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) ☐ Quarter 2 (April 1 – June 30) X Quarter 3 (July 1 – September 30) ☐ Quarter 4 (October 4 – December 31)	
Project Title: Self De-Icing LED Signals		
Project Manager: Carla Anderson	**Phone:** 785-296-0357	**E-mail:** Carla.anderson@ks.gov
Project Investigator: Hongyi Cai	**Phone:** 785-864-2597	**E-mail:** hycai@ku.edu
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	$144,310	55%

Quarterly Project Statistics:

Total Project Expenses This Quarter	Total Amount of Funds Expended This Quarter	Percentage of Work Completed This Quarter
$21,454	$21,454	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.

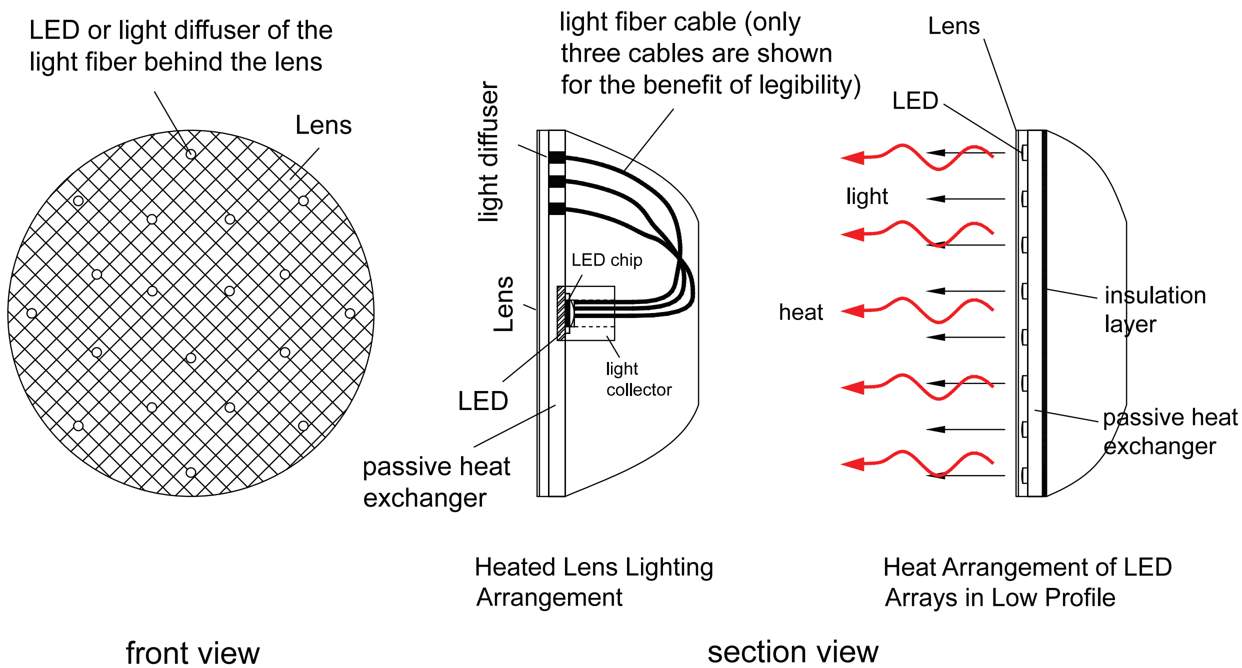


Figure 1 The concept of the self de-icing LED signal light, which adopts new architecture of "Heated Lens Lighting Arrangement" or "Heat Arrangement of LED Arrays in Low Profile"

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 third quarter (July 1, 2018 – September 30, 2018) of the project period, we have the following accomplishments.

First, we have been testing the closed-course performance and reliability of the prototypes previously mounted on the roof of M2SEC building (**Figure 1**). 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 signaling time cycles are adjustable, might be adjusted in the upcoming winter season for testing different cycles. We recently replaced the existing power extension cord connecting the cabinet on the roof to a wall outlet with two 100 ft heavy-duty contractor grade outdoor extension cord, to satisfy the fire code requirements by long-term tests on the roof. A data logger mounted on the tripod pole was connected to 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. 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.

