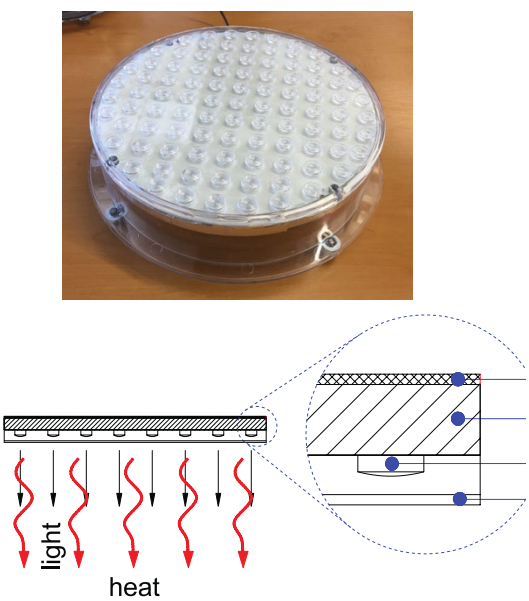


Figure 3 The concept and a prototype of the self-de-icing LED signal light, which deploys new architecture of "Integrated Light and Heat Arrangement of LEDs in Low Profile" (Patent No. US 10,215,441 B2) to harvest both the light and the heat generated by the same LEDs for lighting and heating uses. The heat generated by the LEDs is harvested by the passive heat exchanger and stored to heat the lens for melting snow and de-icing in wintery conditions.

To lower the power consumption in summer, the self-de-icing LED signal modules are equipped with a remote ambient temperature sensor wired to their LED driver. In cold weather, when the ambient air temperature drops below 4 °C (39.2 °F), the remote temperature sensor switches the driver's power output to full output to prevent snow and ice accumulation on the signal lens. In warm weather, when the ambient air temperature is above 4 °C (39.2 °F) and there is no risk of snow and ice accumulation, the signals will have only derated power output, at about 26-32% of the full power output, for energy saving. Meanwhile, the maintained signal light output meets the code requirements. Table 1 summarizes how the remote temperature sensor of the signals switches their power output in accordance with the ambient air temperature. The derated power output in warm weather will also largely extend the useful life of the product in field implementation.

Table 1 The remote temperature sensor of the signals switches their power output in accordance with the ambient air temperature.

Ambient air temperature	> 4 °C (39.2 °F)	≤ 4 °C (39.2 °F)
Red LED signal	**Derated 32%** power output	**full** power output
Yellow LED signals	**Derated 26%** power output	**full** power output
Green LED signals	**Derated 32%** power output	**full** power output

INVESTIGATION

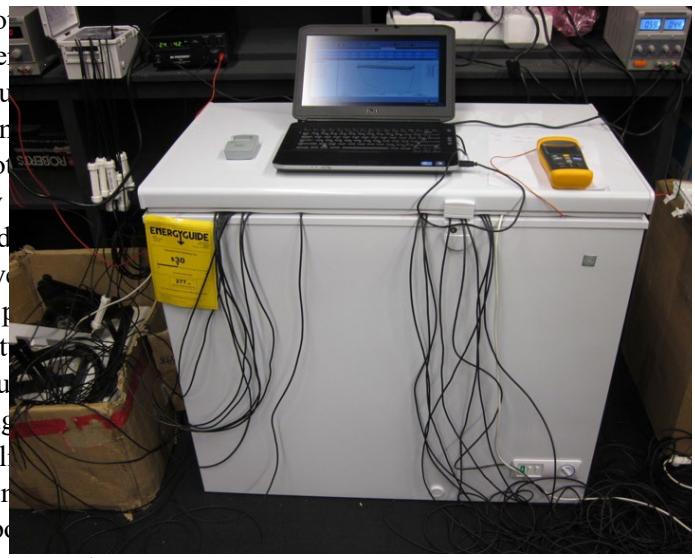
The work of this project was divided into three stages, including Stage 1 – Laboratory Development and Testing, Stage 2 – Performance and Reliability Tests on the Roof, and Stage 3 – Field Tests.

A. Laboratory Development and Testing

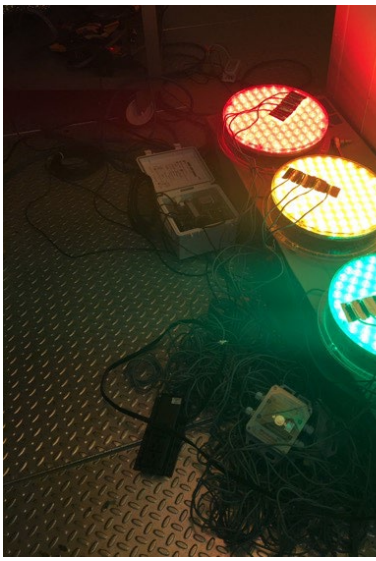
At Stage 1, the new self-de-icing LED signals were developed and tested in the University of Kansas lighting research laboratory and its dark room, and the Cold Room in the LEEP2 engineering complex. The innovative architecture of "Integrated Light and Heat Arrangement of Low Profile Light-Emitting Diode Fixture" (Patent No. US 10,215,441 B2) was adopted for the new self-de-icing LED signals and tested in the laboratory to enhance the integrative heating and lighting performance while reducing costs.

Needed equipment, components and materials were procured to build a total of five generations of proto
(R, Y, and G). Several othe
companies have been produ
other parts needed for assen
final porotypes. Each proto
module consists of (a) new
in low profile using 96 med
LEDs; (b) an insulation lay
back of the light engine as p
innovative system architect
of two self-designed and cu
LED drivers (one for red lig
the other for green/yellow l
integrated with a remote ter
sensor for controlling the p
in light of the ambient air temperature and an on/off switch for winter and summer modes; (d) new signal housing custom made by a plastic molding company using UV stabilized polycarbonate materials; and (e) a new signal lens disc integrated with 96 small Fresnel lenses for light collimation of individual LEDs. The new light engines for appropriate color LED modules (R, Y, G) were self-designed and custom-made with the aid of the industrial partner (the Sunlite Science & Technology). On top of the light engine, the Fresnel lens disc with 96 lenses (each lens in diameter 15 mm, focal length 11.5 mm or less, thickness 1.5-2.0 mm) was mounted with a gap of ¼" for optimal LED light collimation and balanced thermal performance. The signal housing was also continuously revised for quick assembly of final products.

All prototypes were tested in the laboratory for further improvements and testing. Laboratory testing of all heating and lighting parameters of the prototypes with the desired specifications that meet the ITE codes and standards was completed. The prototypes were also tested in a controlled cold room for the performance of the ambient temperature sensor connected to the LED driver, and the power output of the LED drivers was adjusted accordingly. Figure 4 shows the testing of three fully functional prototypes (R, G, Y) of the new signals in a freezer located in the dark room, and then in a well-controlled Cold Room with controllable ambient air temperature. In those tests, the signals were continuously powered by DC power sources.



(a) in a freezer in the dark room



(b) in the cold room

Figure 4 Prototypes (R, G, Y) of the self-de-icing LED signals were tested in a freezer and the well-

controlled Cold Room located for their thermal performance when the signals were powered continuously with DC power sources.

Table 2 and Figure 5 show the results of a typical test of the 5th generation signals, indicating the temperature difference between the signal lens and the ambient air temperature was all larger than 30° C for all signals, when the signals were powered continuously with full power output (current 0.837 A for green light, 0.838 A for yellow light, and 1.115 A for red light).

Table 2 Typical thermal performance of a 5th generation prototypes (R, G, Y) of the self-de-icing signals in a freezer when continuously powered by a DC power source with 100% power output

Test conditions	**Freezer, 3 signals tested together**	
Ambient Air Temp	Ambient air	-11.5° C
Lens Surface Temp	Green light (current 0.837 A)	19.2 ° C
	Yellow light (current 0.838 A)	21.1 ° C
	Red light (current 1.115 A)	19.8 ° C
Temp Difference (Δ) above Ambient	Green light (current 0.837 A)	**Δ 30.7° C**
	Yellow light (current 0.838 A)	**Δ 32.6° C**
	Red light (current 1.115 A)	**Δ 31.3° C**

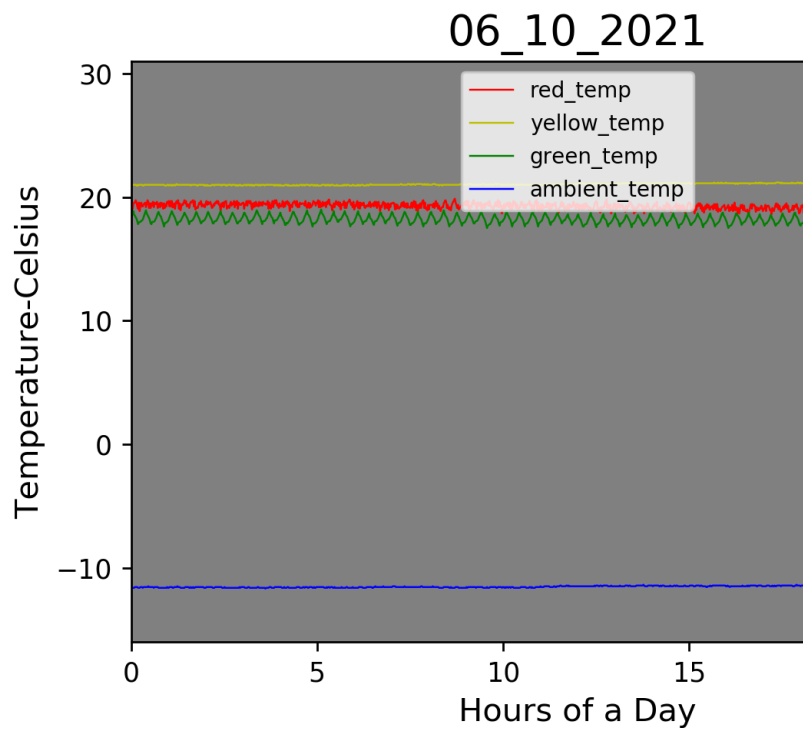


Figure 5 The thermal performance of the 5th generation prototypes of the self-de-icing LED signals tested in a freezer, powered continuously with DC power sources with full power output.

