

## TRANSPORTATION POOLED FUND PROGRAM QUARTERLY PROGRESS REPORT

Lead Agency (University or Contractor): \_\_Kansas DOT\_\_\_\_\_

**INSTRUCTIONS:**

*Project Managers and/or research project investigators should complete a quarterly progress report for each calendar quarter during which the projects are active. Please provide a project schedule status of the research activities tied to each task that is defined in the proposal; a percentage completion of each task; a concise discussion (2 or 3 sentences) of the current status, including accomplishments and problems encountered, if any. List all tasks, even if no work was done during this period.*

<b>Transportation Pooled Fund Project Number</b> <b>TPF-5(351)</b>		<b>Transportation Pooled Fund Program - Report Period:</b> <input type="checkbox"/> Quarter 1 (January 1 – March 31) <input checked="" type="checkbox"/> Quarter 2 (April 1 – June 30) <input type="checkbox"/> Quarter 3 (July 1 – September 30) <input type="checkbox"/> Quarter 4 (October 1 – December 31)	
<b>Project Title: Self De-Icing LED Signals</b>			
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<b>Lead Agency Project ID:</b> <b>RE-0721-01</b>	<b>Other Project ID (i.e., contract #):</b>	<b>Project Start Date:</b> August 15, 2016	
<b>Original Project End Date:</b> <b>August 2019</b>	<b>Current Project End Date:</b> <b>December 2021</b>	<b>Number of Extensions:</b> 2	

Project schedule status:

On schedule     
  On revised schedule     
  Ahead of schedule     
  Behind schedule

Overall Project Statistics:

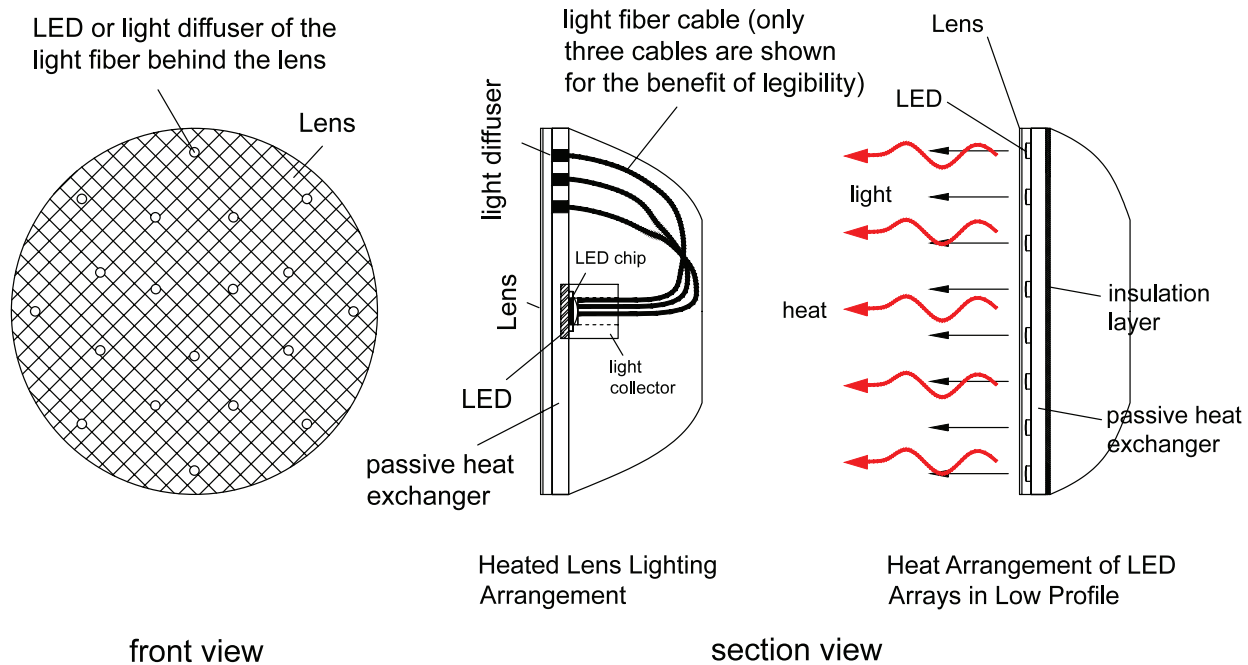
Total Project Budget	Total Cost to Date for Project	Total Percentage of Work Completed
\$240,000 original, \$360,000 with addendum	\$ 345,342.18	94%

Quarterly Project Statistics:

Total Project Expenses This Quarter	Total Amount of Funds Expended This Quarter	Percentage of Work Completed This Quarter
\$ 7,632.00	\$ 7,632.00	2%

## Project Description:

This pooled fund project will develop and demonstrate new self-de-icing LED signals for highway signalized intersections applications to solve a well-known problem of the existing LED signal light whose lens is too cool to melt snow and de-ice in wintry conditions. The self-de-icing LED signals will adopt one or both of two novel architectures (Figure 1), including (a) “Heated Lens Lighting Arrangement” that uses a single high-power LED and (b) “Heat Arrangement of LED Arrays in Low Profile” that deploys multiple LEDs. 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 wintry conditions.