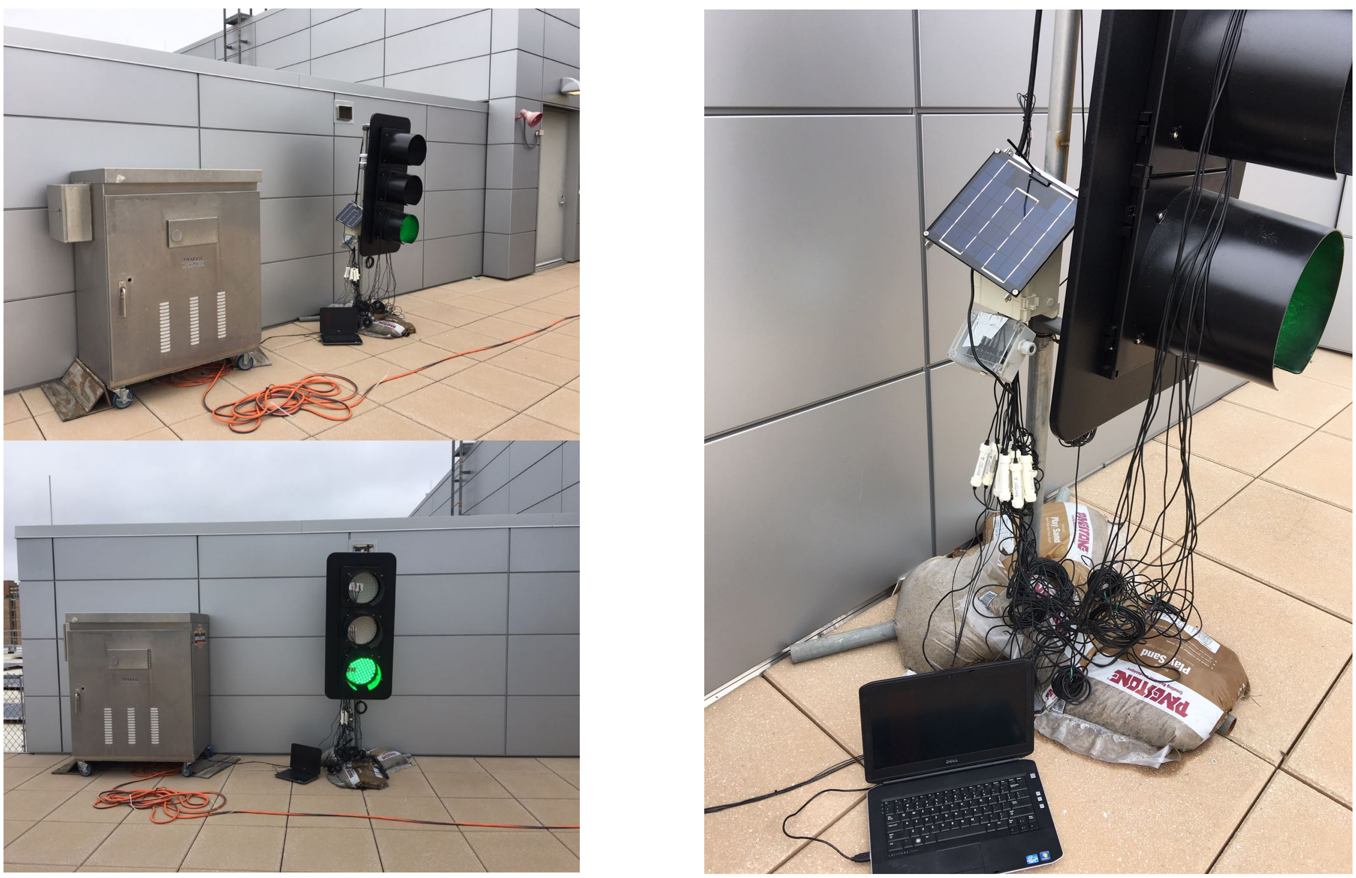


Figure 1 The closed-course performance and reliability tests of the fully working prototypes mounted on the roof of M2SEC building. The roof tests will be continuously conducted in 2019 with necessary real-time adjustments.