Moreover, the lighting performance of different generations of the prototype signals was measured at both derated/dimmed mode when the ambient air temperature is above 4 °C (39.2 °F) and full power output mode when the ambient air temperature is below 4 °C (39.2 °F), respectively. Tables 4 and 5 summarize the measurement results of the 4th and 5th generation prototypes, all passed the code requirements (Table 3). The signal lights were brighter when they have full power output. It is worth mentioning that the prototype signals still have potentials to further lower their derated power output for more energy saving, still meeting the code requirements for light output.

Table 3 Peak minimum maintained luminous intensity values of $I_{(-2.5°, 0°)}$, measured at vertical off-axis viewing angle of $\theta_{vert} = -2.5°$ and horizontal off-axis viewing angle $\theta_{horiz} = 0°$, of signal lights with a lens diameter of 12 inches by color of the module as required by the code [6]

Light color	$I_{(-2.5°, 0°)}$ 300 mm (12" in diameter)
Red	365 cd
Yellow	910 cd
Green	475 cd

Table 4 Lighting performance of the 4th generation signal lights of different colors with derated/dimmed output and full output, respectively, all passed the code requirements of $I_{(-2.5°,\ 0°)}$

ilting angle θ_{vert} °)	Intensity (cd)					
	ed, Dimmed	ellow, Dimmed	reen, Dimmed	ed, Full output	ellow, Full output	reen, Full output
	54.3	124.87	719.9	884.9	124.7	808.2
.5	69.9	126.54	739.9	869.9	144.7	819.8
	81.4	131.54	751.6	839.9	164.7	819.8
.5	97.3	134.87	754.9	809.9	174.7	804.8
	012.6	138.2	754.9	774.9	184.7	774.8
.5	**028.9**	**136.54**	**749.9**	**759.9**	**189.7**	**754.8**
	365	**910**	**475**	**365**	**910**	**475**
	048.6	134.87	734.9	734.9	194.7	739.8
.5	066.1	129.87	719.9	719.9	194.7	704.8
	086.6	124.87	709.9	704.9	191.4	666.5
.5	099.9	116.54	689.9	689.9	184.7	629.8
	109.4	109.87	673.2	679.9	184.7	604.8
	118.9	089.87	624.9	649.9	154.7	548.2
	121.9	069.87	589.9	619.9	104.8	489.8
	107.1	038.21	564.9	584.9	056.4	459.9
	088.4	009.88	534.9	559.9	006.4	404.9
0	073.8	984.88	514.9	536.6	941.4	364.9
0	47.1	703.23	407.4	452.2	374.8	214.9
0	75.8	44.97	79.1	64	78.3	13.8
0	5.9	52.16	70.5	39.8	97.3	70
0	7.2	20.91	38.5	10.3	35.3	16.5
0	08.3	59.49	83.7	71.7	24.1	84.3
0	1.9	52.49	31.5	0.8	08.1	06.2

Table 5 Lighting performance of the 5th generation signal lights of different colors with derated/dimmed output and full output, respectively, all passed the code requirements of $I_{(-2.5°,\ 0°)}$

ilting angle θ_{vert} °)	Intensity (cd)					
	ed, Dimmed	ellow, Dimmed	reen, Dimmed	ed, Full output	ellow, Full output	reen, Full output
	67.5	088.2	713.3	277.2	903.8	740.9
.5	68.1	089.6	721.3	277.9	903.4	741.6
	68.1	091.6	728.0	281.9	927.6	747.6
.5	71.5	091.6	733.4	283.3	932.3	791.2
	76.2	089.6	740.8	288.0	928.3	818.1
	80.9	**087.6**	**751.5**	**300.0**	**945.7**	**827.5**
.5	**365 (code)**	**910 (code)**	**475 (code)**	**365 (code)**	**910 (code)**	**475 (code)**
	85.6	088.2	761.5	301.4	925.6	832.2
.5	91.6	091.6	772.3	316.8	932.3	835.5
	97.0	093.6	785.0	328.2	977.9	838.2
.5	08.4	099.6	801.8	351.7	988.6	900.6
	21.1	109.0	821.2	394.6	028.2	932.1
	41.9	129.2	873.6	459.7	173.1	960.3
	74.8	163.4	954.7	518.7	197.3	127.3
	21.7	199.6	027.2	618.7	311.3	203.1
	78.1	208.3	129.8	597.2	953.1	407.7
0	73.4	153.3	127.1	521.4	725.0	382.2
1	22.4	021.8	959.4	338.3	275.6	115.2
2	52.6	778.3	1845.4	134.3	667.8	952.9
3	26.5	452.3	1768.3	98.2	2048.0	829.5
4	91.7	178.6	1630.7	31.2	1744.1	625.6
5	99.1	23.0	9343.0	68.8	1532.1	162.0
0	45.6	37.4	4763.5	56.2	2760.7	37.2
5	02.6	301.2	3713.9	88.5	5551.4	502.4
0	2.5	232.8	2849.5	50.3	4216.6	404.5
0	7.7	159.0	173.7	17.4	318.0	376.4
0	3.0	133.5	143.6	7.8	193.9	132.8

0	3.1	55.6	77.1	5.8	85.1	85.1
0	3.5	8.5	13.4	0.3	88.5	80.4
0	.0	8.3	8.4	1.5	4.5	2.6
0	.4	0.8	8.2	2.1	9.7	5.6

Additionally, the signal lens's surface luminance uniformity was tested based on the code requirements, as shown in Figure 6. It was found that the max/min ratio is in a range of 5.5-8.3 for different colors (R, G, Y), less than the code requirements of max/min ratio of maximum 10. For further improvement on the lens surface luminance uniformity, we could modify the Fresnel lens disc surface treatment with possible frosted surface in those gaps between lenses from current transparent surface. Based on the computer simulation, this could increase the uniformity while not significantly affect the signal light distribution.

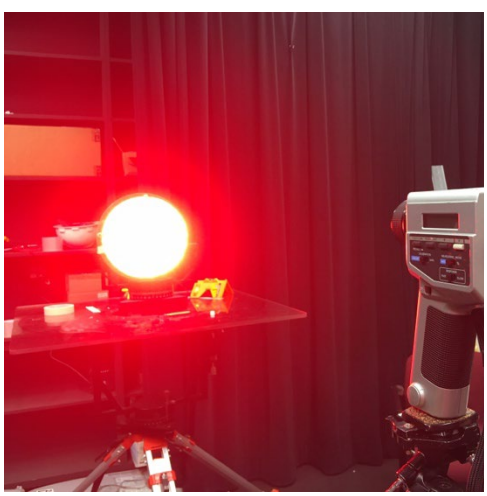


Figure 6 Lab measurement of the signal lens surface luminance using the code recommended measurement method with a luminance meter.

B. Performance and Reliability Tests on the Roof

Work in Stage 2 focused on closed-course performance and reliability tests of the new signals on the roof of the University of Kansas engineering complex. The fully functional prototypes of different generations were continuously tested on the roof, powered by a real traffic control cabinet. As shown in Figure 7, three prototypes were mounted on a signal pole, powered by a traffic control cabinet in real signaling time cycles (in a cycle length of 90 seconds, red signal light ON for 50 seconds, green signal light ON for 35 seconds, yellow signal light ON for 5 seconds) for comprehensive heating and lighting performance tests. The signaling time cycles are adjustable for testing different cycles. The roof testing has been continuously conducted since 2018 through multiple snowstorms in the past years, with the 5th generation prototypes still under ongoing testing.

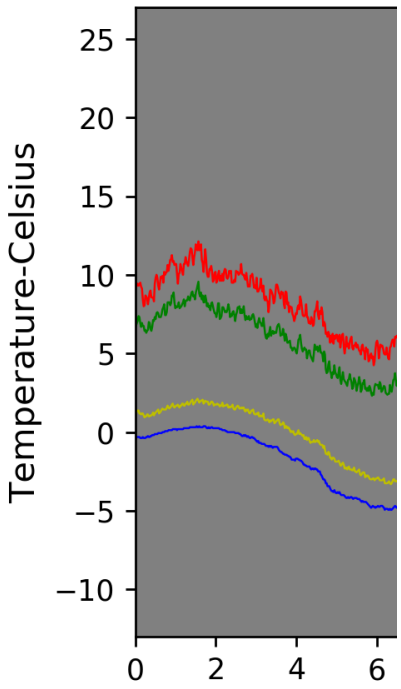
Furthermore, we developed a house-built field monitoring system that was continuously tested on the roof. With a few improvements, the system was proven reliable for data recording. As shown in Figure 8, the field monitoring system consists of a Raspberry PI computer, three cable cameras used to monitor three signal lights (Red, Yellow, Green) in each unit, four temperature sensors used to record the lens' surface temperature of the three signal lights (Red, Yellow, Green) and the ambient air temperature, USB flash drivers used to store the year around test data (pictures and temperature dataset), power supplies, and mounting accessories. The field monitoring system was set up to take photos of the lens' surface and record the lens' surface temperature data every 20 seconds in winter seasons (when the ambient temperature is lower than 4 °C (39.2 °F)) and every hour in summer seasons. The temperature sensor was mounted on the lower edge of the signal lens to prevent blocking the driver's view to the signal light. After validation on the roof, the system would be mounted at every field test site for year-around real-time monitoring and data recording of the new signals.

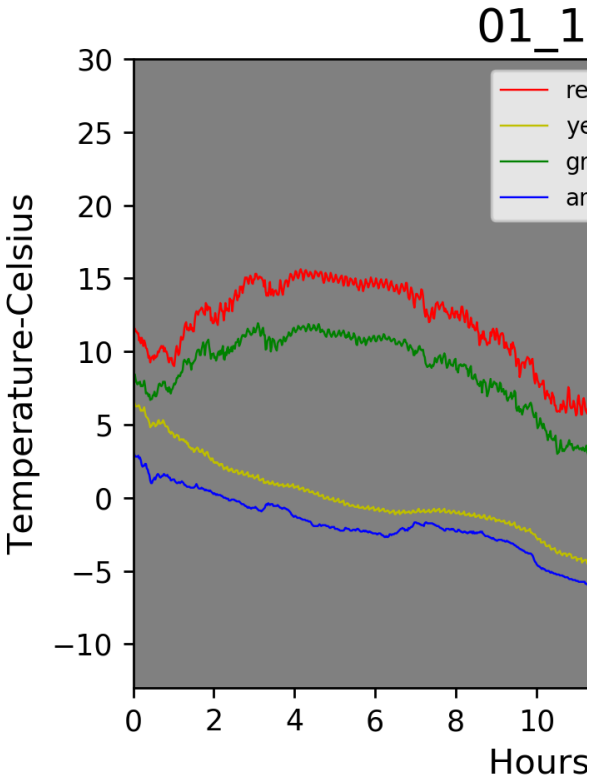
Figure 7 Prototypes of the new type of self-de-icing LED signals (Red, Yellow, Green) for highway signalized intersections, and their performance and reliability tests on the roof of the University of Kansas engineering complex, powered by a real traffic control cabinet.

