TRANSPORATION 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.

Transportation Pooled Fund Project Number **TPF-5(351)**		**Transportation Pooled Fund Program - Report Period:** ☐ Quarter 1 (January 1 – March 31) X Quarter 2 (April 1 – June 30) ☐ Quarter 3 (July 1 – September 30) ☐ Quarter 4 (October 4 – December 31)
Project Title: Self De-Icing LED Signals		
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Lead Agency Project ID: **RE-0721-01**	**Other Project ID (i.e., contract #):**	**Project Start Date:** August 15, 2016
Original Project End Date: **August 2019**	**Current Project End Date:** **August 2019**	**Number of Extensions:** 0

Project schedule status:

X 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, $320,000 with addendum	$122,856	50%

Quarterly Project Statistics:

Total Project Expenses This Quarter	Total Amount of Funds Expended This Quarter	Percentage of Work Completed This Quarter
$14,759	$14,759	5%

Project Description:

This pooled fund project will develop and demonstrate new self de-icing LED signals for highway signalized intersections and railroad signaling 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 wintery 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 wintery conditions.

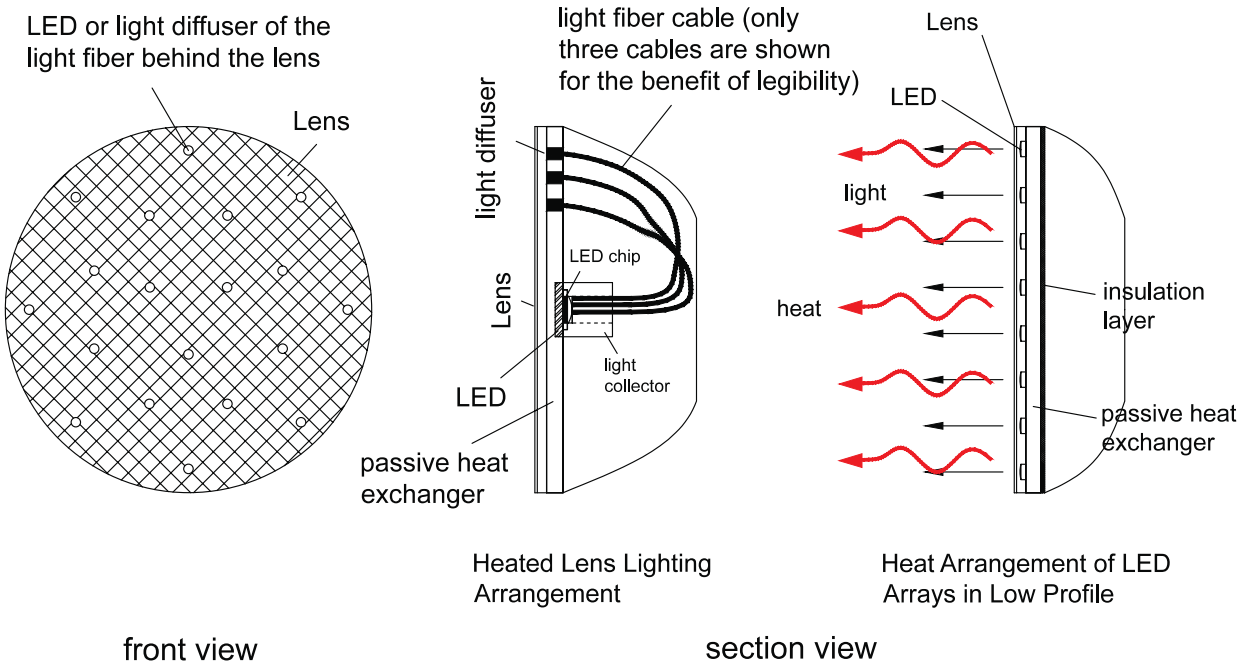


Figure 1 The concept of the self de-icing LED signal light, which adopts new architecture of "Heated Lens Lighting Arrangement" or "Heat Arrangement of LED Arrays in Low Profile"

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 and railroad wayside or at-grade crossing signal lights. 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 or rail track sections and the desired technical specifications for testing the prototypes.

The investigative approach for the proposed project is divided into the 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 highway signalized intersections and rail track sections. 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.