**Figure 1** The concept of the self-de-icing LED signal light, which adopts new architecture of “Heated Lens Lighting Arrangement” or “Heat Arrangement of LED Arrays in Low Profile”

Fully working prototypes of the self-de-icing LED signals have been developed and tested in the laboratory. They have been tested in closed-course settings on the roof of an engineering building followed by field tests on highway intersection. Each participating agency is required to provide support of three years of funding (\$20,000/year, totaling \$60,000) and will be guaranteed a field test site in each state for testing the fully working prototypes catering to their specific needs of the new type of signals. The research team will work with each participating agency to identify the desired test site on highway intersections and the desired technical specifications for testing the prototypes.

The investigative approach for the proposed project is divided into three stages. Work in Stage 1 focuses on laboratory development and tests. Work in Stage 2 focuses on testing the three prototypes in a closed-course setting on the roof of the University of Kansas engineering complex and powered by the signal controller cabinet. Work in the third and final stage involves field testing of the developed prototypes on identified test sites. On-site demonstration of the prototype signals will also be held for project partners and state DOTs to initiate the implementation process. A final report will provide all relevant data and results along with plans for implementation of the self-de-icing LED signals in affected states.

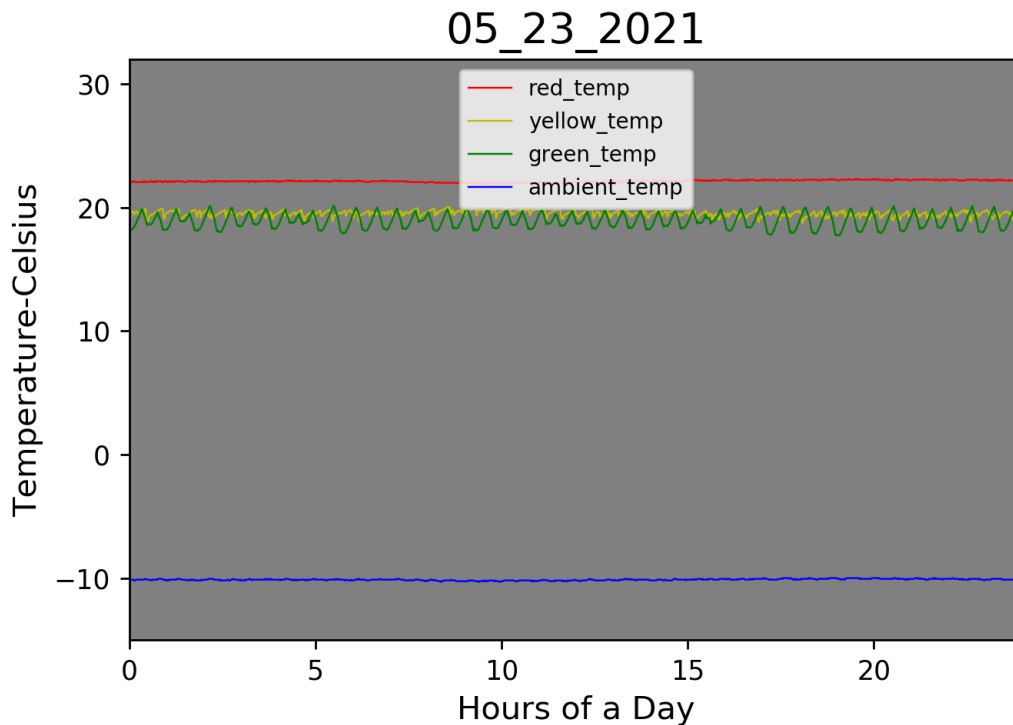
**Progress this Quarter (includes meetings, work plan status, contract status, significant progress, etc.):**

During the second quarter (April 1, 2021 – June 30, 2021) of the project period, we have the following accomplishments.

In the present quarter (April 1, 2021 – June 30, 2021), firstly, 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). Then, with improvements on the mold injection technology in the factory, one sample of third generation fresnel lens disc was tested with shortened focal length of 11.9 mm, but still > 11.5 mm. Continuous revisions on the mold is being considered for making fourth generation fresnel lens disc with optimized focal length of 11.5 mm or less in mass production. Meanwhile, twenty (20) new samples of the third generation fresnel lens disc were produced and delivered for assembly of the fifth generation of the prototypes of the final product for field tests this summer. The fifth generation prototypes and associated field remote monitoring systems have been fully prepared and tested for other field test sites to be conducted in Michigan, Wisconsin, Maryland, and New Jersey & Pennsylvania, which are participating in field testing and evaluation of the prototypes. Moreover, an introduction to field test of the self-de-icing signal is ready to be used by signal crews of different states for test site selection and mounting the new self-de-icing signals and the corresponding data recording and remote monitoring system for the upcoming field test site use.

More details are listed as follows.