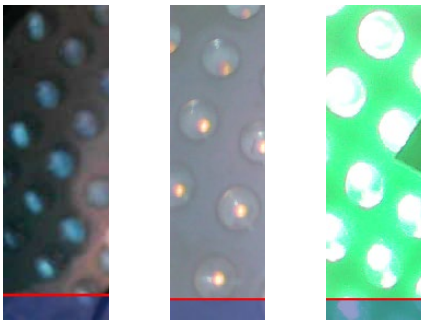
Figure 8 Equipment for testing the closed-course performance and reliability of fully working prototypes mounted on the roof, powered by the signal controller cabinet with real signaling time cycles (in a cycle length of 90 seconds, red signal light ON for 50 seconds, green signal light ON for 35 seconds, and yellow signal light ON for 5 seconds). The field performance monitoring system consists of a Raspberry PI computer with a USB driver for recording year-around data, three cable cameras used to monitor three signal lights (R, G, Y) in each unit, four temperature sensors used to record the lens' surface temperature of the three signal lights and the ambient air temperature, power supplies, and mounting accessories.

Figure 9 shows the results of the roof tests with the field monitoring system, including temperature figures, photos of the lens' surface (R, G, Y), and recorded temperature data log, in both winter and summer. Based on the roof test results, improvements on plastic housing with desired changes were made for quick assembly and tested in the laboratory with satisfactory performance. Other issues with the second-generation LED drivers were resolved with needed changes, and the ambient temperature sensor of the drivers was improved for switching power output at 4°C with acceptable

tolerances. A total of 21 new LED drivers of the third generation were tested for their field performance and further improved for the control of the yield rate in production. Those drivers were then assembled in the 4th and 5th generation fully working prototypes for field tests, whose switching temperature of the ambient temperature sensor was tested and validated around 4°C. New Fresnel lens disc was also continuously improved with lower unit price and higher quality control.







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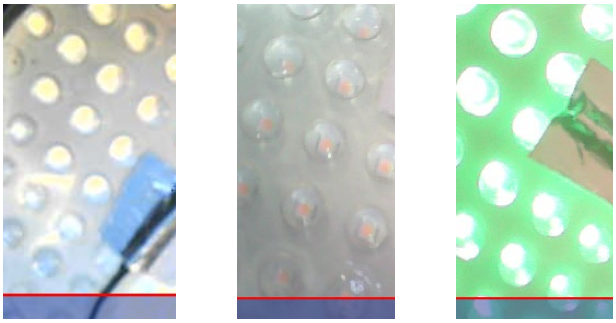

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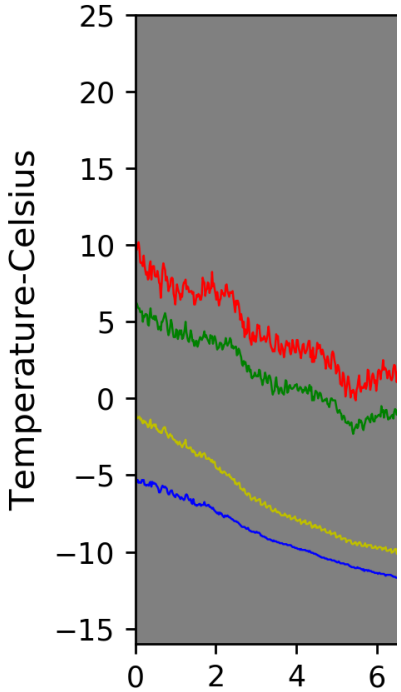

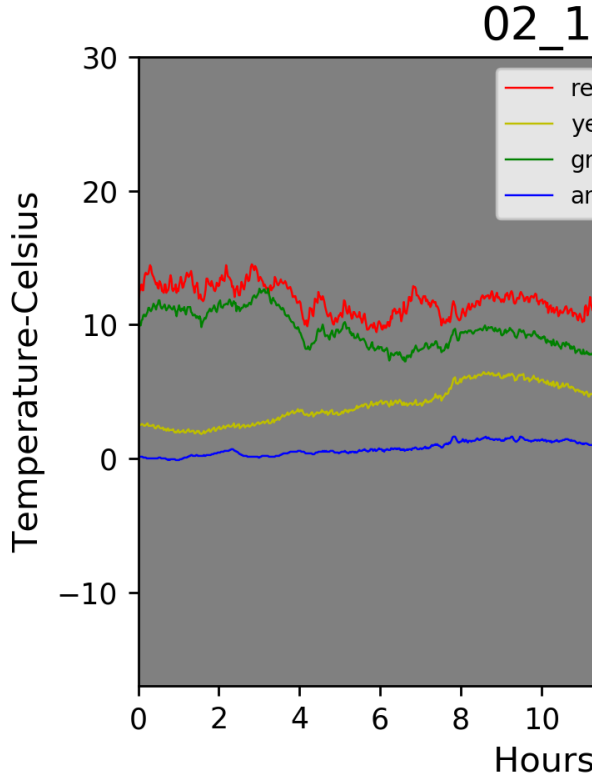

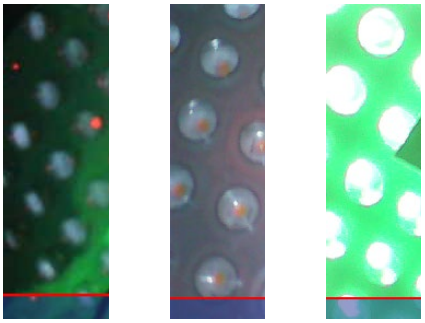

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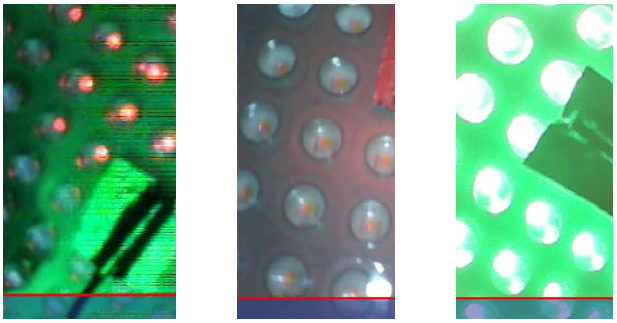

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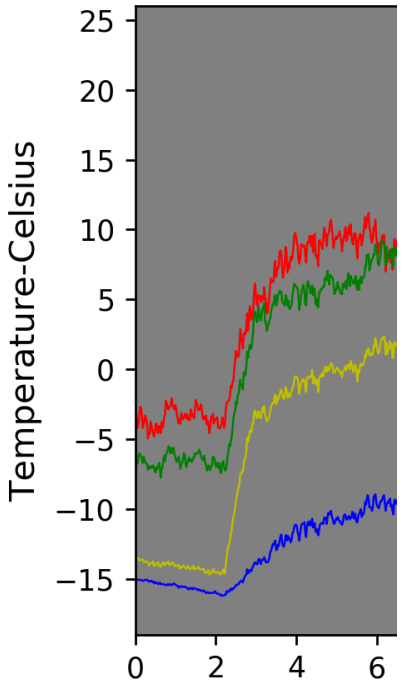
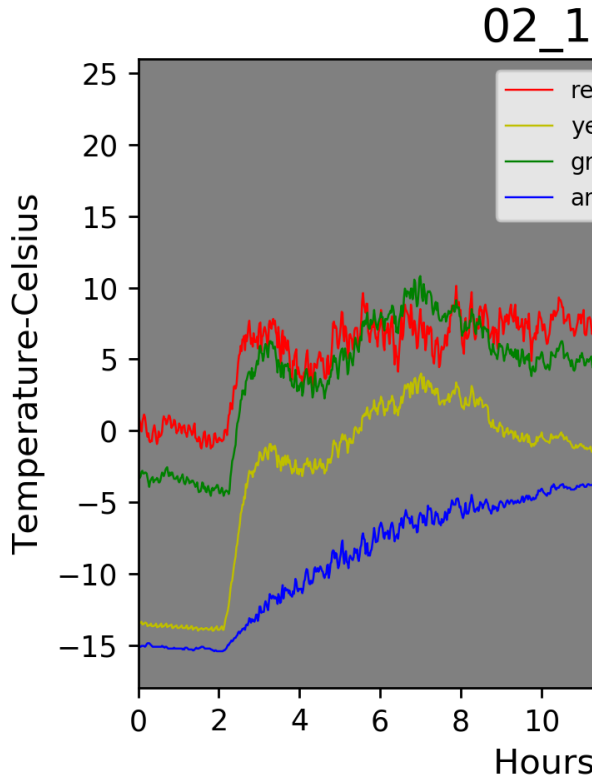
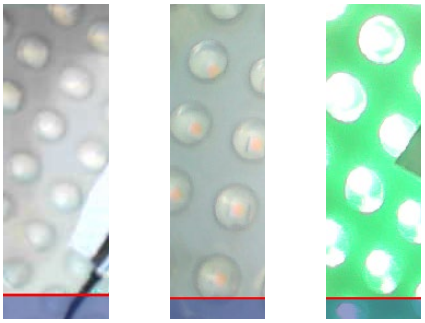
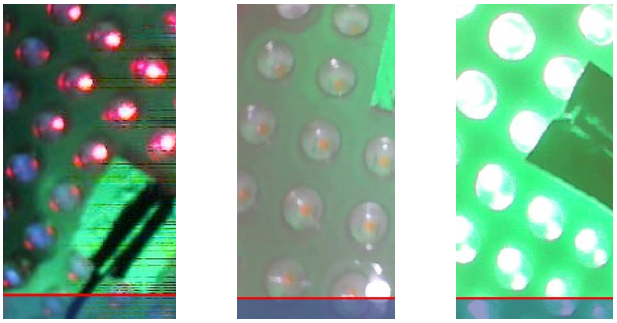