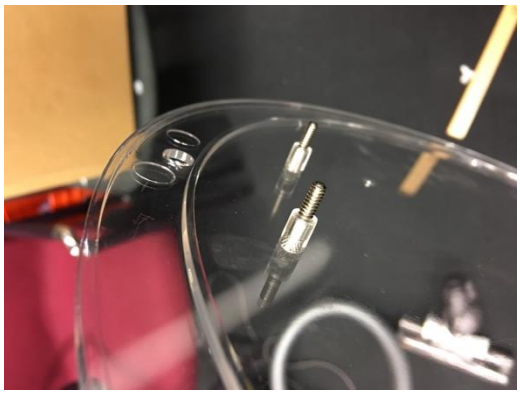
Progress this Quarter (includes meetings, work plan status, contract status, significant progress, etc.):

During the second quarter (April 1, 2018 – June 30, 2018) in 2018 of the project period, we have the following accomplishments.

In the past quarter, the research team has closely worked with the plastic molding company — Eco Molding — to custom make the new housing of the fully working prototype signals of Type 1, with up-to-date inputs from other assembly parts, such as Fresnal lens, custom-made LED drivers with temperature sensors, mounting glass panels, and screws, etc.. Eco Molding company has custom made three working samples (Figure 1) of the new plastic housing in April for validation of the designed geometries for further adjustments before the actual production. Those samples (Figure 1) were thoroughly tested in the laboratory and then on the roof of an engineering building – M2SEC building. Based on the test results, we decided to improve the connection strength of the screws integrated with the plastic housing, by using new type of screws (Figure 2), which are self designed and will be custom-made with Fastenal company. The old screws have no head, which could not resist the rotation when tighten using tools. The new screws are designed with a rectangular head, which will increase the connection strength of the screw in the plastic housing, to resist the rotation inside the plastic housing and easily pulling off from the housing. The new screw is self designed and will be custom made by Fastenal company, which will be used in the final products of the housing.

Figure 1 Three samples the finalized design of the new housing of the fully working prototype signals of Type 1, modelled in the factory of Eco Molding. Each sample includes three plastic parts: the whole-piece of new housing that accommodate 96 small Fresnel lenses for light collimation of individual LEDs, a cover for

the new light engine, and a new back cover for the housing which will be used to mount the new custom-made LED drivers.



Old screws in samples

Sample of old screws without head

New screws in samples

New screws with rectangular head

Figure 2 Screws used in the finalized design of the new housing of the fully working prototype signals of Type 1. The old screws have no head, which could not resist the rotation when tighten using tools. The new screws are designed with a rectangular head, which will increase the connection strength of the screw in the plastic housing, to resist the rotation inside the plastic housing and easily pulling off from the housing. The new screw is self designed and will be custom made by Fastenal company.

As a result, six additional fully working samples of the housing (Figure 3) were custom made using the samples of new screws and provided in June for continuous roof and field tests. Compared to the old housing, the new housing has several improvements, including:

- Using new types of screws with rectangular head in the molding process, which increases the connection strength.
- Adding one more hold in part 2 to allow electrical wiring passing through.
- Improvement of the surface smoothness during molding process of part 1 with 96 niches for mounting Fresnel lenses.
- (Planned for) adding another hole in the side surface of part 1 for mounting temperature sensors (awaiting the actual dimensions of the temperature sensor to be used in the new LED driver to be provided by the LED driver company).

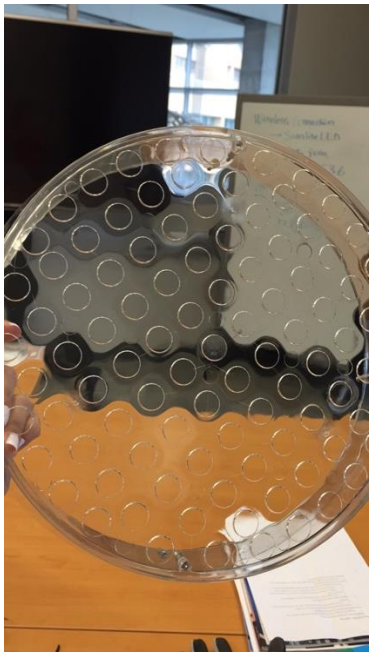


Figure 3 Six additional samples the finalized design of the new housing of the fully working prototype signals of Type 1, modelled in the factory of Eco Molding. Each sample includes three plastic parts: the whole-piece of new housing that accommodate 96 small Fresnel lenses for light collimation of individual LEDs, a cover for the new light engine, and another back cover for the housing which will be used to mount the new custom-made LED drivers.

As shown in Figures 1 and 3, the entire new plastic housing is made of UV Stabilized Polycarbonate materials. The material shall be transparent with visible light transmittance at least 88%, and strong enough to hold wild temperature in a range of -40°C (-40°F) to +74°C (+165°F) without any problems like cracks, shape changing, or turning yellow due to long time exposure to air, moisture, heat, and UV light. The warranty should be at least 5 years (by code), ideally 10-15 years. Final products of the new plastic housing will be available for field tests starting in next quarter.