Firstly, we have tested the lighting and thermal performance of the improved second generation fresnel lens disc, 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). Figure 1 shows the thermal performance tested in the laboratory of the 5<sup>th</sup> generation prototypes deployed with the 2<sup>nd</sup> generation fresnel lens, the temperature differences between the signal lens and the ambient were found very similar to the prior thermal test results, indicating the 2<sup>nd</sup> generation fresnel lens disc would have similar thermal performance as the 1<sup>st</sup> generation.



**Figure 1** Thermal test results of the 5<sup>th</sup> generation self-de-icing signal deployed with the 2<sup>nd</sup> generation fresnel lens disc, the temperature differences between the signal lens and the ambient were found very similar to the prior thermal test results

Table 1 shows the lighting performance of the 2<sup>nd</sup> generation fresnel lens disc. The test results shown the lighting performance has passed the code requirements as listed in Table 2. However, it was found that the lighting performance of the 2<sup>nd</sup> generation fresnel lens disc (40 new samples) is different from that of the 1<sup>st</sup> generation in that the peak lighting performance of the 2<sup>nd</sup> generation fresnel lens disc (40 new samples) is around 20 degree off axis, which is different from 8-9 deg of the 1<sup>st</sup> generation (old 20 samples). The main cause is the focal length of the fresnel lenses, which was not optimized as 12.5-13.0 mm (> designed 11.5 mm).

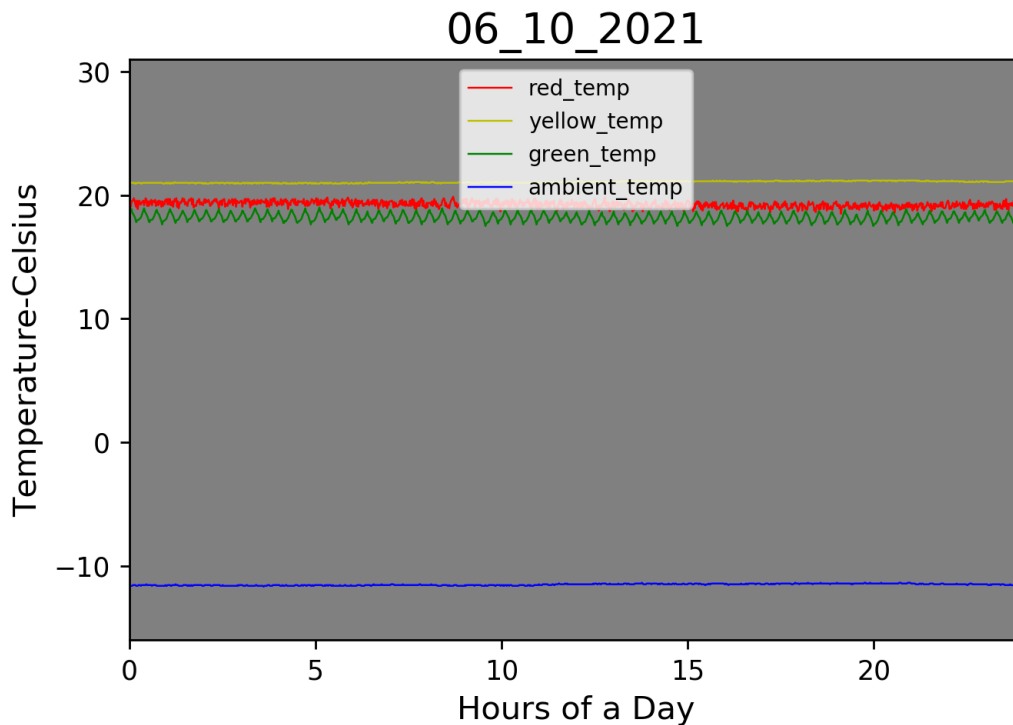
**TABLE 1** Lighting performance of the second batch of 40 samples of the fresnel lens disc (**generation 2**), measured on **May 11<sup>th</sup> 2021**

Tilting angle $\theta_{\text{vert}}$ (°)	Intensity (cd)					
	Red, Dimmed	Yellow, Dimmed	Green, Dimmed	Red, Full output	Yellow, Full output	Green, Full output
0	679.9	1846.6	1382.1	1205.0	3145.7	1995.0
0.5	673.5	1856.2	1374.2	1182.6	3152.1	1995.0
1	663.9	1857.7	1371.0	1176.3	3160.1	1996.6
1.5	656.0	1859.3	1366.2	1168.3	3160.1	1982.2
2	652.8	1854.6	1367.8	1158.7	3158.5	1980.6
<b>2.5</b>	<b>651.2</b>	<b>1853.0</b>	<b>1371.0</b>	<b>1150.7</b>	<b>3155.3</b>	<b>1979.0</b>
3	651.2	1846.6	1371.0	1145.9	3148.9	1982.2
5	660.7	1857.7	1374.2	1160.3	3136.1	1983.8
7	675.1	1886.5	1402.9	1181.0	3153.7	1998.2
9	687.9	1897.6	1410.9	1206.6	3209.6	2031.7
11	700.6	1936.0	1444.4	1228.9	3297.3	2082.8
13	721.4	1993.4	1514.6	1268.8	3375.5	2173.8
15	761.3	2070.0	1632.7	1326.3	3503.2	2392.4
<b>20</b>	<b>911.3</b>	<b>2216.8</b>	<b>1875.3</b>	<b>1683.8</b>	<b>3726.7</b>	<b>2698.8</b>
25	304.8	686.3	798.0	574.6	1157.1	1144.3
30	129.3	362.3	379.8	223.4	609.7	541.0
50	60.6	153.2	164.4	106.9	258.6	236.2
70	47.9	122.9	113.3	81.4	207.5	164.4
90	9.6	16.0	19.2	12.8	33.5	33.5