Figure 2 shows a typical daily test results recorded on 08/27 under cloudy sky. Based on the data, it is discovered that the temperature variation due to the signals being on/off in each signal timing circle is insignificant, meaning the surface temperature of each signal lights (RED, YELLOW, GREEN) would remain almost stable without much drop when the signal light is off in its timing cycle. The surface temperature of each signal light was mostly in consistency with the ambient temperature of the air. Yet significant surface temperature variations were observed when the signal light was facing the sun in the morning with significant solar heat gain when the sun was visible or without solar heat gain when sun was hidden behind the cloud.

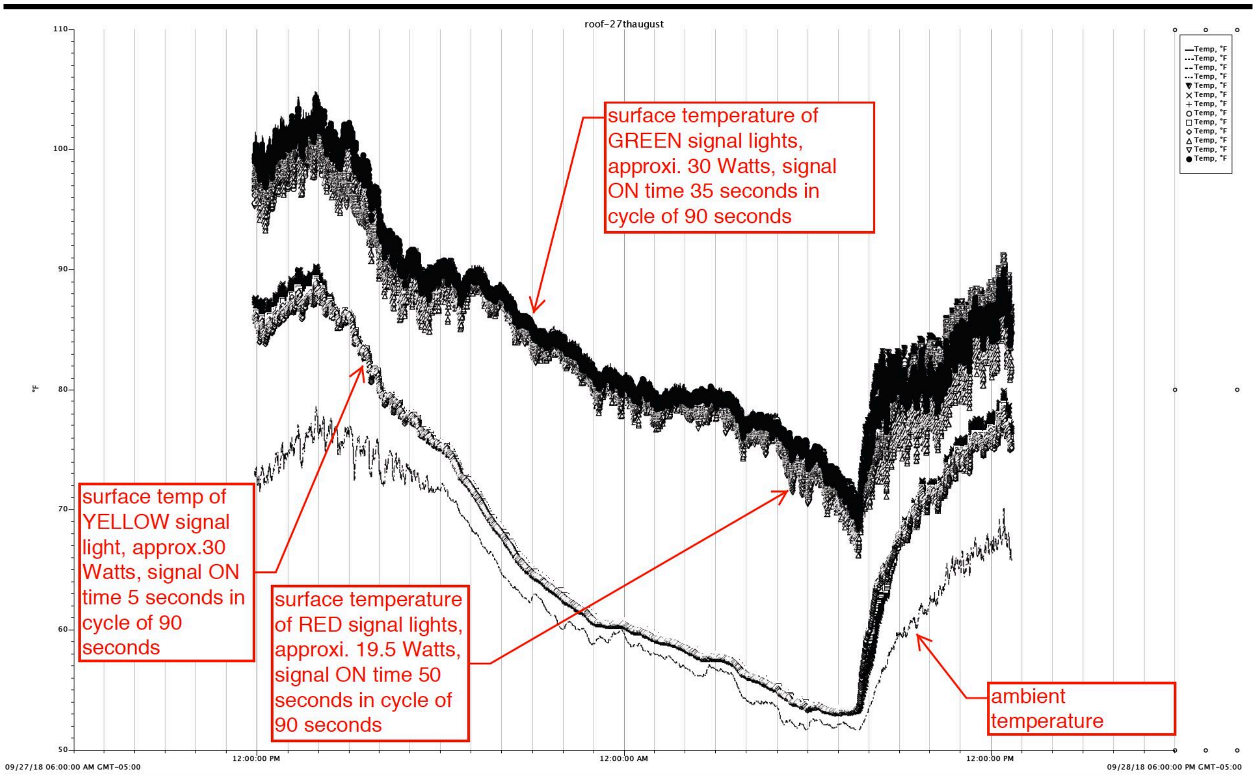
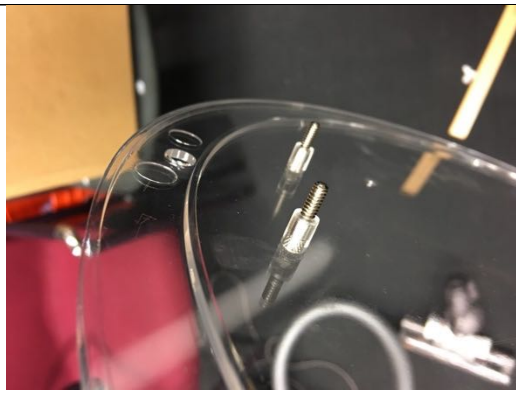