The samples of new housing were used to assemble the self de-icing LED signal lights (in R, Y, G colors) with available LED drivers (fixed current output 0.8A, maximum 30 Watt) and other assembling parts as disclosed in the 9th report. The fully working prototypes were first tested in the laboratory for thermal and lighting performances. The prototypes were first tested in a chest-freezer to simulate extremely cold environments with an ambient temperature lower than zero degree Fahrenheit. The thermal test results are summarized in Tables 1-3. Note that during the laboratory tests using the available custom-made LED driver (fixed current output 0.8A, maximum 30 Watt), the Yellow signal light and Green signal light consumes approximately 28.5 W and 28.7 W, respectively, while the RED signal light consumes only approximately 19.5 W.

To improve the thermal performance of Red signal lights limited by the available LED driver with fixed single current output (0.8 A), we adjusted the electric current running through the signal light, by using an adjustable DC power sources. We increased the current to 1.0A and then 1.1A, and measured the surface temperature of the housing lens. The results are summarized in Tables 4 and 5.

Table 1 Surface temperatures of **YELLOW** signal lights using the available custom-made LED driver (fixed current output 0.8A, maximum 30 Watt). The actual power consumption of Yellow light is approximately 29.5 Watts.

Yellow Signal Light (0.8A, approx. 29.5 Watt)		Temperature difference above ambient temp
Mean temperature sensor 1	50.94 °F	58.61 °F
Mean temperature sensor 2	53.70 °F	61.37 °F
Mean temperature sensor 3	55.55 °F	63.22 °F
Mean temperature sensor 4	54.41 °F	62.07 °F
Mean temperature sensor5	53.57 °F	61.24 °F
Mean temperature, ambient	-7.67 °F	
Mean temperature of all five sensors	**53.63°F**	
Mean temp increase above ambient	**61.30 °F**	

Table 2 Surface temperatures of **GREEN** signal lights using the available custom-made LED driver (fixed current output 0.8A, maximum 30 Watt. The actual power consumption of Yellow light is approximately 30.0 Watts.

GREEN Signal Light (0.8A, approx. 30.0 Watt)		Temperature difference above ambient temp
Mean temperature sensor 1	56.94 °F	63.12 °F
Mean temperature sensor 2	58.37 °F	64.56 °F
Mean temperature sensor 3	61.44 °F	67.63 °F
Mean temperature sensor 4	60.68 °F	66.87 °F
Mean temperature sensor5	59.17 °F	65.35 °F
Mean temperature, ambient	-6.19 °F	
Mean temperature of all five sensors	**59.32°F**	
Mean temp increase above ambient	**65.51 °F**	

Table 3 Surface temperatures of **RED** signal lights using the available custom-made LED driver (fixed current output 0.8A, maximum 30 Watt). The actual power consumption of Yellow light is approximately 19.5 Watts).

RED Signal Light (0.8A, approx. 19.5 Watt)		Temperature difference above ambient temp
Mean temperature sensor 1	32.22 °F	44.34 °F
Mean temperature sensor 2	33.86 °F	45.98 °F
Mean temperature sensor 3	35.39 °F	47.51 °F
Mean temperature sensor 4	35.58 °F	47.70 °F
Mean temperature sensor5	34.78 °F	46.90 °F
Mean temperature, ambient	-12.12 °F	
Mean temperature of all five sensors	**34.37°F**	
Mean temp increase above ambient	**46.49 °F**	

Table 4 Surface temperatures of **RED** signal lights using the adjustable DC power source (current = 1.0A). The actual power consumption of Yellow light is approximately 25.5 Watts)

RED Signal Light (1.0A, approx. 25.5 Watt)		Temperature difference above ambient temp
Mean temperature sensor 1	41.43 °F	53.99 °F
Mean temperature sensor 2	41.55 °F	54.11 °F
Mean temperature sensor 3	40.91 °F	53.48 °F
Mean temperature sensor 4	39.22 °F	51.78 °F
Mean temperature sensor5	41.20 °F	53.76 °F
Mean temperature, ambient	-12.56 °F	
Mean temperature of all five sensors	**40.86°F**	
Mean temp increase above ambient	**53.42 °F**	

Table 5 Surface temperatures of **RED** signal lights using the adjustable DC power source (current = 1.1A). The actual power consumption of Yellow light is approximately 29.2 Watts)

RED Signal Light (1.1A, approx. 29.2 Watt)		Temperature difference above ambient temp
Mean temperature sensor 1	44.87 °F	57.38 °F
Mean temperature sensor 2	45.06 °F	57.56 °F
Mean temperature sensor 3	44.39 °F	56.90 °F
Mean temperature sensor 4	42.64 °F	55.14 °F
Mean temperature sensor5	44.72 °F	57.22 °F
Mean temperature, ambient	-12.50 °F	
Mean temperature of all five sensors	**44.34°F**	
Mean temp increase above ambient	**56.84 °F**	

Moreover, in the laboratory, we also conducted a thorough measurement of the light output of R, Y, and G signal lights, in comparison to the codes and standards. The lighting performances of those signal lights are summarized below in Tables 6-8.