**TABLE 2** Peak minimum maintained luminous intensity values of  $I_{(-2.5^\circ, 0^\circ)}$ , measured at vertical off-axis viewing angle of  $\theta_{\text{vert}} = -2.5^\circ$  and horizontal off-axis viewing angle  $\theta_{\text{horiz}} = 0^\circ$ , of signal lights with a lens diameter of 12 inches by color of the module as required by the code <sup>[10]</sup>

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

Secondly, we also tested the thermal and lighting performance of the 3<sup>rd</sup> generation fresnel lens disc (21 new samples). With improvements on the mold injection technology in the factory, the 3<sup>rd</sup> generation fresnel lens disc was tested with shortened focal length of 11.9 mm, but still > 11.5 mm. Figure 2 shows the thermal performance of the 5<sup>th</sup> prototypes of signals deployed with the 3<sup>rd</sup> generation fresnel lens disc. The temperature differences between the signal lens and the ambient were found very similar to the prior thermal test results. More detailed information on lens surface temperature increase is shown in Table 3.



**FIGURE 2** The thermal performance of the 5<sup>th</sup> generation prototypes of the self-de-icing LED signals deployed with the 3<sup>rd</sup> generation fresnel lens disc, tested in a freezer, powered continuously with DC power sources with full power output.

**TABLE 3** Typical thermal performance of a 5<sup>th</sup> 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	
<b>Ambient Air Temp</b>	Ambient air	-11.5° C
<b>Lens Surface Temp</b>	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
<b>Temp Difference (<math>\Delta</math>) above Ambient</b>	Green light (current 0.837 A)	$\Delta$ 30.7° C
	Yellow light (current 0.838 A)	$\Delta$ 32.6° C
	Red light (current 1.115 A)	$\Delta$ 31.3° C

Additionally, we also measured the lighting performance of the 5<sup>th</sup> generations of the prototype signals, which deployed with the 3<sup>rd</sup> generation fresnel lens disc, 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. TABLE 4 summarizes the measurement results, all passed the code requirements (TABLE 2). 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 yet still meeting the code requirements for light output for more energy saving. Table 5 shows the measured focal length of the 3<sup>rd</sup> generation fresnel lens disc in our laboratory.

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

Tilting angle $\theta_{\text{vert}}$ (°)	Intensity (cd)					
	Red, Dimmed	Yellow, Dimmed	Green, Dimmed	Red, Full output	Yellow, Full output	Green, Full output
0	667.5	2088.2	1713.3	1277.2	3900.8	2740.9
0.5	668.1	2089.6	1721.3	1277.9	3903.4	2741.6
1	668.1	2091.6	1728.0	1281.9	3927.6	2747.6
1.5	671.5	2091.6	1733.4	1283.3	3932.3	2791.2
2	676.2	2089.6	1740.8	1288.0	3928.3	2818.1
<b>2.5</b>	<b>680.9</b> <b>&gt; 365</b> <b>(code)</b>	<b>2087.6</b> <b>&gt; 910</b> <b>(code)</b>	<b>1751.5</b> <b>&gt; 475</b> <b>(code)</b>	<b>1300.0</b> <b>&gt; 365</b> <b>(code)</b>	<b>3945.7</b> <b>&gt; 910</b> <b>(code)</b>	<b>2827.5</b> <b>&gt; 475</b> <b>(code)</b>
3	685.6	2088.2	1761.5	1301.4	3925.6	2832.2
3.5	691.6	2091.6	1772.3	1316.8	3932.3	2835.5
4	697.0	2093.6	1785.0	1328.2	3977.9	2838.2
4.5	708.4	2099.6	1801.8	1351.7	3988.6	2900.6
5	721.1	2109.0	1821.2	1394.6	4028.2	2932.1
6	741.9	2129.2	1873.6	1459.7	4173.1	2960.3