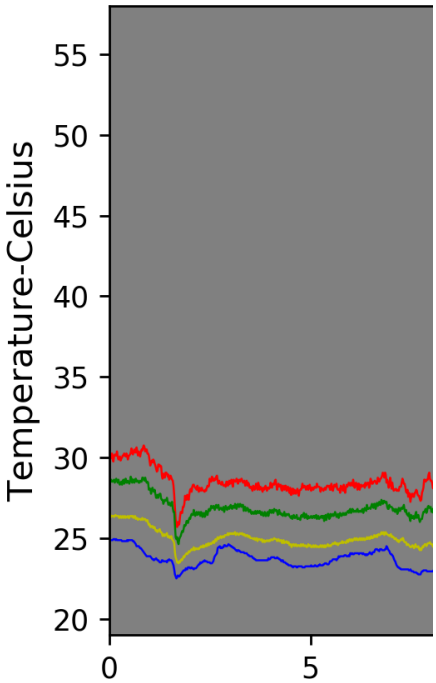




Red Yellow Green



Red Yellow Green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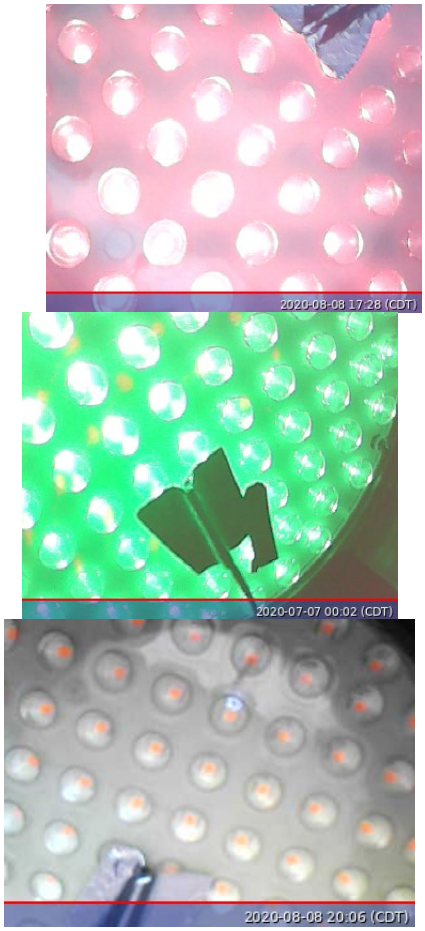
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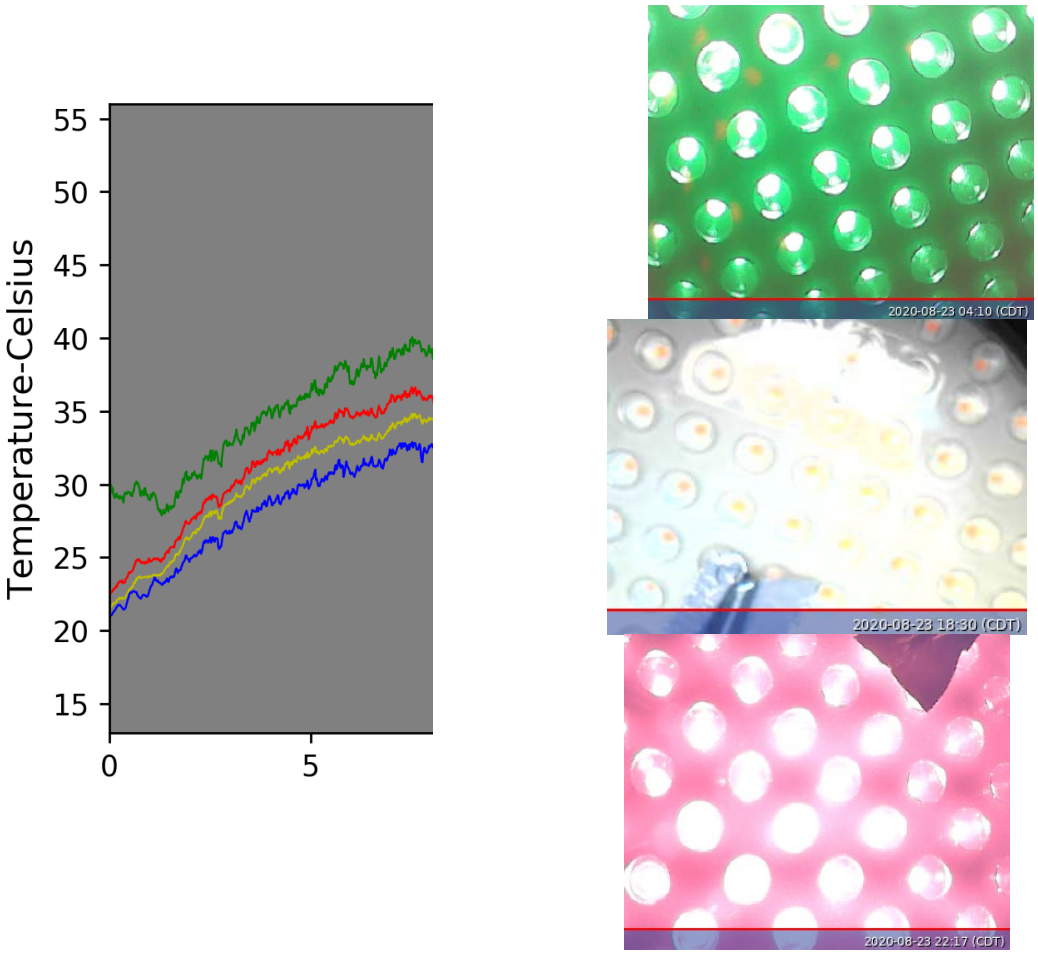


Figure 9 Sample results of the ongoing roof tests with the field monitoring system, including photos of the lens' surface and temperature data recorded every 20 seconds in winter seasons (when the ambient temperature is lower than 4° C) and every hour in summer seasons.

C. Field tests

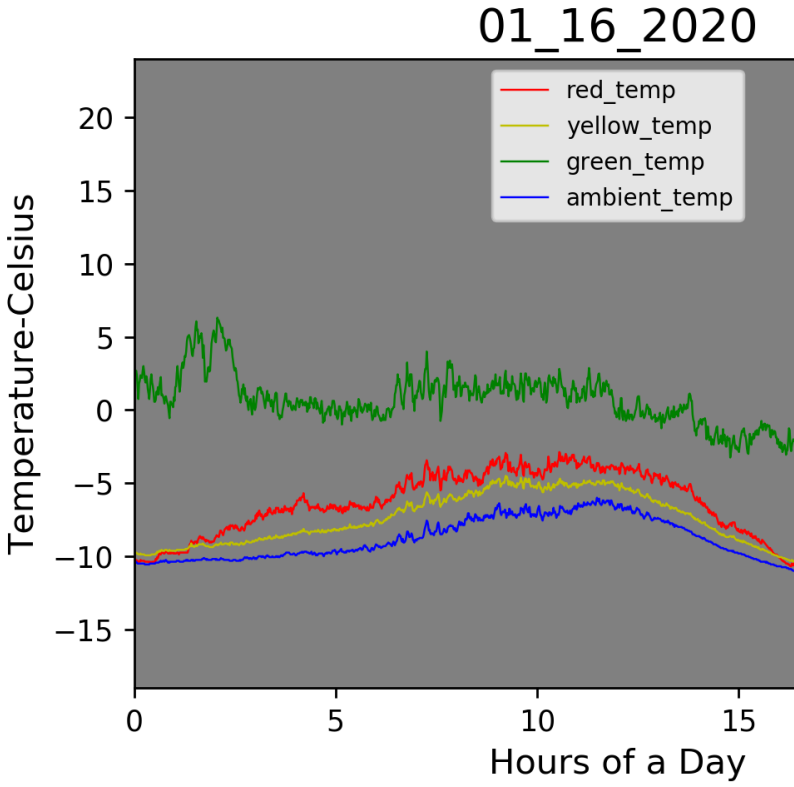
Work in the third stage involved field testing at selected highway signalized intersections in different states. Seven states (Kansas, California, Michigan, New Jersey, Wisconsin, Pennsylvania, and Maryland) participated in field testing and evaluation of the prototypes. Fully functional prototypes were assembled and thoroughly tested in the laboratory and on the roof in preparation for field tests. In the field, prototype LED

modules (R. G, Y) of the self-de-icing signals were used to replace the existing LED modules installed on pole-mounted side signals on the right shoulder as backup to the overhead signals. Additionally, the remote monitoring system was built in-house, all put in a plastic weather-proof plastic box for field installation. At each field test site, the system was mounted near the signal head for year-around monitoring and data recording of the real-time performance the signals (R, G, Y). Real-time performance for melting snow and deicing was monitored by the field monitoring system for year-around data recording. The realistic field performance of the prototype signals would help project partners and state DOTs evaluate and initiate the implementation process.

The first field test site was set up On Dec. 4, 2019, in Lawrence, Kansas at the intersection of County Rd 458 (or 1200 Rd) /US-59 on a side signal head facing north, as shown in Figure 10. Note that this test site has a dominant green light with much longer signal timing than the red and yellow lights. Fourth generation prototypes were installed and monitored. Since then, the new signals and the remote monitoring system have been tested onsite continuously, already survived several snowstorms in three winters and hot climate in three summers. For example, Figure 11 shows the performance of the signals in the Lawrence test site in 2020, 2021, and 2022. The Lawrence field test is still ongoing.

Location: at the intersection of County Rd 458 (or 1200 R

Figure 10 The first field test site in Kansas, with the help from the Lawrence city signal crew and the Kansas Department of Transportation.