Table 9 lists the lighting requirements by codes and standards. By comparing the tests results with the codes, it is obvious our signal lights have much higher light output than the codes and standards required in all viewing angles from 0 deg to 70 deg as measured. Therefore, we could lower the power consumptions of those signal lights in warm seasons without losing the capacity of lighting performance.

Table 6 Lighting performance of **RED** signal lights powered by the available custom-made LED driver (fixed current output 0.8A, maximum 30 Watt). The actual power consumption of RED light is approximately 19.5 Watts)

RED signal lights, Wattage 19.5 W

Angle in deg	Illuminance (Lux)	Illuminance (Lux)	Illuminance (Lux)	Average E (lux)	distance (meter)	Intensity (cd)
0	147.6	147.4	147.6	147.5	2.236	737.6
0.5	148.7	148.5	148.5	148.6	2.236	742.8
1	149.7	149.6	149	149.4	2.236	747.1
1.5	151	150.9	150.9	150.9	2.236	754.6
2	151.8	151.7	151.8	151.8	2.236	758.8
2.5	152.8	152.8	152.7	152.8	2.236	763.8
3	153.6	153.5	153.6	153.6	2.236	767.8
3.5	154	154	154	154.0	2.236	770.0
4	154.4	154.4	154.3	154.4	2.236	771.8
4.5	157.8	156.9	157.8	157.5	2.236	787.5
5	158	157.9	157.9	157.9	2.236	789.6
6	157.6	157.5	157.5	157.5	2.236	787.6
7	156.2	156	155.9	156.0	2.236	780.1
8	154.3	154.2	154.2	154.2	2.236	771.1
9	153	152.8	152.8	152.9	2.236	764.3
10	152	151.9	151.8	151.9	2.236	759.5
20	141.3	141.3	141.2	141.3	2.236	706.3
30	132.3	132.2	132	132.2	2.236	660.8
40	27.92	27.93	27.88	27.9	2.236	139.5
50	13.52	13.54	13.53	13.5	2.236	67.6
60	12.83	12.83	12.86	12.8	2.236	64.2
70	10.66	10.66	10.64	10.7	2.236	53.3

Table 7 Lighting performance of **GREEN** signal lights powered by the available custom-made LED driver (fixed current output 0.8A, maximum 30 Watt). The actual power consumption of Green light is approximately 30.0 Watts)

GREEN signal lights, Wattage 30.0 W

Angle in deg	Illuminance (Lux)	Illuminance (Lux)	Illuminance (Lux)	Average E (lux)	distance (meter)	Intensity (cd)
0	267	267	267.1	267.0	2.236	1335.1
0.5	269.4	269.3	269.4	269.4	2.236	1346.8
1	270.8	270.5	270.8	270.7	2.236	1353.4
1.5	272.2	272.1	272.2	272.2	2.236	1360.8
2	273.5	273.5	273.6	273.5	2.236	1367.6
2.5	274.1	274.3	274.3	274.2	2.236	1371.1
3	275.3	275.4	275.4	275.4	2.236	1376.7
3.5	276.6	276.6	276.6	276.6	2.236	1382.9
4	277.6	277.7	277.7	277.7	2.236	1388.2
4.5	278.3	278.5	278.5	278.4	2.236	1392.1
5	280.2	279.7	279.6	279.8	2.236	1399.1
6	279.4	279.4	279.6	279.5	2.236	1397.2
7	278.5	278.5	278.6	278.5	2.236	1392.6
8	277	277.4	277.4	277.3	2.236	1386.2
9	275.1	275.4	275.4	275.3	2.236	1376.4
10	274.1	273.9	274.2	274.1	2.236	1370.3
20	263.3	263.4	263.4	263.4	2.236	1316.8
30	258.3	258.5	258.5	258.4	2.236	1292.1
40	81.4	81.4	81.3	81.4	2.236	406.8
50	28.05	28.07	28.04	28.1	2.236	140.3
60	23.6	23.61	23.6	23.6	2.236	118.0
70	26.7	26.7	26.7	26.7	2.236	133.5

Table 8 Lighting performance of **YELLOW** signal lights powered by the available custom-made LED driver (fixed current output 0.8A, maximum 30 Watt). The actual power consumption of Yellow light is approximately 29.5 Watts)