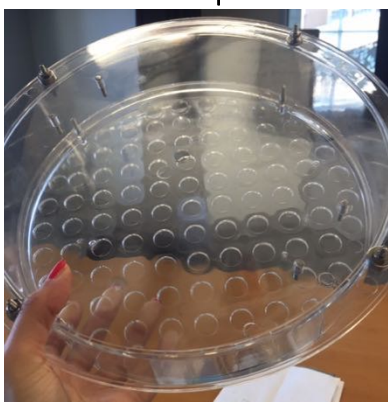
Figure 2 A typical day portion of the test data recorded on Aug 27, showing surface temperature changes with ambient air temperature and solar heat gain in the morning.

Second, in the present quarter, we have designed and custom made new types of screws (**Figure 3**, the bottom pictures) 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. As shown in **Figure 3**, the original screws we used have no head, which could not resist the rotation when tighten using tools. Later, the screws were improved with a rectangular head, which had proven increased connection strength of the screw in the plastic housing but still not strong enough to prevent pulling off from the housing. Moreover, the improved screws were not easily to make in factory. As a result, we have self designed and custom made new screws in a factory for mass production, as shown in Figure 3 in the bottom pictures, which are finalized screws for new housings in the field.



Old screws in samples of housing

Sample of old screw without head



Improved screws in samples of housing current tested on roof

Improved screws with rectangular head, replacecd with custom made screws below

Finalized new screws in samples

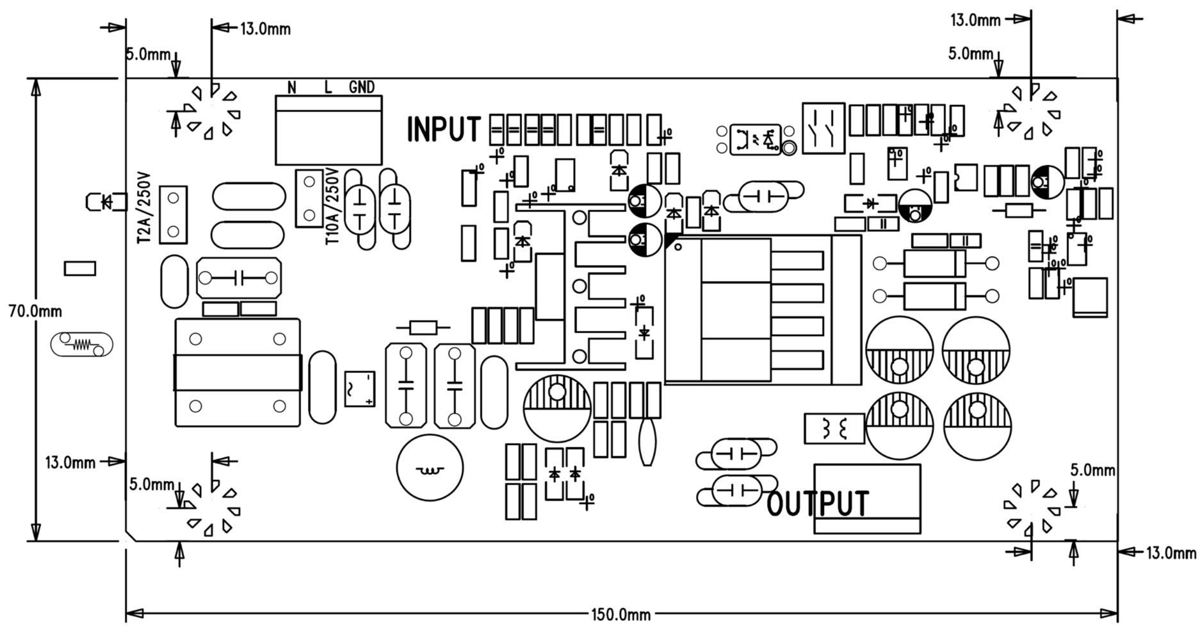
Finalized new screws, self design, custom made

Figure 3 Three generations of screws used in the plastic housing. The top pictures show the original old screws with no head, which could not resist the rotation when tighten using tools. The pictures in the middle show the improved screws 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 pictures at the bottom show the self-designed and custom-made new screws in final products of mass production, which have been used in the finalized design of the new housing.