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2020-01-16 15:07 (CST)


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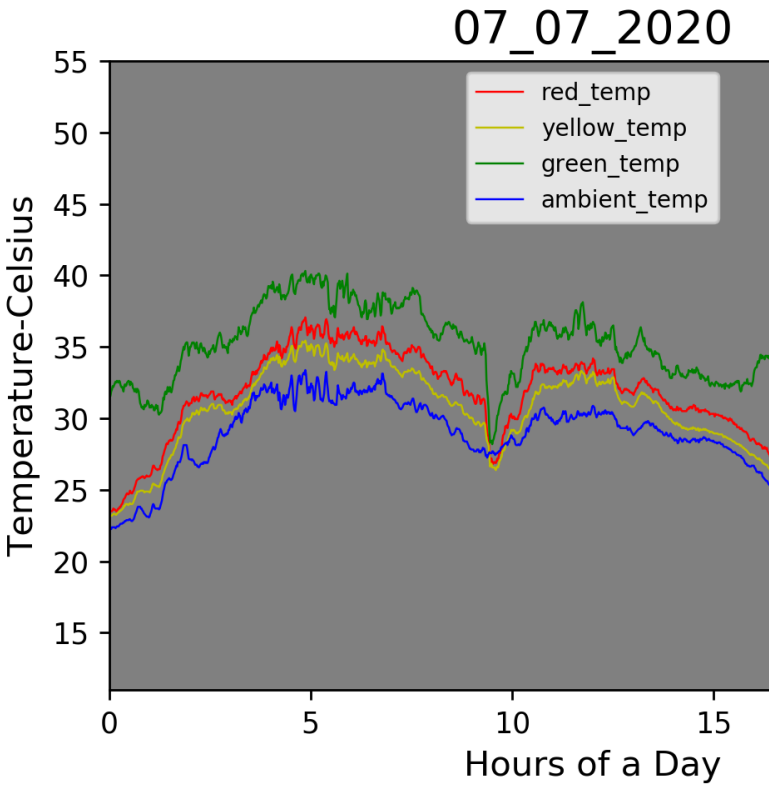
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Hours of a Day


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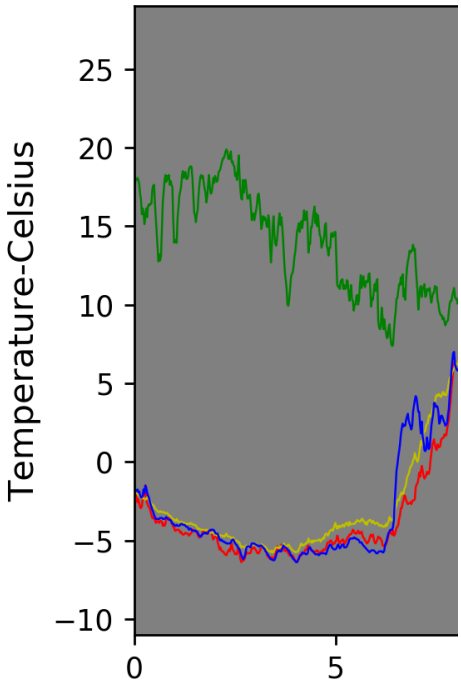
2020-07-07 08:44 (CDT)


2020-07-07 14:01 (CDT)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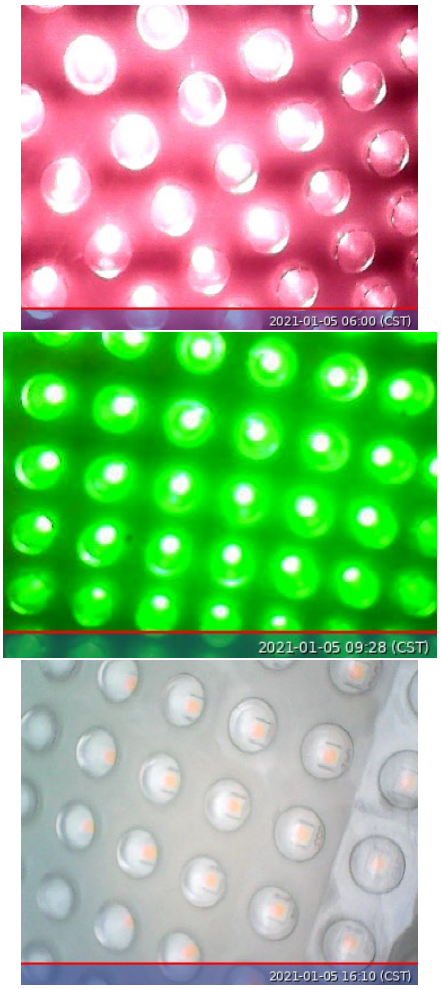
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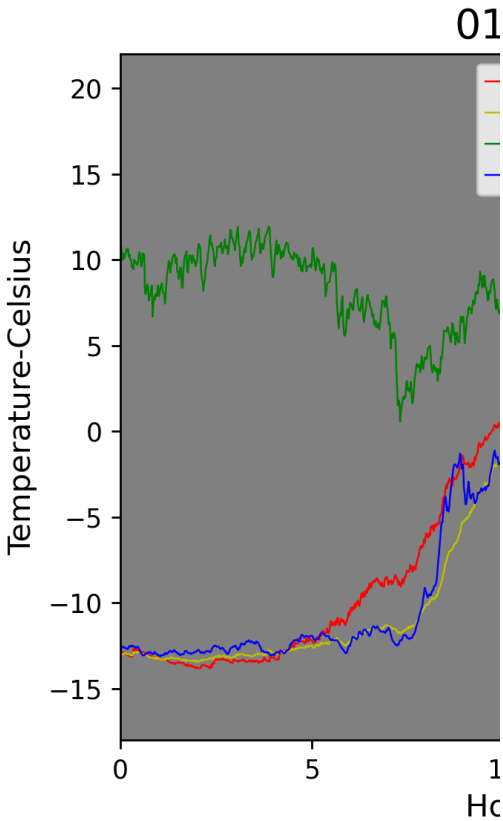
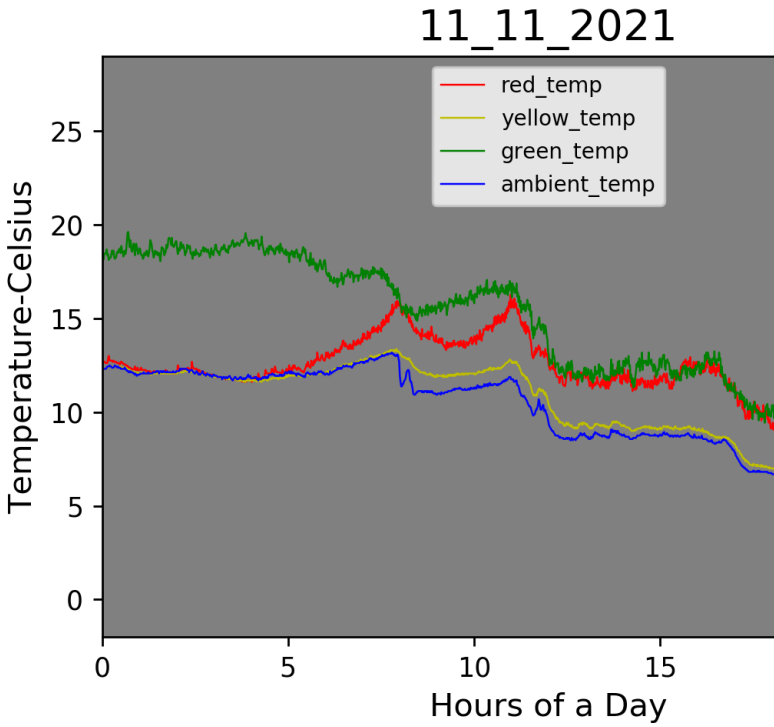


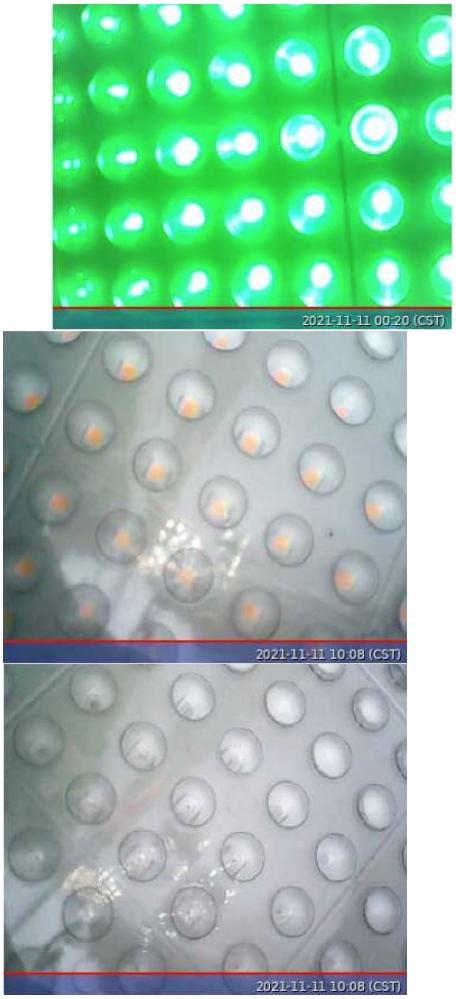
Figure 11 Lawrence field test data during the coldest days in winter and hottest days in summer showing the performance of the red, yellow, and green signal lights under different weather conditions. Test results were collected at the intersection of County Rd 458 (or 1200 Rd) /US-59, where the selected signals are on the side of the road shoulder, facing north.

Two additional field tests were conducted in Michigan and Wisconsin in November 2021. On November 3rd, 2021, the 5th generation prototypes (R, Y, G) were installed on the pole in test site in Wisconsin (Location: STH 100 & Center Street, Milwaukee County, Wauwatosa, Wisconsin) (Figure 12), meanwhile, the remote data monitoring system was mounted on the top of the pole behind the signal head for remote data monitoring and collection. The signal crew with Wisconsin DOT helped the field installation, wiring and on-site testing. All tested signals are facing north.

Figure 12 Field installation and setup of the onsite testing at the test site of Wisconsin (Location: STH 100 & Center Street, Milwaukee County, Wauwatosa, Wisconsin), with the aid of the signal crew of Wisconsin DOT. A tunnel visor was installed with hook for mounting the cable camera on each signal module. The signals are all facing north.

As shown in Figure 13, the signals at the Wisconsin test site have been working normally in both mild and cold weather, ready for the upcoming severe winter storms. It was found that, as indicated in most data figures, in the early morning before sunrise, the green signal light was remained powered on in almost all of the time at that intersection due to traffic control while the red and yellow signals were rarely powered on, resulting in a large temperature increase on the green signal lens above the ambient air, with minimal heat buildup on the red and yellow signal lenses (due to no power for approximately 6 hours), which could take a long time to warm up when their power was resumed later, longer than the otherwise needed time under normal operation conditions.