YELLOW signal lights, Wattage 29.5 W

Angle in deg	Illuminance (Lux)	Illuminance (Lux)	Illuminance (Lux)	Average E (lux)	distance (meter)	Intensity (cd)
0	511	511	511	511.0	2.236	2554.8
0.5	514	514	514	514.0	2.236	2569.8
1	517	517	517	517.0	2.236	2584.8
1.5	520	520	520	520.0	2.236	2599.8
2	523	523	523	523.0	2.236	2614.8
2.5	523	523	523	523.0	2.236	2614.8
3	524	524	524	524.0	2.236	2619.8
3.5	525	524	525	524.7	2.236	2623.2
4	524	524	523.5	523.8	2.236	2619.0
4.5	523	523	523	523.0	2.236	2614.8
5	522.5	523	523	522.8	2.236	2614.0
6	518	519	519	518.7	2.236	2593.2
7	512	512.1	512	512.0	2.236	2560.0
8	508	508	508	508.0	2.236	2539.8
9	501	501.1	501	501.0	2.236	2505.0
10	497.1	497.1	497.3	497.2	2.236	2485.7
20	441	441	441	441.0	2.236	2204.9
30	334	335	335	334.7	2.236	1673.2
40	64.3	64.2	64.3	64.3	2.236	321.3
50	43.1	43.2	43.2	43.2	2.236	215.8
60	57.1	57	57	57.0	2.236	285.1
70	29.4	29.5	29.4	29.4	2.236	147.2

Table 9 Lighting performance required by codes and standards.

Peak minimum maintained luminous intensity values, at θ_{Vert} = –2.5 deg and θ_{Horiz} = 0 deg [$\mathbf{I}_{(-2.5, 0)}$], by size and color of the module are:

Color	$\mathbf{I}_{(-2.5, 0)}$ 200mm	300mm
Red	165 cd	365 cd
Yellow	410 cd	910 cd
Green	215 cd	475 cd

Minimum Maintained Luminous Intensity Values—VTCSH LED Circular Signal

Vertical Angle	Horizontal Angle	Luminous Intensity (candela)					
		200mm (8-inch)			300 mm (12-inch)		
		Red	Yellow	Green	Red	Yellow	Green
+12.5	2.5	17	41	22	37	91	48
	7.5	13	33	17	29	73	38
+7.5	2.5	31	78	41	69	173	90
	7.5	25	62	32	55	137	71
	12.5	18	45	24	40	100	52
+2.5	2.5	68	168	88	150	373	195
	7.5	56	139	73	124	309	162
	12.5	38	94	49	84	209	109
	17.5	21	53	28	47	118	62
	22.5	12	29	15	26	64	33
-2.5	2.5	162	402	211	358	892	466
	7.5	132	328	172	292	728	380
	12.5	91	226	118	201	501	261
	17.5	53	131	69	117	291	152
	22.5	28	70	37	62	155	81
	27.5	15	37	19	33	82	43
-7.5	2.5	127	316	166	281	701	366
	7.5	106	262	138	234	582	304
	12.5	71	176	92	157	391	204
	17.5	41	103	54	91	228	119
	22.5	21	53	28	47	118	62
	27.5	12	29	15	26	64	33
-12.5	2.5	50	123	65	110	273	143
	7.5	40	98	52	88	218	114
	12.5	28	70	37	62	155	81
	17.5	17	41	22	37	91	48
	22.5	8	21	11	18	46	24
	27.5	5	12	6	11	27	14
-17.5	2.5	23	57	30	51	127	67
	7.5	18	45	24	40	100	52
	12.5	13	33	17	29	73	38
	17.5	7	16	9	15	36	19
	22.5	3	8	4	7	18	10
-22.5	2.5	17	41	22	37	91	48
	7.5	13	33	17	29	73	38
	12.5	10	25	13	22	55	29
	17.5	5	12	6	11	27	14
-27.5	2.5	12	29	15	26	64	33
	7.5	8	21	11	18	46	24

Note 1: Luminous intensity values for equivalent left and right horizontal angles are the same.
Note 2: Tabulated values of luminous intensity are rounded to the nearest whole value.

Based on the thermal test results, it is obvious we need two configurations of the custom-made 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).

Additionally, all LED drivers will need controls from a real-time ambient temperature sensor for power output. The ambient temperature sensor will be mounted on the housing exposed to the outdoor temperature and wired through a hole to the driver MCB board. An on/off switch will be used on the MCB board to turn the temperature sensors on/off if necessary. When the temperature sensor is turned off or failed for any reasons, the default power output of the LED driver will be 100% (For Yellow + Green LED lights, output 0.8 A, maximum 30 Watts; For Red LED light, output 1.1 A, maximum 30 Watts).

