Self De-Icing LED Signals

Project Key Information

This proposed project will develop multiple prototypes of a new type of self de-icing LED signals for highway signalized intersections and railroad signaling applications and validate them using the field tests. The innovative concept — "Heated Lens Lighting Arrangement" — was thoroughly tested in 2014. A non-provisional patent application (No. PCT/US14/53503) was filed on Aug 29, 2014.

A total of $300,000 is needed for this proposed project, for the Pooled Fund. The TRB Rail Safety IDEA program has committed $50,000 and another $50,000 from the TRB NCHRP Highway IDEA program has been committed for a '*Self-Deicing LED Signals for Railroads and Highway Intersection'* Project which is an associated project.

Project Budget:	$300,000 from the pooled fund
Project Duration:	36 months
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Executive Summary

The self de-icing LED signal light is aimed to solve a well-known problem of the existing LED signal light that does not generate sufficient heat in the forward direction towards the lens of the signal necessary to melt snow and ice. Snow and ice can easily accumulate on the lens within the signal hood in wintery conditions and block light to the drivers of vehicles or locomotive engineers. This can decrease the performance of signalized intersections and railroads and also result in collisions in inclement weather conditions. This is a problem in the snowy regions in North America for which a viable retrofit has not been developed or tested.

Most of the electricity consumed by the LEDs actually becomes heat (70%) rather than light [1]. The self de-icing LED signal light has self-efficacy for prevention of the buildup and accumulation of ice, sleet, and snow on the lens of the signals during wintery conditions. There is no need of additional heat generators (e.g., resistance wires or infrared LEDs) and sensors to control them. The self de-icing LED signal light harvests both the light and the heat generated by the same LED, thus, is more energy efficient than the existing "cool" LED signal light.

The new self de-icing LED signals have two significant benefits, including (i) safety and performance efficiency and (ii) overall user cost savings, which are expected to transform the use and operation of the existing signal lights in snowy regions in North America. Once validated in this proposed project, the self de-icing LED signal light is expected to be a viable retrofit to the existing "cool" LED signal lights and other obsolete energy inefficient incandescent signal lights installed at the highway signalized intersections and railroad wayside and at-grade crossings. Additionally, the self de-icing LED signal light is expected to extend into other rail applications (e.g., commuter or light rail), or in other surface transportation applications including airport taxiway/apron lighting and seaport applications located in cold weather zones. Although the self de-icing LED signals are targeted for colder weather regions, they can certainly be installed in warmer climate where they may see only a limited number of cold weather days.

The self de-icing LED signal light is designed as a swappable system with the existing LED and incandescent signal lights to avoid the high cost of replacing an entire system with new equipment. By design, the self de-icing LED signal light does not alter the functions and sizes of the existing signals. No extra installations other than "re-lamping" are needed. There is no need to change anything outside of the signal housing, e.g., additional wiring or increased electric power capacity of the signal controller cabinet. Manual labor to sweep the snow and ice off the lens or paint chemicals on the lens to prevent their buildup is no longer needed. As a result, replacing the existing "cool" LED signals with the self de-icing LED signals can gain an annual overall user cost saving of approximately $28.10/signal light over a service life of 11.4 years, with a payback period of 4.51 years. Given the potential number of signals that can be swapped out with the new ones, the potential payoff for practice is huge. For example, a large community such as New York City with 12,460 signalized intersections can save 8.4 million dollars/year.

The Problem to Solve

Signalized intersections with snow-covered traffic signals must be treated as four-way stop controlled intersections, which increase delay and decrease intersection performance. The drivers of vehicles cannot read the snow-clogged LED signal lights and safely come to a complete stop. This can result in dangerous head-on/rear/crossing collisions. Fig. 1(a) shows an example of the snow-clogged "cool" LED traffic lights which resulted in a fatal crash in 2009 in Oswego, NY. A female driver was killed who was making a left turn on green when struck by a vehicle traveling the opposite direction, because the "cool" LED traffic signal facing the other driver was obscured by snow [2]. Another example is shown in Fig. 1(b). Confused drivers ran the red lights resulting in a crash at the intersection of Smith and Hummel Roads in Brook Park, OH in 2014 [3]. Current solutions to this problem include traffic signal crews sweeping off the snow and ice, as shown in Fig. 1 (c) (d), and painting chemicals to prevent the buildup of snow and ice on the signal lens.