Third, we have designed and custom made two types of LED drivers, as shown in **Figure 4**, 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 (**see Figure 4**) for controlling the power output in light of the ambient air temperature. The PCB default output will be 100% in case the temperature sensor fails. Additionally, an on/off switch is designed for temperature controls in winter and summer modes which could override the operation of the temperature sensor. There will be 100% output if temperature control is switched to off. The switch is used for testing purpose and product quality control. In real operation in the field, the switch will be turned on as default and the temperature sensor will automatically control the power output of the signal lights, by following the rules below:

A. When the air temperature is above 4 degree Celsius, the driver output will be derated and should be the following
   - For Yellow + Green LED lights, output current 0.5 A, 17- 18 Watts
   - For Red LED light, output current min 0.6 A, 15-16 Watts

B. In comparison, when the outdoor temperature reaches 4 degree Celsius or lower, or in case the temperature sensor is turned off or failed for any reasons, the driver output should be the default 100% as following:
   - For Yellow + Green LED lights, output 0.8 A, maximum 30 Watts
   - For Red LED light, output 1.1 A, maximum 30 Watts



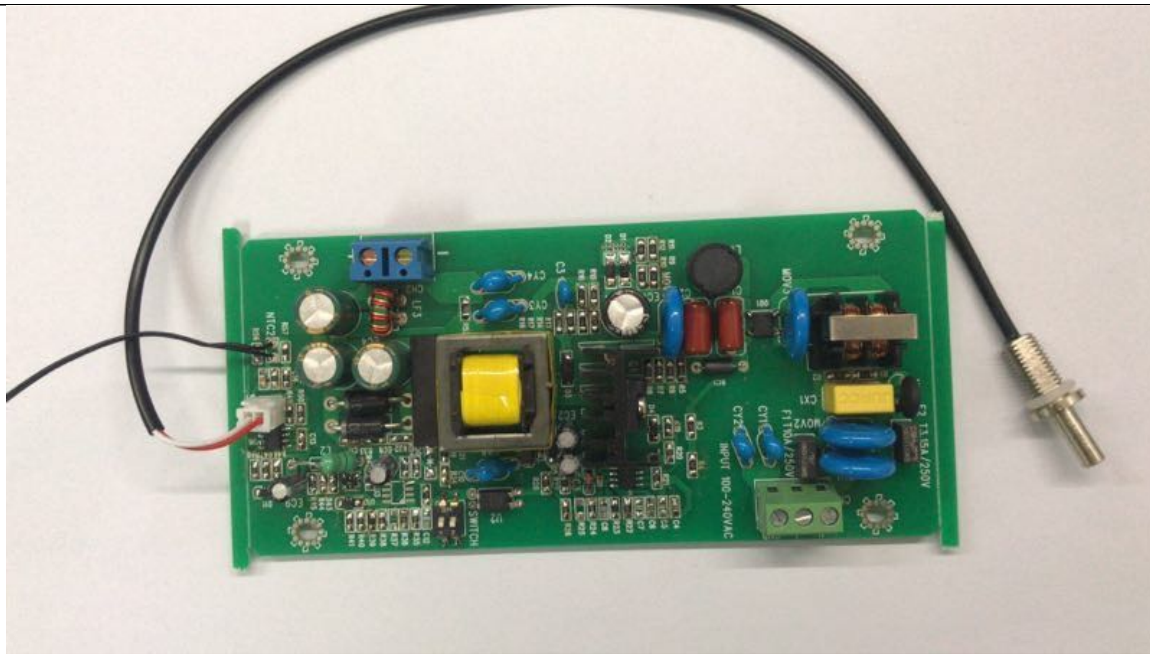
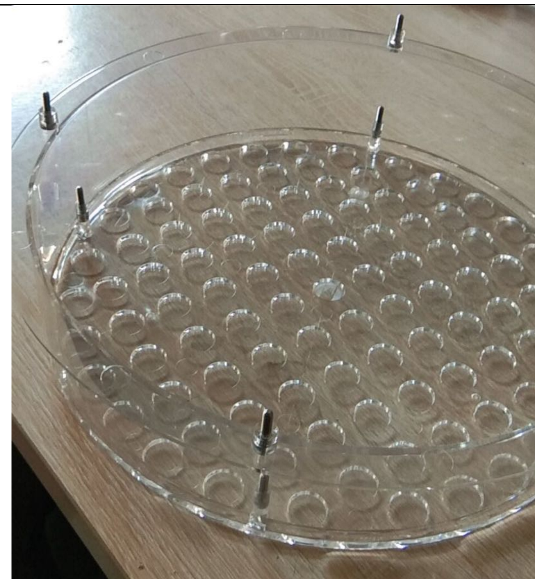
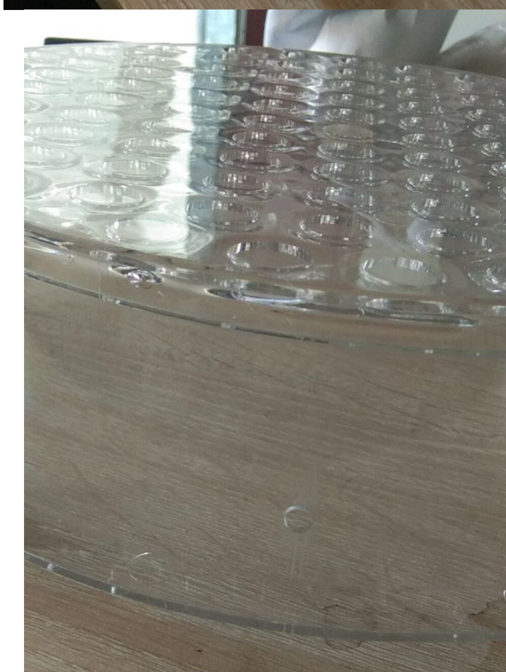