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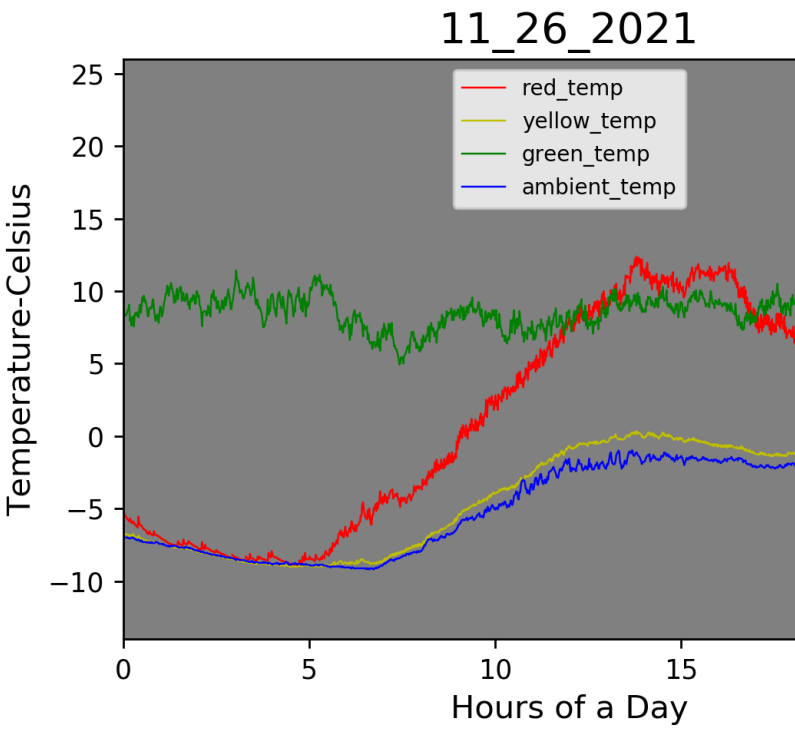
11_26_2021
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yellow_temp
green_temp
ambient_temp
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Hours of a Day


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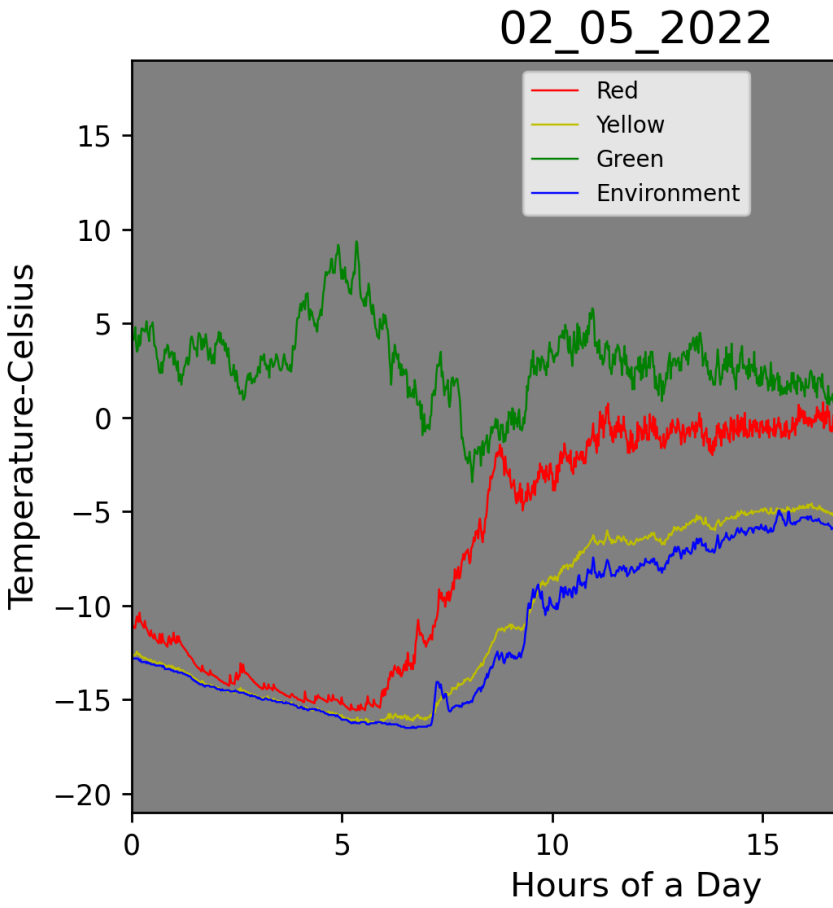
02_05_2022
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Yellow
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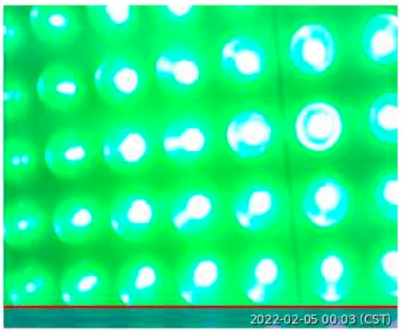
Hours of a Day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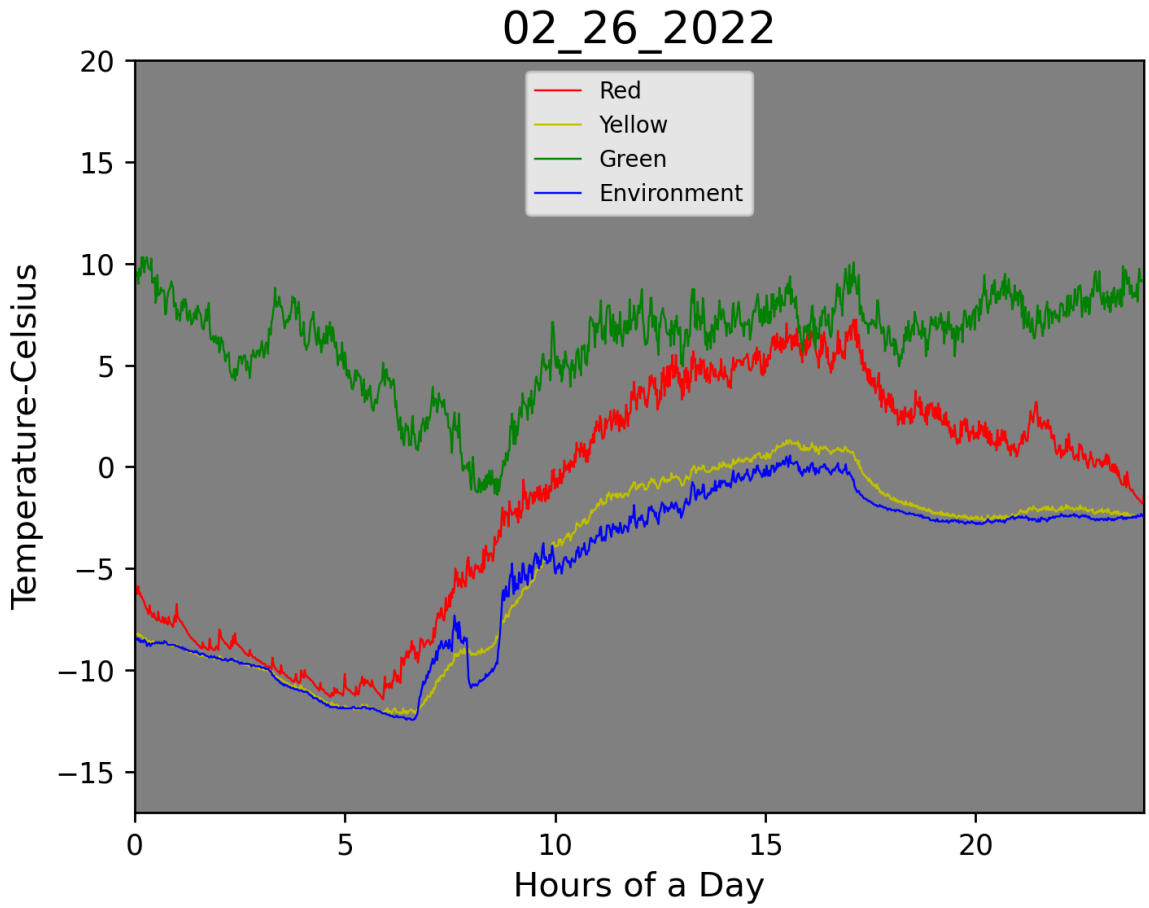
02_26_2022
Red
Yellow
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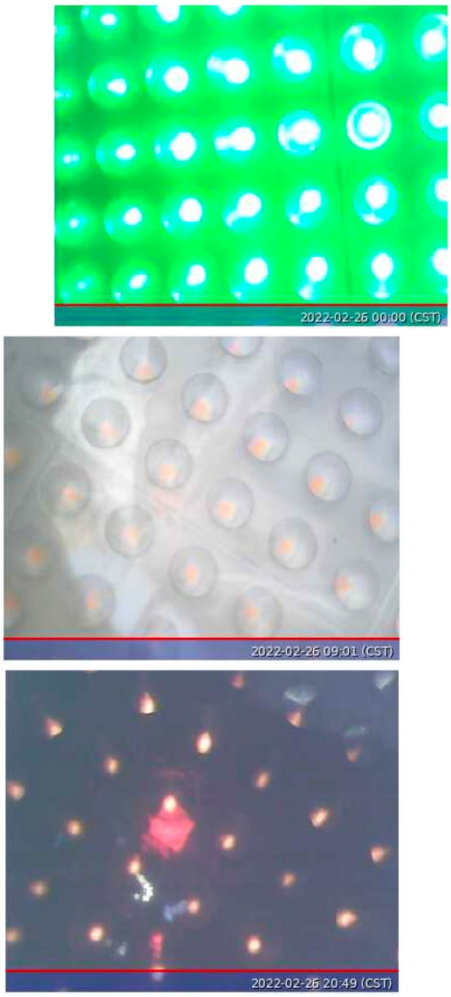
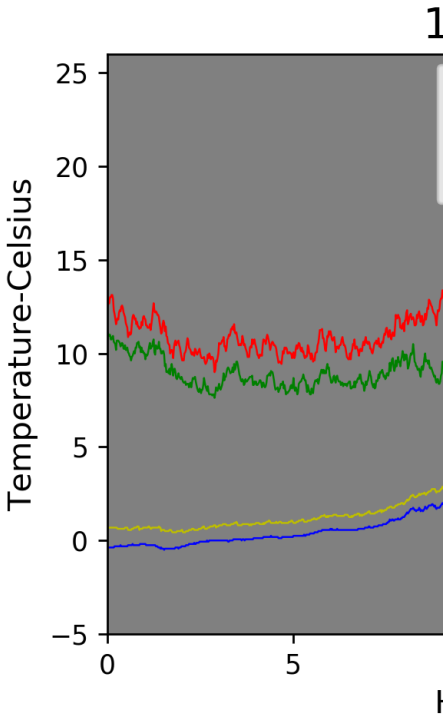


Figure 13 Wisconsin field test data collected in November 2021 after the field installation on November 3rd, showing the normal performance of the red, yellow, and green signal lights under mild and cold weather conditions, especially for the green signal light which had the longest power-on time. Note that due to traffic control in the early morning before sunrise, the green signal light was remained always powered on at that intersection while red and yellow signals were rarely powered on, resulting in a large temperature gap between the green signal lens and the ambient air, with minimal heat buildup on the red and yellow signal lenses during the traffic control period (midnight - sunrise).