(a) (b) (c) (d)

Fig. 1 Snow-clogged "cool" LED traffic lights and their cleaning off by hand [3, 4]

Snow-clogged railroad signal lights also hinder the normal train operations under snowy and icy conditions. If the locomotive engineers and conductors cannot read the wayside and at-grade crossing signals, the safety is significantly compromised. This can result in dangerous head-on/rear/crossing collisions, collisions of trains with buffer stops, and possible derailment in inclement weather conditions. One example of a snow-covered railroad crossbucks and signal lights is shown in Fig. 2 (a) (b), which resulted in a train/vehicle crash on May 04, 2010 in Winterburn, Alberta, Canada [5]. Additionally, the Transportation Safety Board of Canada investigated a 2010 derailment of a passenger train in Quebec [6]. They found that the wayside signals were snow covered at the time of the incident (Fig. 2 (c) (d)).

(a) (b) (c) (d)

Fig. 2 Snow-clogged railroad signals, (a) the crossbucks and signal lights taken within two hours of the crossing crash [5], (b) the wayside signals with snow buildup on the lens in Quebec [6]

Given that 39 states and over 70% of the population of the United States and the entire country of Canada are located in snowy regions that receive at least five inches of snow each year [7, 8], this problem of snow-clogged "cool" LED signal lights in cold winter is a very typical and expansive problem in which a viable retrofit has not been developed or tested that does not compromise the efficiency, brightness, and operation complexity of the system.

The Concept of the Self De-Icing Signal Lights in Detail

The self de-icing LED signal light adopts a "Heated Lens Lighting Arrangement" (non-provisional patent application No. PCT/US14/53503) to harvest both the light and the heat generated by the same LED for illumination and heating of the signal lens.

This concept is illustrated in Fig. 3 and Fig. 4. One side of a passive heat exchanger (a metal disk) is mounted closely adjacent or proximate to the lens of the new signal light. A single high-power LED is mounted to the other side of the passive heat exchanger at the center, using bolts and nuts, screws, or other types of fasteners. The heat generated by the LED is conducted by the passive heat exchanger to heat the lens for melting snow and de-icing in wintertime conditions. The light emitted from the LED to the back of the signal housing, which is otherwise trapped inside, is redirected back through the passive heat exchanger to the lens using a bundle of light fiber cables. The fiber cables are bundled at the end and connected to a light collector, which is mounted on top of the LED to collect all light. At the other end, each fiber cable is fitted with a diffusive light emitter, which is mounted through a hole on the front side of the passive heat exchanger. The light diffusers of all fiber cables are evenly distributed behind the lens to generate uniform light distribution across the lens.