When the ambient temperature is above 4 degree Celsius, the LED driver output shall be derated to satisfy the lighting performance requirements without producing too much heat which is unnecessary in warm seasons. We conducted a second round of lighting performance tests to find the most properly derated power outputs of R, Y, and G signal lights. It was found that when the temperature is above 4 degree Celsius, the LED driver output should be the following:

- 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

In comparison, when the outdoor temperature reaches 4 degree Celsius or lower, the LED driver output should be the following:

- For Yellow + Green LED lights, output 0.8 A, maximum 30 Watts
- For Red LED light, output 1.1 A, maximum 30 Watts

The lighting performance results of the derated power outputs of R, Y, G signal lights are summarized in Tables 10-12. As shown in Tables 10-12, the lighting performance of the derated signal lights have satisfied the lighting requirements of the codes and standards.

In summary, the updated configurations of the new custom-made LED drivers to be used in the field tests include the following. The updated LED drivers are currently custom-making by W&T ELECTRONICS CO., LTD.

- Dimensions: 234.2*70*30 mm (L*W*H), for Yellow + Green LED lights
- With temperature Sensor control, when the temperature is above 4 degree Celsius, the LED driver output will be derated. When the temperature sensor is turned off or failed for any reasons, the power output will be restored to 100% as default.
- For Yellow + Green LED lights, output 0.8 A, maximum 30 Watts, Standard O/P: 0.8 A, Max 30 W; Derated O/P: 0.5A, 17W~18W
- For Red LED light, output 1.1 A, maximum 30 Watts, Standard O/P: 1.1 A, Max 30 W; Derated O/P: 0.6A, 15W~16W

Table 10 Lighting performance of **RED** signal lights powered by DC power source (current output 0.6A. The actual power consumption of RED light is approximately 14.25 Watts)

RED signal lights, 0.6 A, wattage 14.25 W

Angle in deg	Illuminance (Lux)	Illuminance (Lux)	Illuminance (Lux)	Average E (lux)	distance (meter)	Intensity (cd)
0	118.1	118.1	118.1	118.1	2.236	590.5
0.5	118.9	118.9	118.9	118.9	2.236	594.5
1	119.3	119.3	119.3	119.3	2.236	596.5
1.5	120.2	120.2	120.2	120.2	2.236	601.0
2	120.7	120.7	120.7	120.7	2.236	603.5
2.5	120.8	120.8	120.8	120.8	2.236	604.0
3	121.1	121.1	121.1	121.1	2.236	605.5
3.5	121.2	121.2	121.2	121.2	2.236	606.0
4	121.3	121.3	121.3	121.3	2.236	606.5
4.5	120.9	120.8	120.8	120.8	2.236	604.1
5	120.8	120.8	120.8	120.8	2.236	604.0
6	120.1	120.1	120.1	120.1	2.236	600.5
7	119	119	118.9	119.0	2.236	594.8
8	118.2	118.2	118.2	118.2	2.236	591.0
9	117.4	117.4	117.4	117.4	2.236	587.0
10	116.4	116.3	116.3	116.3	2.236	581.6
20	108.9	108.8	108.8	108.8	2.236	544.1
30	103.6	103.6	103.6	103.6	2.236	518.0
40	20.33	20.27	20.28	20.3	2.236	101.5
50	9.63	9.62	9.62	9.6	2.236	48.1
60	11.57	11.36	11.41	11.4	2.236	57.2
70	7.52	7.51	7.51	7.5	2.236	37.6

Table 11 Lighting performance of **GREEN** signal lights powered by DC power source (current output 0.5A). The actual power consumption of Green light is approximately 18.3 Watts)