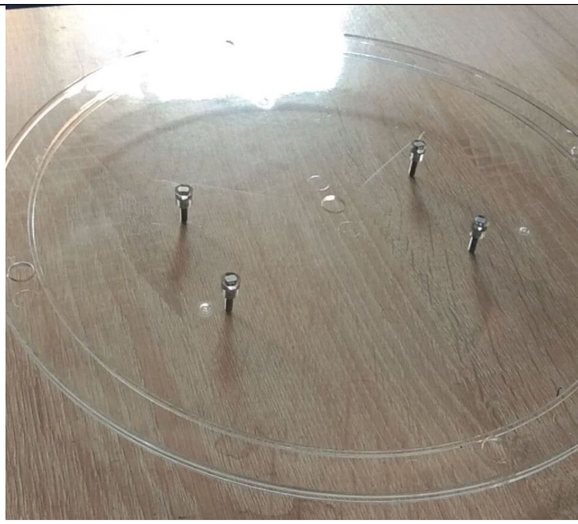
Figure 4 The finalized design and a sample product of the new custom-made LED drivers, including one type for red light (input: 100-240 VAC, output: 0.6-1.1 A, max 30 W), and a second type for green/yellow light (input: 100-240 VAC, output: 0.5-0.8 A, max 30 W). Both types of LED drivers are integrated with a remote temperature sensor and an on/off switch for winter and summer modes.

Fourth, 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 (**Figure 5**) of the finalized new plastic housing for validations tests before actual product production. We will start testing those samples in the laboratory and also on the roof of an engineering building – M2SEC building.

- The finalized new screws, as shown in **Figure 3** in bottom pictures, are now used in the new plastic housing (**Figure 5**) with greatly increased connection strength and assembly convenience.
- The adjustment of mounting locations of the LED drivers on the back cover of the housing (**Figure 5**).
- The addition of a new hole/opening on the side of the housing (**Figure 5**) for mounting of the ambient temperature sensor connected to the LED driver.