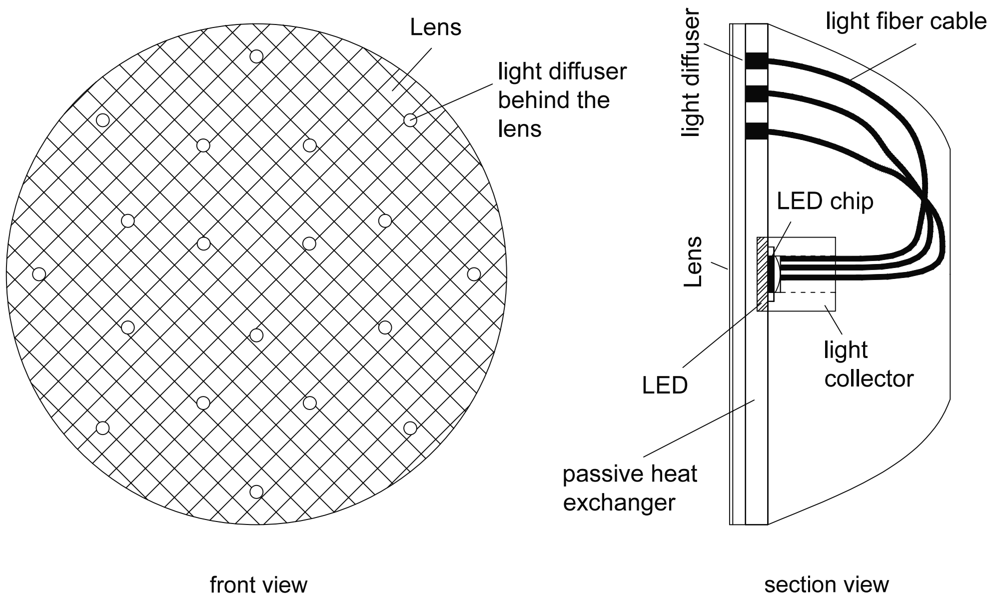

Fig. 3 The front and section view of the self de-icing LED signal light. The heat generated by the LED is harvested by the passive heat exchanger and stored to heat the lens for melting snow and de-icing in wintery conditions. The otherwise trapped LED light is re-directed to the front lens using a bundle of light fibers (only three fibers are shown for the benefit of legibility).

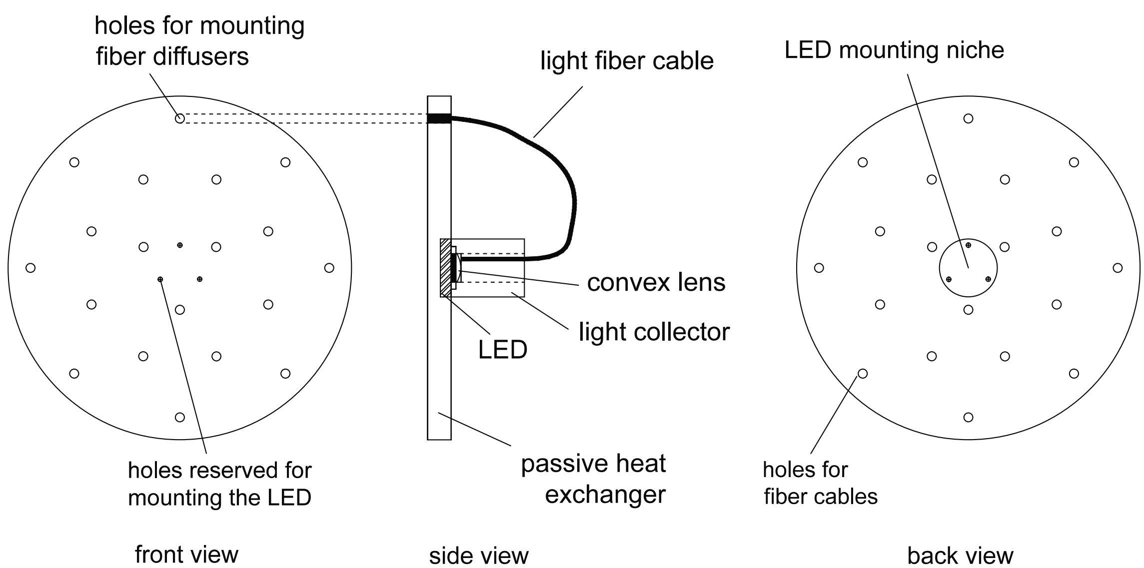

Fig. 4 The re-direction of the LED light through the passive heat exchanger plate using many light fiber cables (only one is shown for the benefit of legibility). The length of the light fiber cables is approximately 1 foot. The light loss during such a short distance of transmission may be negligible. The passive heat exchanger plate has a uniform thickness. On the back of the passive heat exchanger, the LED is surface mounted at the center by sitting in a niche (or flush mounted) using fasteners (nuts & bolts, screws, etc.) and bonded with heat adhesive.

Fig. 5 and Fig. 6 show the deployment of the "Heated Lens Lighting Arrangement" for other types of signals, including arrow signals (Fig. 5), and transit signals (Fig. 6).