GREEN signal lights, 0.5A, wattage 18.3 W

Angle in deg	Illuminance (Lux)	Illuminance (Lux)	Illuminance (Lux)	Average E (lux)	distance (meter)	Intensity (cd)
0	229.6	229.6	229.6	229.6	2.236	1147.9
0.5	23.04	230.4	230.4	161.3	2.236	806.4
1	230.7	230.7	230.7	230.7	2.236	1153.4
1.5	230.9	230.9	230.9	230.9	2.236	1154.4
2	230.6	230.6	230.6	230.6	2.236	1152.9
2.5	230.2	230.2	230.2	230.2	2.236	1150.9
3	229.7	229.6	229.6	229.6	2.236	1148.1
3.5	228.8	228.7	228.7	228.7	2.236	1143.6
4	227.5	227.5	227.5	227.5	2.236	1137.4
4.5	225.9	225.8	225.8	225.8	2.236	1129.1
5	224.7	224.8	224.7	224.7	2.236	1123.6
6	220.7	220.8	220.8	220.8	2.236	1103.8
7	218.1	218.1	218.1	218.1	2.236	1090.4
8	214.7	214.6	214.5	214.6	2.236	1072.9
9	212.3	212.3	212.3	212.3	2.236	1061.4
10	209.5	209.5	209.5	209.5	2.236	1047.4
20	197.9	198.1	198.2	198.1	2.236	990.3
30	142.9	142.9	142.6	142.8	2.236	714.0
40	24.28	24.28	24.28	24.3	2.236	121.4
50	18.28	18.28	18.28	18.3	2.236	91.4
60	24.26	24.26	24.26	24.3	2.236	121.3
70	18.75	18.75	18.75	18.8	2.236	93.7

Table 12 Lighting performance of **YELLOW** signal lights powered by DC power source (current output 0.5A). The actual power consumption of Yellow light is approximately 17.35 Watts)

YELLOW signal lights, 0.5A, Wattage 17.35 W

Angle in deg	Illuminance (Lux)	Illuminance (Lux)	Illuminance (Lux)	Average E (lux)	distance (meter)	Intensity (cd)
0	331	331	331	331.0	2.236	1654.9
0.5	333	333	333	333.0	2.236	1664.9
1	334	334	334	334.0	2.236	1669.9
1.5	336	336	336	336.0	2.236	1679.9
2	339	339	339	339.0	2.236	1694.9
2.5	341	341	341	341.0	2.236	1704.9
3	343	343	343	343.0	2.236	1714.9
3.5	345	345	345	345.0	2.236	1724.9
4	346	346	346	346.0	2.236	1729.9
4.5	347	347	347	347.0	2.236	1734.9
5	347	347	347	347.0	2.236	1734.9
6	348	348	348	348.0	2.236	1739.9
7	347	347	347	347.0	2.236	1734.9
8	346	346	346	346.0	2.236	1729.9
9	345	345	345	345.0	2.236	1724.9
10	342	342	342	342.0	2.236	1709.9
20	305	305	305	305.0	2.236	1524.9
30	246	246	246	246.0	2.236	1229.9
40	46.4	46.4	46.4	46.4	2.236	232.0
50	31.3	31.3	31.2	31.3	2.236	156.3
60	31.4	31.4	31.4	31.4	2.236	157.0
70	18.91	18.92	18.92	18.9	2.236	94.6

Next, with satisfactory laboratory lighting and thermal performances, we have conducted the closed-course performance and reliability tests of the fully working prototypes mounted on the roof of the University of Kansas engineering complex - M2SEC building. All signal lights were powered by the signal controller cabinet with real signaling time cycles. Figure 4 shows the test setup on the roof, including the power cabinet, the signal lights mounted on the tripod, a data logger mounted on the tripod pole, and a total of 12 temperature sensors mounted on each of the surfaces of the signal lights (4 sensors on each signal light lens), and one more ambient temperature sensor attached on the pole covered in a solar shader to prevent the impact of solar heat on the ambient temperature sensor. The roof tests have been conducted for several weeks and are still ongoing for adjustments. The temperature data were recorded every 10 seconds continuously over the entire test period. Table 13 shows example test results of the roof tests.

Figure 4 The closed-course performance and reliability tests of the fully working prototypes mounted on the roof of the University of Kansas engineering complex - M2SEC building. All signal lights were powered by the signal controller cabinet. The test setup on the roof includes the power cabinet, the signal lights mounted on the tripod, a data logger mounted on the tripod pole, and temperature sensors mounted on the surfaces of the signal lights.