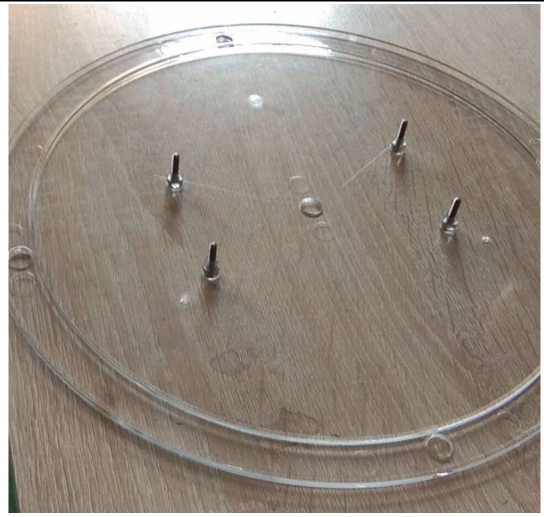
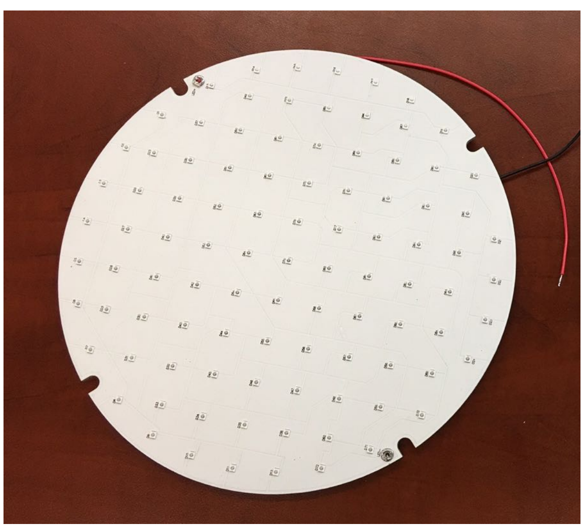


Figure 5 Samples the finalized design of the new housing of the fully working prototype signals of Type 1, prepared for field tests, with changes made to accommodate new screws, new LED drivers, adding a temperature sensor mounting hole in the side surface of part 1 for mounting temperature sensors, and improvement of the surface smoothness during molding process of part 1 with 96 niches for mounting Fresnel lenses.

Fifth, we have produced 60 pcs of the finalized LED engines with the aid of the industrial partner (**Figure 6 a**), ready for the upcoming field tests. We have also updated and custom made 60 pcs of glass disc (**Figure 6b**) 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 (**Figure 6b**) for mounting the glass disc to the LED light engine.



(a) LED engine sample

(a) 60 pcs LED engines

(b) Updated glass disc, custom made

(b) 60 pcs glass discs

(c) Glass disc mounting bar, custom made

Figure 6 Other custom-made pieces in preparation for field tests in the upcoming winter season, including (a) 60 pieces of LED engines as the final products to be tested in the field, (b) 60 pcs of glass discs for the LED engine assembly, (c) custom-made plastic mounting bars for mounting the glass disc in signal lens.

Additionally, we are working on getting improvement on custom-made Fresnal lens (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.

Anticipated work next quarter:

Starting from Oct 1, 2018 till December 31, 2018, we are planning to conduct the following tasks.

1. Assemble all prototypes to be tested in the field sites.

2. Identify field test sites and test specifications at each site with the aid of sponsor states.

3. Initial field trips will be scheduled for field installation and kick off of the continuous testing. In preparation for the remote monitoring of the field tests.

4. Continue conducting roof testing of the prototypes in the closed-setting for continuous improvements.

Significant Results:

As of September 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, 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 (**Figure 1**). 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 (**Figure 3**, the bottom pictures) 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, as shown in **Figure 4**, 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 (**see Figure 4**) 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.

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- We have also updated and custom made 60 pcs of glass disc (**Figure 6b**) 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 (**Figure 6b**) for mounting the glass disc to the LED light engine.

- We are working on getting improvement on custom-made Fresnal 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.

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.