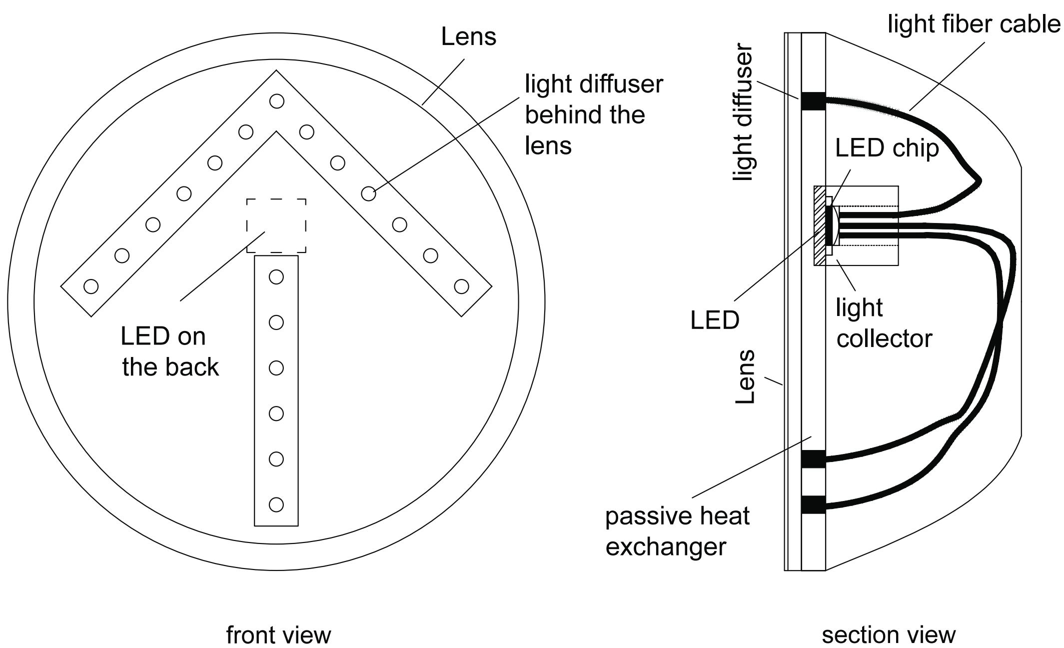

Fig. 5 The deployment of the “Heated Lens Lighting Arrangement” for arrow signals.

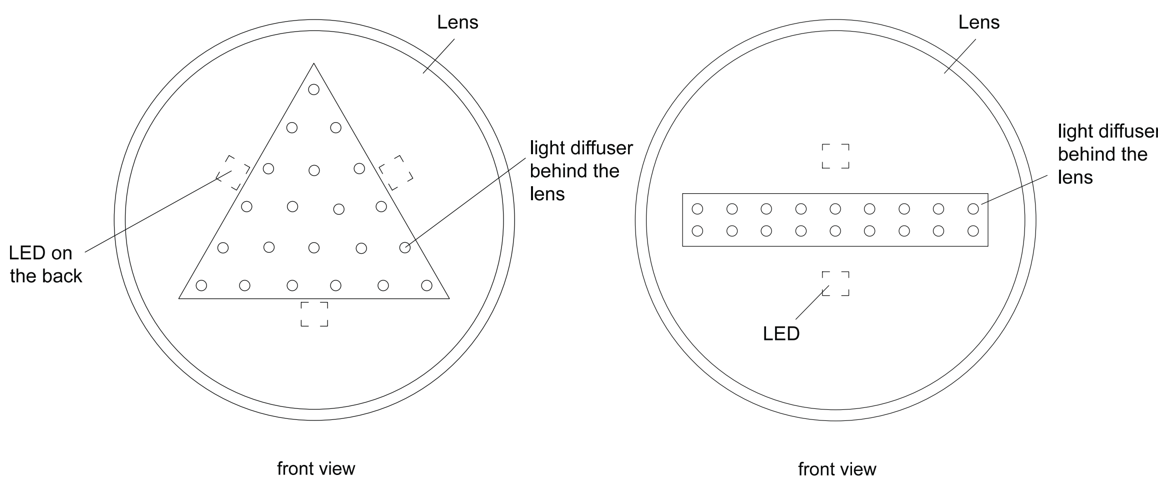

Fig. 6 The deployment of the “Heated Lens Lighting Arrangement” for transit signals.