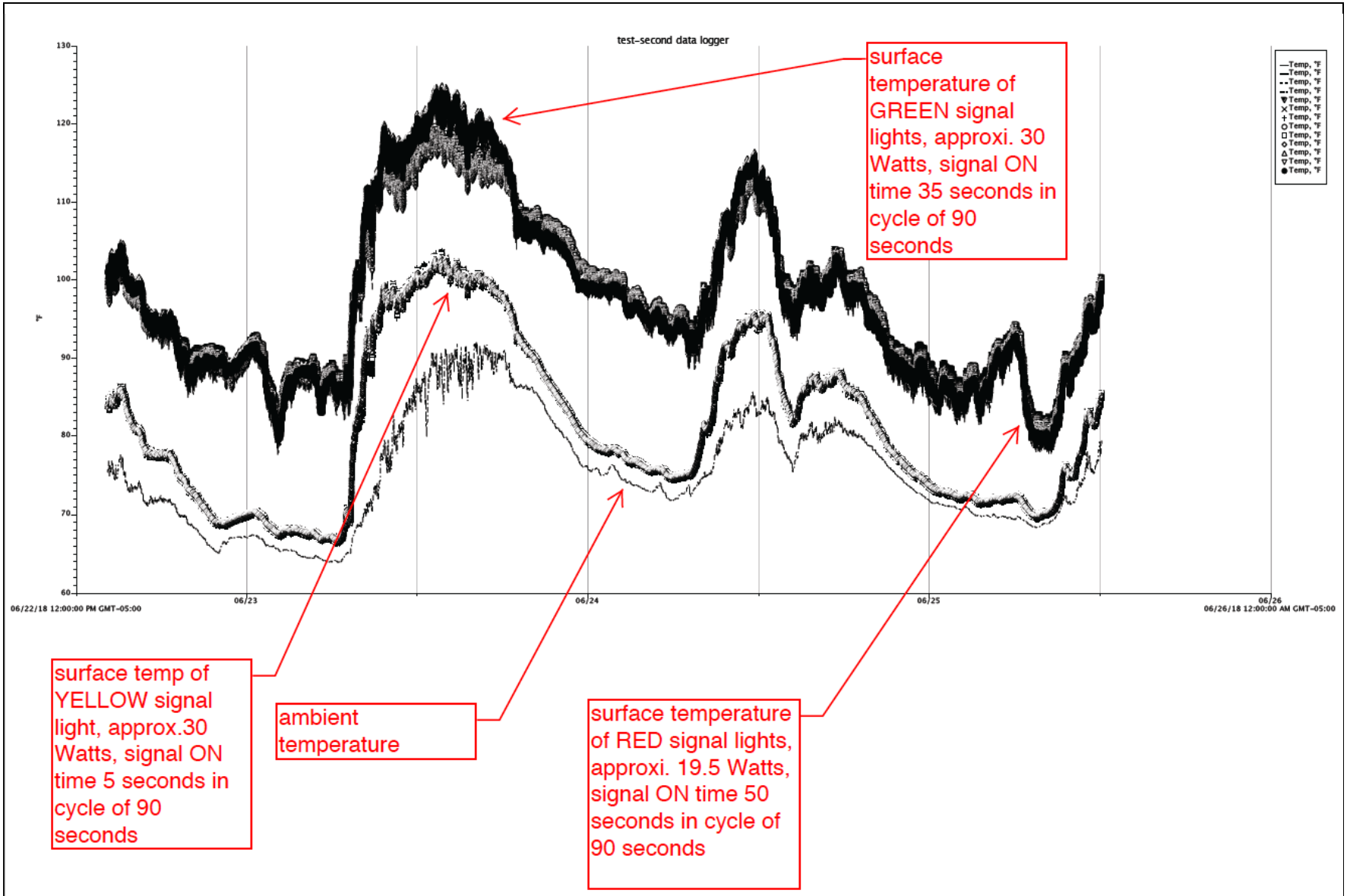


Table 13, temperature test results of RED, YELLOW, and GREEN signal lights mounted on the roof of M2SEC building

Table 13 shows only a portion of the test data, which were recorded in three continuous days. Based on Table 13, it is discovered that the temperature variation due to the on/off signal timing circle of each signa light powered by the cabinet is insignificant, meaning the surface temperature of each signal lights (RED, YELLOW, GREEN) would remain almost stable with insignificant changes when the signal light is on its off mode. Yet significant surface temperature increase was observed when the signal light was facing the sun with significant solar heat gain. As a result, new custom-made LED drivers for RED signal light are necessary with specifications of aforementioned.

The roof tests are still ongoing with possible adjustments of the signaling cycles. For example, we are testing Red signal light which is ON for 50 seconds or longer in a cycle length of 90 seconds. For the green light LEDs, signal light ON time is 35 seconds or longer every 90 seconds. Similarly, for the yellow light LEDs, the signal light ON time is only 5 seconds. Further test results will be used for evaluation of the readiness of the fully working prototypes for field tests in the upcoming winter season.

Anticipated work next quarter:

Starting from July 1, 2018 till Sept. 30, 2018, we are planning to conduct the following tasks.

1. The molding company will continue making products of the LED signal housing for field tests.
2. Custom-made LED light engines and all other electronics, including the new types of LED drivers with temperature sensor will be ready for assembly.
3. Identify field test sites and test specifications at each site with the aid of sponsor states. Field trips will be tentatively scheduled.
4. Final fully-working prototypes for field tests will be ready for field tests.

Significant Results:

As of June 30, 2018, 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 (Figure 2), 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, Figure 5).

- 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 (Figure 2) 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

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.