7	774.8	2163.4	1954.7	1518.7	4197.3	3127.3
8	821.7	2199.6	2027.2	1618.7	4311.3	3203.1
9	878.1	2208.3	2129.8	1597.2	3953.1	3407.7
10	873.4	2153.3	2127.1	1521.4	3725.0	3382.2
11	822.4	2021.8	1959.4	1338.3	3275.6	3115.2
12	752.6	1778.3	1845.4	1134.3	2667.8	2952.9
13	626.5	1452.3	1768.3	898.2	2048.0	2829.5
14	491.7	1178.6	1630.7	731.2	1744.1	2625.6
15	399.1	923.0	1343.0	668.8	1532.1	2162.0
20	145.6	437.4	463.5	256.2	760.7	737.2
25	102.6	301.2	313.9	188.5	551.4	502.4
30	82.5	232.8	249.5	150.3	416.6	404.5
40	57.7	159.0	173.7	117.4	318.0	276.4
50	53.0	133.5	143.6	77.8	193.9	232.8
60	63.1	155.6	177.1	75.8	185.1	285.1
70	23.5	88.5	113.4	50.3	188.5	180.4
80	8.0	48.3	58.4	21.5	74.5	92.6
90	3.4	20.8	28.2	12.1	59.7	45.6

**TABLE 5** Focal length of the third SINGLE sample of the fresnel lens disc (**generation 3**), measured on **June 13<sup>th</sup> 2021**

Test method	Measurement #1	Measurement #2
Parallel light with optical bench method	11.9 mm	12.0 mm
Image method with ceiling light $(\frac{1}{U} + \frac{1}{V} = \frac{1}{f})$	11.9 mm	

Accordingly, we summarized the lighting performance of different generations of the fresnel lens disc in Table 6, for comparison. It was found that the maximum numbers (the peak lighting performance) of the generation 3 (a single sample) is around 15 deg, different from 20 deg of the generation 2 fresnel lens disc (40 new samples) and 8-9 deg of generation 1 (old 20 samples). All generation peak values are different from the individual Fresnel lens in blue color (model 1511, focal length 11.5mm) around 1-3 deg. Also, the lighting performance of the generation 3 (a single sample) is improved, with peak light values around 15 deg, but still not close to the target values of ideally 1-3 deg or < 10 deg. The measured focal length is around 11.9-12.0 mm, still longer than the designed 11.5 mm.

**TABLE 6** The lighting performance of the generation 3 (21 new samples) is different from that of the generation 2 fresnel lens disc (40 new samples) and that of generation 1 (old 20 samples).

Generation of fresnel lens	Tilting angle $\theta_{\text{vert}}$ (°)	Intensity (cd)					
		Red, Dimmed	Yellow, Dimmed	Green, Dimmed	Red, Full output	Yellow, Full output	Green, Full output
<b>Gen 3</b> <b>(June 11, 2021)</b>	<b>2.5</b>	<b>656.0</b>	<b>1782.4</b>	<b>1467.2</b>	<b>1208.0</b>	<b>3067.2</b>	<b>2121.6</b>
<b>Gen 2</b> <b>(May 11, 2021)</b>	<b>2.5</b>	<b>651.2</b>	<b>1853.0</b>	<b>1371.0</b>	<b>1150.7</b>	<b>3155.3</b>	<b>1979.0</b>
<b>Gen 1</b> <b>(March 2, 2021)</b>	<b>2.5</b>	<b>680.9</b>	<b>2087.6</b>	<b>1751.5</b>	<b>1300.0</b>	<b>3945.7</b>	<b>2827.5</b>
<b>Individual lenses</b> <b>(Nov 27, 2018)</b>	<b>2.5</b>		<b>2136.54</b>	<b>1749.9</b>		<b>4189.7</b>	<b>2754.8</b>

As a result, possible solutions include the following two options are still under consideration with the engineers in the factory:

1. Option 1: continue to improve the injection technology to make new samples close to 11.5 mm, with error of 2%, that is 11.3-11.7 mm.
2. Option 2: revise the mold to make the target focal length shorter than the designed 11.5 mm, for example, **10.5 mm**, to make new samples focal length close to 10.5-11.5 mm.

Thirdly, we have prepared more **5<sup>th</sup> generation** prototypes of the self-de-icing signals for more test sites in Michigan, Wisconsin, Maryland, and New Jersey & Pennsylvania, as shown in FIGURE 3.

We would need help from each participating state, a city, and their signal crew for selection of a good test site for installation of the prototypes for testing them for at least two years after the installation. The whole field installation may take 3-4 hours or less.