Additionally, on November 4th, 2021, the 5th generation prototypes (R, Y, G) were installed in the test site in Michigan (located in the MDOT OFS Operations Field Services (6333 Lansing Rd, Lansing, MI 48917)) right in front of the signal shop with the aid of the signal crew of Michigan DOT, as shown in Figure 14. The remote data monitoring system was also mounted on the top of the signal pole close to the signal head to collect real-time performance data of the signals, as shown in Figure 15. Since then, the test signals at the Michigan test site have been working normally in both mild and cold weather, ready for the upcoming severe winter storms.

Figure 14 Field installation and setup of the onsite testing at the test site of Michigan in front of the signal shop (6333 Lansing Rd, Lansing, MI 48917), with the aid of the signal crew of Michigan DOT. A tunnel visor was installed with hook for mounting the cable camera on each signal module. The signals are facing north.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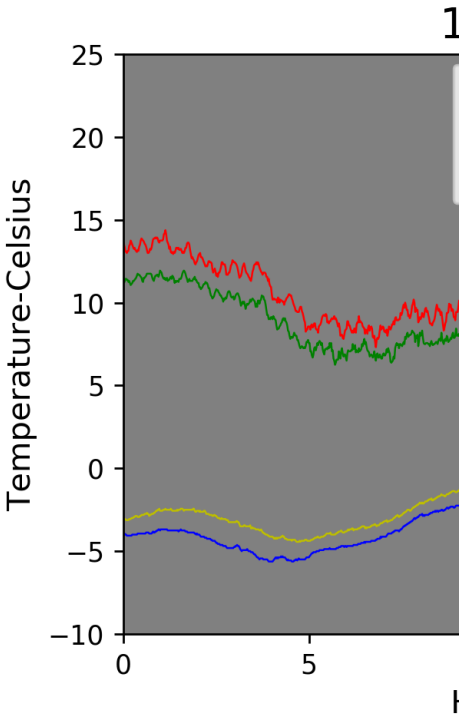
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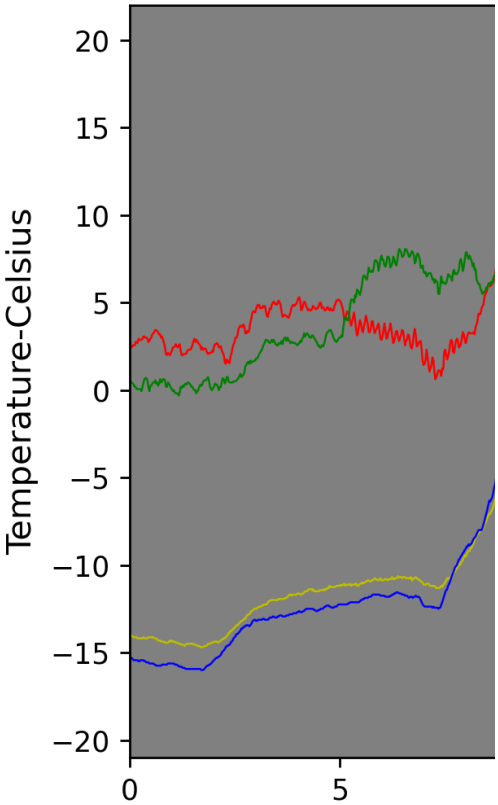
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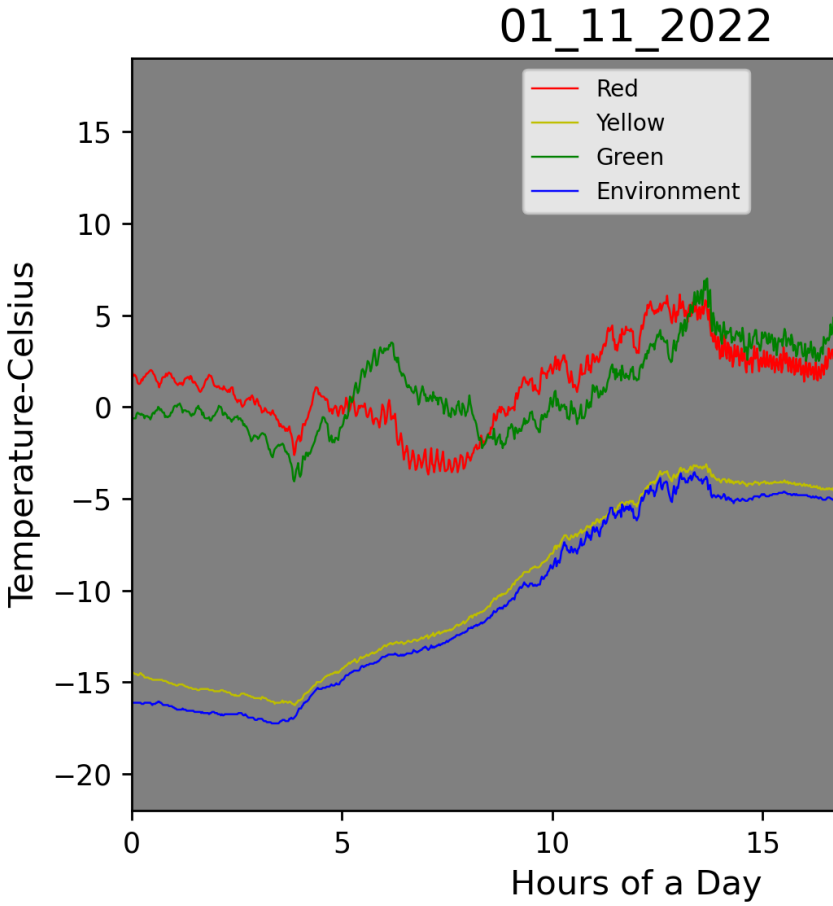
2022-01-03 14:33 (CST)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Hours of a Day

Figure 15 The Michigan field test data collected since November 2021, showing the normal performance of the red, yellow, and green signal lights under mild and cold weather conditions. Note that there was a change in timing sequence after Nov 17 2021 by the signal engineer, which impacted the performance of the signals.

PLANS FOR IMPLEMENTATION

For potential technology transfer and implementation of the self-de-icing LED signals, a patent has been issued for the innovation of "Integrated Light and Heat Arrangement of LEDs in Low Profile" (Patent No. US 10,215,441 B2) adopted in the self-de-icing signal. Two more patents were already granted for a relevant innovation of "Heated Lens Lighting Arrangement" (Patent Nos. US 9,851,086 B2 and US 10,253,965 B2). The research team and the University of Kansas Center for Technology Commercialization have been reaching out to the signal industry for patent licensing. Following the ongoing field tests and evaluation, pilot replacement programs are necessary to displace the existing signals with the self-de-icing LED signals in some collaborative state departments of transportation (e.g., Kansas, California, Maryland, Michigan, New Jersey, Pennsylvania, Wisconsin, Utah) as well as counties and cities. Their revision in railroad applications is also expected with the support of the Union Pacific Railroad and the Burlington Northern and Santa Fe Railroad.

Once validated, the self-de-icing LED signal light is expected to be a viable replacement of the existing "cool" LED signal lights, the obsolete incandescent signal lights, and other emergent LED signal lights using additional heat generators and control sensors. If the self-de-icing LED signals are implemented in practice in the snow-belt states, transportation agencies, districts, and cities, the railroad companies and the driving public could expect significant benefits, including safety and efficiency, cost savings, and environmental sustainability. This system will not alter the function and sizes of the existing signal lights. There will be no need to add additional wiring inside and outside of the existing signal controller cabinets, and no need to change anything outside of the signal housing. The self-de-icing LED signal lights could offer savings on annual maintenance costs.

We have launched a start-up company SSLaH Tech, Inc. for further R&D, implementation & commercialization of the product. Table 6 is the timelines for our planned major activities to transfer the technology to practice.

Table 6 Timelines for major activities to transfer the technology to practice.

Date of Completion	Action	Reason
2019 – 2024	Product Testing in field	Ensure product is capable of patent use
2021 – 2023	Initial Market Testing	Launch prototypes into market in the participating agencies
2021 – 2023	Cost Benefit Analysis	Use market testing research to update more accurate figures
2021 – 2023	Pricing Strategy	Use market testing research to update more accurate figures
2022 – 2024	Licensing Pitch	Concept is proven now time to reach out to potential buyers
2022 – 2025	Leverage IP to other Markets	Expand into other markets

CONCLUSIONS

A new type of self-de-icing LED signals has been developed and tested in the field for highway signalized intersections to solve a well-known problem of the existing LED signal light whose lens is too cool to melt snow and de-ice in wintery conditions. The self-de-icing LED signals adopt a novel system architecture of "*Integrated Light and Heat Arrangement of Low Profile Light-Emitting Diode Fixture*" (Patent No. US 10,215,441 B2). The heat generated by the LED(s) is harvested by the passive heat exchanger and stored to heat the lens for melting snow and de-icing in wintery conditions. Fully working prototypes of the self-de-icing LED signals have been developed and tested in the laboratory and closed-course settings on the roof of an engineering building followed by field tests at selected highway intersections in Kansas, Wisconsin and Michigan, with possible future tests in other interested states and counties for implementation of this technology. The realistic performance of the prototype signals in the field would help project partners and state DOTs evaluate and initiate the implementation process in the future.

In this project, we finalized the signal housing that adopts a whole piece design with smooth and flat outside surface, which were tested with a maximum tolerance of 1.5 mm for mass production, and integrated with 96 Fresnel lens niches on the inside surface. We also designed and custom-made new types of screws to improve the connection strength of the screws integrated with the plastic housing. We started custom-making and modeling of the signal housing. Three samples were first delivered for examinations and laboratory tests for necessary calibrations and further improvements. With minor adjustments for field tests, six improved samples were delivered and thoroughly tested in laboratory and closed-setting tests on the roof. We accordingly improved and finalized the plastic housing of the fully working prototype signals with changes/improvements, assisted by the plastic molding company, which custom made seven samples of the finalized new plastic housing for validations tests before actual product production. Finally, we produced 60 more pieces of the finalized housing made of Markrolon 2807 with the aid of the industrial partner for field tests.

A Fresnel lens disc with 96 small Fresnel lenses integrated on it to focus the light as a collimator lens was designed with the desired improvements and custom-made in a factory through injection mold. As a result, the previously adopted solution using 96 individual lenses mounted in the housing niches with the aid of glass disc was replaced by this whole piece of plastic disc embedded with 96 Fresnel lenses on it. Corrections have been made in the injection mold for better fitting in the housing niches. Forty (40) samples of the improved second-generation Fresnel lens disc were tested with satisfactory thermal performance but the lighting performance was not optimized due to increased focal length of 12.5-13.0 mm (> 11.5 mm). With improvements on the mold injection technology in the factory, 21 new samples of third-generation Fresnel lens disc were tested with shortened focal length of 11.9 mm, but still > 11.5 mm, and similar thermal performance. The new Fresnel lens disc was then adopted in the 5th generation prototypes of the self-de-icing signals for field tests. We are working with the factory to revise the mold and change the Fresnel lens focal length to 10 mm, in order to produce the next generation and final products in the mass production with a focal length of approximately 11-11.5 mm.

Moreover, we designed and custom made two types of LED drivers, including one type of custom-made LED driver for red signal light (input: 100-240 VAC, output: 0.6-1.1 A, max 30 W), and a second type custom made LED driver for green/yellow signal light (input: 100-240 VAC, output: 0.5-0.8 A, max 30 W). Both types of LED drivers are integrated with a remote temperature sensor for controlling the power output in light of the ambient air temperature. When the ambient air temperature is above 4° Celsius, the LED driver output will be derated (For Yellow + Green LED lights, output current 0.5 A, approximately 17- 18 Watts; For Red LED light, output current min 0.6 A, approximately 15-16 Watts). When the temperature sensor is turned off or failed for any reasons, the power output will be restored to 100% as default. An on/off switch was designed for temperature controls in

winter and summer modes which could override the operation of the temperature sensor. We then started custom-making the LED drivers with desired specifications based on our test results. Seven LED drivers were delivered for sample testing. Based on the lab test results on the second generation of LED drivers, a total of 21 new LED drivers of the third generation for the field tests were made and under testing in the laboratory for their field performance and further improvements needed for the control of the yield rate in production. Based on the test results, the third-generation LED drivers may need further improvements towards the fourth generation, which will resolve two issues: 1) light power-up delay (the time delay between power on and signal light on) for about 0.5 second, 2) unstable output performance of the drivers, due to unsecured soldering of wire connections by hands.

Additionally, we developed a field monitoring system powered by Raspberry 3B+ motherboard, fitted with three cable cameras used to monitor three signal lights (Red, Yellow, Green) in each unit, four temperature sensors used to record the lens' surface temperature of the three signal lights (Red, Yellow, Green) and the ambient air temperature, USB flash drivers used to store the year around test data (pictures and temperature dataset), power supplies, and mounting accessories. Later, the field monitoring system has added LTE mobile communication device with data plan to remotely send the data of the signal performance back to the laboratory on daily basis for real-time performance monitoring. The remote monitoring system was custom built in house and thoroughly tested in the lab and on the roof. The system would be mounted at every field test site for year-around real-time monitoring and data recording of the new signals.

In this project, we assembled and tested a total of five generations of the prototype self-de-icing LED signal lights in the laboratory. It was proven that the self-deicing signal lights have higher light output than the codes and standards required in all viewing angles from 0° to 70° as measured, even at the derated power output. The 4th generation fully working prototypes of the self-de-icing signal lights for field tests were assembled and thoroughly tested in the laboratory in preparation for the first field test site set up in Kansas at the intersection of County Rd 458 (or 1200 Rd) /US-59 in December 2019. All new equipment including the performance monitoring system for data recording were installed on side signals facing north. The 4th generation of self-de-icing signals tested in the Lawrence site in Kansas have survived both winter and summer sessions in the past three years, functioning as expected, without any signs of snow and ice accumulation on the signal lens in cold winter, and abnormal performance in hot summer. The 5th generation prototype and field remote monitoring system were fully prepared and tested for other field test sites. On November 3rd and 4th, 2021, two more field test sites in Wisconsin and Michigan were selected, where the 5th generation prototypes were installed and tested on site, for continuously field testing in the following 2-5 years through both winter and summer seasons. The remote data monitoring system was installed on the pole close to the back of the signal head at each test site and since then, has recorded all data that could be retrieved online on daily basis. The collected Michigan and Wisconsin field test data have shown normal performance of the red, yellow, and green signal lights under the first cold weather condition.

More field tests could be conducted by Maryland, New Jersey, Utah, and other states as well as interested counties and cities in the cold zone for future implementation of the new technology. A manual has been prepared for signal crews for mounting the new self-de-icing signals and the corresponding data recording and remote monitoring system for the upcoming field test sites.

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APPENDIX: RESEARCH RESULTS

NCHRP IDEA Program Committee

September 2022

Project title:
Self-de-icing LED Signals for Railroads and Highway Intersections

Task Number: 190

Start Date: 11/24/2015

Completion Date: 08/31/2019

Product Category: New or improved tool or equipment

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Self-de-icing LED Signals for Railroads and Highway Intersections

Developed a new type of self-de-icing LED signal for prevention of snow and ice accumulated on the lens within the signal hood in wintery conditions

WHAT WAS THE NEED?

This project has developed a new type of self-de-icing LED signal for highway signalized intersections and railroad signaling applications to solve a well-known problem of the existing LED signal light with lens too cool to melt snow and deice in wintery conditions. The snow-clogged signal lights can decrease the performance of signalized intersections and railroads and may result in collisions in inclement weather conditions.

WHAT WAS OUR GOAL?

The goal was to develop the self-de-icing LED signal light, make fully functional prototypes, and test them in the laboratory, closed-course environment on the roof, and then in the field for years in preparation for technology transfer and implementation.

WHAT DID WE DO?

Approximately 70-80% of the electricity consumed by LEDs is converted to heat. The self-de-icing LED signal employs an architecture of "Integrated Light and Heat Arrangement of LEDs in Low Profile" (***Patent No. US 10,215,441 B2***) to harvest both the light and the heat generated by the same LEDs. The LED heat is then harnessed to heat the lens for

melting snow and de-icing in wintery conditions. The investigation is divided into three stages. Stage 1 focuses on laboratory research and development and tests of the prototype self-de-icing LED signals. Stage 2 focuses on testing three fully working prototypes mounted in closed-course settings on the roof of an engineering building and powered by the signal controller cabinet, to avoid interruption on people and ground traffic. Stage 3 focuses on the field tests of the fully working prototypes on identified highway signalized intersections.

WHAT WAS THE OUTCOME?

The research team developed and tested a total of five generations of prototypes of the self-de-icing LED signals (12 in.) in red, green, and yellow light colors. Their thermal and lighting performance was tested to meet all requirements to ensure their readiness for follow-up field tests. The prototypes are installed on pole-mounted signals as backup to the existing primary signals in Kansas, Wisconsin, and Michigan. At each test site, the real-time performance of the prototype signals is monitored and recorded by a remote field-monitoring system. Year-around test data (pictures and temperature data set) are recorded and stored on USB flash drives and also sent back to the team via remote cellular data transmission on daily basis. The collected field data are used for real-time performance evaluation of the new signals for future implementation in practice by the project partners.

Field test in Kansas

Field test in Wisconsin

Field test in Michigan

WHAT IS THE BENEFIT?

Once validated, the self-de-icing LED signal light is expected to be a viable replacement of the existing "cool" LED signal lights, the obsolete incandescent signal lights, and other emergent LED signal lights using additional heat generators and control sensors. If the self-de-icing LED signals are implemented in practice in the snow-belt states, transportation agencies, districts, and cities, the railroad companies and the driving public could expect significant benefits, including safety and efficiency, cost savings, and environmental sustainability. This system will not alter the function and sizes of the existing signal lights. There will be no need to add additional wiring inside and outside of the existing signal controller cabinets, and no need to change anything outside of the signal housing. The self-de-icing LED signal lights could offer savings on annual maintenance costs.

Two patents were granted for the innovation of "Heated Lens Lighting Arrangement" (Patent Nos. US 9,851,086 B2 and US 10,253,965 B2). Another patent was issued for the innovation of "Integrated Light and Heat Arrangement of LEDs in Low Profile" (Patent No. US 10,215,441 B2). The research team and the University of Kansas Center for Technology Commercialization have been reaching out to the signal industry for patent

licensing. Following the ongoing field tests and evaluation, pilot replacement programs are necessary to displace the existing signals with the self-de-icing LED signals in some collaborative state departments of transportation (e.g., Kansas, California, Maryland, Michigan, New Jersey, Pennsylvania, and Wisconsin). Once validated, the self-de-icing LED signals in various sizes are expected to be installed at highway intersections, Class I railroads, commuter railroads, and short-line railroads in cold weather zones.

LEARN MORE

For more information, please view the final report posted on the NCHRP IDEA website.