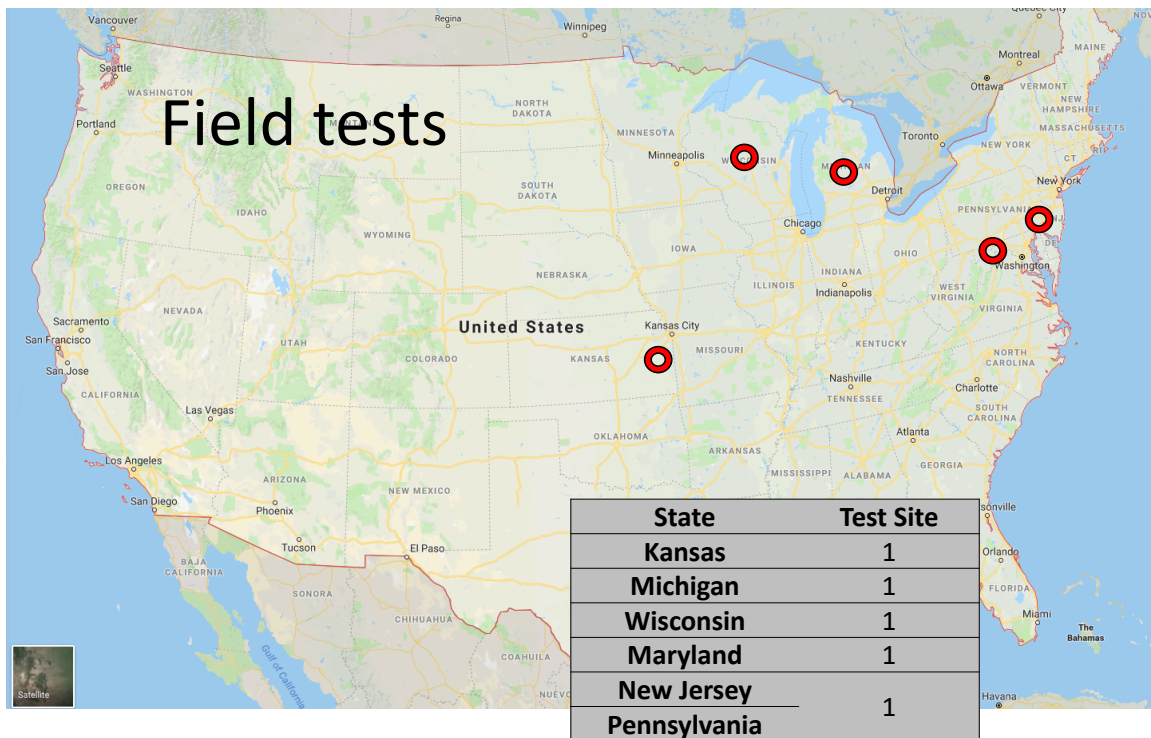
There are **a few recommendations on the selection of a good test site**, as follows:

- a) The site has a good chance to see a lot of snow and ice in winter.
- b) The intersection has well-balanced traffic by direction so that the signal timing for **red** and **green** lights is also balanced.
- c) The selected signals are on the side of the road shoulder.
- d) The test site has good mobile signal coverage for the remote monitoring system.

The field installation will need help from the signal crew on two tasks listed below. The data will be remotely and automatically collected by the data monitoring system installed together with the new self-de-icing signals, with minimum support in need from the signal crew in the future.



- a) Replacement of the existing signals with the new prototypes.
- b) Installation of the remote monitoring system in a weather proof plastic box, wired with temperature sensors and cable cameras that are mounted on the signal lens and visor for data collection.



**FIGURE 3** We are ready for testing the **5<sup>th</sup> generation** of self-de-icing signals in other field test sites in Michigan (1), Wisconsin (1), Maryland (1), and New Jersey & Pennsylvania (joint 1)

We have reached out each participating states for the expected field tests, and are currently waiting for their follow-up for communication and coloration with the signal crew in each test site. We are looking forward to the research trips in summer to install all 5<sup>th</sup> generation prototypes in different state.

**Anticipated work next quarter:**

Starting from April 1, 2021 till June 30, 2021, we are planning to conduct the following tasks.

1. Continue to communicate with each participating state to select the field test sites, to install the 5<sup>th</sup> generation of prototypes deployed with the 3<sup>rd</sup> generation fresnel lens disc in test sites in Michigan, New Jersey, Wisconsin, Pennsylvania, and Maryland.
2. Start new field test installation in the summer, sometimes in between July and August, if possible.
3. Start writing the final report.

**Significant Results:**

As of Dec 31, 2020, we have achieved the following significant results.

- This project was launched in Aug 2016 with six participating states (Kansas, California, Michigan, New Jersey, Wisconsin, and Pennsylvania) and an initial budget of \$240,000. Maryland is expected to officially join the study by the end of this year with additional contribution of three years funding.
- An expert panel meeting was held in early March. Discussions were held on desired specifications of the prototype signals and possible field test sites as well as the field evaluation of the prototypes.
- Necessary equipment, components and insulation materials are being procured to develop and build the fully working prototypes of the finalized design and test for their thermal and lighting performance. We will continue to order LED drivers, electricity monitors, waterproof security video cameras, other mounting accessories and materials, etc., for monitoring the performance of the prototypes in the field tests in the upcoming winter season.
- Appropriate color LED modules, which are not available in the market, were designed in-house and custom-made with the aid of the industrial partner.
- Three preliminary prototype signals (Red, Yellow, and Green) of Type 1 have been developed in house, each deploying 26 custom-made color LEDs mounted in an array via “Heat Arrangement of LED Arrays in Low Profile”. They are under laboratory testing for improvements.
- Tested the lighting and thermal performance of the preliminary prototypes of the Type 1 signal lights (Figure 1). Based on the test results, new design with a lot of changes and improvements has been finalized for final products.
- Finalized the design of Type 1 self de-icing LED signals using 96 custom-made mediate-power color LEDs mounted in an array via “Heat Arrangement of LED Arrays in Low Profile”. Designed in house and custom-made our own color LED modules (for each color R, G, Y) for making the fully working prototype signals of the first type with the aid of our industrial partner.
- Worked with the factories to optimize the mounting method of the custom-made LED modules on the 3-

5 mm thick aluminum MPCB back plate serving as the passive heat exchangers of aluminum alloy for assembly.

- Custom-made three prototypes of the LED signals of Type 1 using 96 custom-made mediate-power color LEDs mounted in an array via “Heat Arrangement of LED Arrays in Low Profile”, with regular paint coating, and finished laboratory testing for improvements and optimizations to finalize the design.
- Improved and custom-made three new signal light engines using 96 medium-power LEDs (0.25 Watt each) mounted in an array via “Heat Arrangement of LED Arrays in Low Profile” but with Tin coating (Figure 3) and tested them to improve the heating performance (to make faster heat transfer).
- Finalized the design of the signal lens that adopts a whole piece design with smooth and flat outside surface and integrated with 96 additional custom-made Fresnel lenses sitting inside the signal lens over each LED on the inside surface to focus the light serving as a collimator lens. Based on the testing results, the signal light engines with TIN coating may have superior thermal performance, however, further testing in the laboratory and field is necessary to validate the final choice.
- Identified and started custom-making the Fresnel Lens from HongXuan Optoelectronic company with diameter 15 mm and focal length 6 mm (model # HX-F015006).
- Developed the new whole-piece signal housing, new Fresnel lenses, LED drivers, and other accessories for the Type 1 self de-icing LED signal lights, with the aid of the industrial partner.
- Found and selected a qualified plastic molding company to custom make the three parts of the plastic housing of fully working prototypes of Type 1 signals that deploy 96 mediate-power LEDs via the architecture of “Heat Arrangement of LED Arrays in Low Profile”. The new housing will be used for the new LED signal lights.
- The non-provisional patent application for the invention of Type 2 self de-icing signal light was officially approved by the USPTO and issued on Dec 26, 2017, patent No. US 9,851,086 B2.
- Started custom-making and modeling of the signal housing. Three samples were delivered for examinations and laboratory tests for necessary calibrations and further improvements.
- Started custom-making the LED drivers with desired specifications based on our test results. Seven LED drivers were delivered for sample testing.
- The custom-made signal housing is ready for production of products with possible minor adjustments for field tests in different states. Six improved samples have been delivered and thoroughly tested in laboratory and closed-setting tests on the roof.
- New type of screws for uses in the signal housing are self-designed and will be custom-made with Fastenal company.
- A company is custom making two improved and finalized types of LED driver, one for YELLOW and GREEN signal lights (output 0.8 A, maximum 30 Watts), the other for RED signal light (output 1.1 A, maximum 30 Watts). The new LED drivers have temperature Sensor control, when the temperature is above 4 degree 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.

- The self-deicing signal lights have higher light output than the codes and standards required in all viewing angles from 0 deg to 70 deg as measured, even at the derated power output.
- We have been conducting a closed-course performance and reliability tests of the fully working prototypes mounted on the roof of the University of Kansas engineering complex - M2SEC building, in preparation for field tests.
- Seven states have officially participated in this project, including Kansas, California, Michigan, New Jersey, Wisconsin, Pennsylvania and Maryland to provide support.
- A project addendum is proposed to conduct two additional field tests, one in Wisconsin and another one in a test site among Maryland, Pennsylvania, and New Jersey. A budget of \$80,000 for the addendum is proposed to be spent starting on 5/18/2018 until the end of the project
- We have been continuously testing the closed-course performance and reliability of the prototypes previously mounted on the roof of M2SEC building. All signal lights were 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 temperature data were recorded every 10 seconds continuously over the entire test period, which will be continuously conducted over both winter and summer seasons in 2019.
- We have designed and custom made new types of screws to improve the connection strength of the screws integrated with the plastic housing. This type of screws are finalized products to be used in all finalized plastic housing.
- We have 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 now integrated with a remote temperature sensor for controlling the power output in light of the ambient air temperature. An on/off switch is designed for temperature controls in winter and summer modes which could override the operation of the temperature sensor.
- We have accordingly improved and finalized the plastic housing of the fully working prototype signals of Type 1 with changes/improvements listed below, with assist of the plastic molding company — Eco Molding. Eco Molding company has custom made seven samples of the finalized new plastic housing for validations tests before actual product production.
- We have produced 60 pcs of the finalized LED engines with the aid of the industrial partner, ready for the upcoming field tests.
- We have also updated and custom made 60 pcs of glass disc which have four small mounting holes removed on the edge (the original glass disc had 8 mounting holes).
- We also custom made plastic mounting bars for mounting the glass disc to the LED light engine.

- We are working on getting improvement on custom-made Fresnel lens model number HX-F0150115 (diameter 15 mm, thickness 2.0 mm, focal length 11.5 mm) to increase tolerance of the thickness (approximately 1.8 – 2.1 mm) while reducing the unit cost.
- We are in preparation for field tests. Three fully functional prototypes of the fourth generation were mounted on a signal pole on the roof of an engineering building, powered by a traffic control cabinet for closed-course performance and reliability tests.
- Three more fully functional prototypes of the fourth generation were also tested in a well-controlled cold room for the performance of the ambient temperature sensor connected to the LED driver for switching full/derated power output. Based on the test results, we are adjusting the power output of the LED drivers. We are also making minor adjustments of the signal housing for quick assembly of the real products. Results have been used to evaluate the readiness of the prototypes for field tests starting in next quarter.
- Corrected some problems and resolved issues of the custom-made LED drivers, including (1) decreased the size of the power connector of the temperature sensor, (2) decreased the length to 6 mm, (3) changed to more reliable single switch, (4) enlarged the inside size of the installation hole to 6mm x 4.5 mm, (5) changed the final designed output current of Yellow/Green LED drivers to 0.40 A (derated) /0.84 A(full output), (6) changed the final designed output current of Red LED drivers to 0.60 A (derated) /1.1 A(full output), (7) improvements on temperature measurement accuracy, redesigned logic circuits, and changes of electronic parts used on the LED PCB boards.
- The signal housing of the fourth generation LED signal lights was revised for quick assembly. We have received the new prototypes of the housing with desired changes, which were tested in the laboratory with satisfactory performance.
- Other parts like glass mounting discs have also been improved in house for enlarging the installation holes to fit the new housing.
- Additional vendors for Fresnel lenses were contacted for lower unit price with higher quality control than the current lens vendor. Based on the lab test results, a total of 5000 PCS of new Fresnel lenses (**Model #1511**) were ordered from the new vendor for field tests.
- Based on the lab test results on the second generation of LED drivers, a total of 21 pcs of the third generation of LED drivers were ordered for lab tests, in preparation for the field tests.
- A total of 21 new LED drivers of the third generation for the field tests were made and are under testing in the laboratory for their field performance and any possible further improvements in need for control of the yield rate in production.
- A new proposal was approved on extended work with increased total project cost of \$360K and extended new end date of June 30, 2021.
- Field monitoring systems powered by Raspberry 3 B+ 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, have been custom built in house and under testing in the lab and on the roof, which will be mounted at each field test site for year-around real-time monitoring and

data recording of the new signals to be tested in the field.

- New fully working prototypes of the signal lights for field tests have been assembled and are under thorough final tests in the laboratory in preparation for upcoming field tests.
- A total of 21 new LED drivers of the third generation were tested 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 0.5-1 second, 2) Unstable output performance of the drivers, due to unsecured soldering of wire connections by hands.
- The 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 roof for field installation. The system will be mounted at every field test site 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 Rd 458 (or 1200 Rd) /US-59. All new equipment including the performance monitoring system for data recording were installed on side signals facing north and already survived the first snowstorm in December.
- More prototypes of the final products are in preparation for other test sites. Seven states (Kansas, California, Michigan, New Jersey, Wisconsin, Pennsylvania, and Maryland) are participating in field testing and evaluation of the prototypes.
- A remedying method in the laboratory for flattening the concaved lens surface, using supplemental heat beneath the lens and added weight on the top inside surface, a thermal lamp was installed inside a box below the glass on which the lens sits, the lens surface was monitored with four temperature sensors connected to a HOBO data logger.
- Talked with the fresnel lens company to modify the design and form factor of the currently adopted 96 individual lenses mounted in the housing to a whole piece of disc embedded with a total of 96 fresnel lenses on it.
- The field monitoring system has added mobile communication information 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, which is under testing on the roof.
- The problem of defective signal light housing with concave lens surface made during the production process has been solved with improved molding technology. A total of 100 new samples are made of Markrolon 2807 and tested with a maximum tolerance of 1.5 mm for mass production.
- A new fresnel disc with 96 small fresnel lenses integrated on it has been designed with the desired improvements, and is currently being custom-made in a factory through injection mold.
- We have installed the new remote monitoring system with mobile communication in the Lawrence test site, in addition to the original reliable “local” data monitoring system that kept running in the past year.

- The self-de-icing signals have survived both winter and summer functioning as expected, without any signs of snow and ice accumulation on the signal lens in cold winter, and abnormal performance in hot summer.
- Corrections have been made in the injection mold for making the new fresnel disc with 96 small fresnel lenses integrated on it.
- Writing a manual to be used by signal crews of different states for mounting the new self-de-icing signals and the corresponding data recording and remote monitoring system, for the upcoming field test site use.
- 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 was tested with shortened focal length of 11.9 mm, but still > 11.5 mm, and similar thermal performance.
- The fifth generation prototypes and associated field remote monitoring systems have been fully prepared and tested for other field test sites to be conducted in Michigan, Wisconsin, Maryland, and New Jersey & Pennsylvania, which are participating in field testing and evaluation of the prototypes.

**Circumstance affecting project or budget. (Please describe any challenges encountered or anticipated that might affect the completion of the project within the time, scope and fiscal constraints set forth in the agreement, along with recommended solutions to those problems).**

None.