The high-power LED is highly efficient throughout a reliable life of 100,000 hours (11.4 years). The LED emits either color light (red, yellow, green) or white light for different types of signals. The LED light may be steadily emitted or flashed for different uses, controlled by an LED driver. The LED provides at least the minimum amount of heat and light for suitable year round operations. The surface temperature of the lens will maintain above the freezing temperature of 32° F even in cold wintertime to prevent the buildup and accumulation of ice, sleet, and snow on the lens. Meanwhile, the lens brightness of the signal light will keep higher than the threshold values (365 cd for red light, 910 cd for yellow light, 475 cd for green light) designed to meet the LED signal performance specification of the Institute of Transportation

Engineers [9]. Moreover, the self de-icing signals will meet the regulated safety requirements of individual railroad corporations (for railroad signals), or other national standards, e.g., AREMA (American Railway Engineering & Maintenance of Way Association), NEMA (National Electrical Manufacturers Association), and ANSI (American National Standards Institute).

The shape of the signal lens is usually flat, in some cases curved. The passive heat exchanger behind the lens is correspondingly flat or curved to maintain a constant spacing between the lens and the passive heat exchanger to increase the uniformity of lens surface temperature. This space may be as small as 0 inches (e.g., contact) or larger than about 1/8 inch. The passive heat exchanger needs to be in a shape and size compatible with the lens (e.g., a plate) and extended to the inside of the lens. The passive heat exchanger may be formed from aluminum or aluminum-copper alloy suitable for conducting heat away from the LED. The lens and the passive heat exchanger will be insulated in the housing of the signal.

The self de-icing LED signal light can fit in the housing of the existing “cool” LED signal light and the obsolete incandescent signal light as a perfect replacement. By design, the self de-icing LED signal light does not alter the functions and sizes of the existing signal lights. The existing hood of the signal light assembly can still be used as it is desired for protection of glare and enhancement of the visibility of signals exposed to direct sunlight. There is also no need to change anything outside of the signal housing, e.g., additional wiring or increased capacity of the electric power output of the signal controller cabinet.

Current Performance or Test Data that Give Credibility to the Proposed System

The concept of the self de-icing LED signals has been thoroughly tested in the University of Kansas (KU) Lighting Research Laboratory in 2014. Table 1 summarizes the test results of the lens surface temperature of red, green and yellow LEDs of different wattages in various test environments (e.g., different ambient temperature, relative humidity, air velocity, signal ON time when the signal lights were connected to a traffic controller cabinet). It was proven in the laboratory tests that the red light high power LEDs deployed in the self de-icing signal lights consumed minimum 16.9 - 20.7 watts to maintain the lens surface temperature above the freezing temperature of 32° F at an ambient temperature of below 10° F, when the signal lights were ON for 44 seconds or longer in a cycle length of 82 seconds. For the green light LEDs, the threshold wattage was found in a range of 18.1 to 22.1 watts when the signal light ON time was 35 seconds or longer every 82 seconds. Similarly, for the yellow light LEDs, the threshold wattage was in a range of 17.3 to 20.8 watts when the signal light ON time was not limited.

It was also found that the lens surface temperature, tested at an ambient temperature of 10° F, would remain stable throughout the cycle length of 82 seconds when the signal light ON time was longer than 35 seconds. The lens surface temperature would start to fluctuate when the signal light ON time was less than 30 seconds, which affected the green and yellow light LEDs (red signal lights often have longer ON time). Otherwise, the green light LEDs, when the signal was ON for 10 seconds every 82 seconds, needed to consume more than 50.7 watts to maintain the lens surface temperature above freezing at an ambient temperature of 10° F. The yellow light LEDs, when the signal was ON for only 3 seconds every 82 seconds, consumed 47.8 watts to maintain the lens surface temperature above freezing at an ambient temperature of 19.3° F. It is likely that the green and yellow light LEDs need to consume 50-60 watts to generate sufficient heat within 3-10 seconds to maintain the lens surface temperature above freezing.

Note that the high-power LEDs deployed in the new self de-icing LED signals would need to consume a bit more power than the existing LED signals to maintain the lens surface temperature above freezing. Such a fair amount of increase in wattage is most likely still within the capacity of typical signal controller cabinets because of their extra power capacity by design. A signal circuit is sized for the ultimate load that can be drawn at one time, including, e.g., 300W for controller, 1800W for two GFCI, 116W/pedestrian display, 165W*N for 12” signal lights (N is the total number of vehicle display lamps illuminated at one time, N=1 per 3 section display, N=2 per 4 or 5 section display) [10]. For example, a typical four legged intersection using 12-vehicle heads and 8-pedestrian heads would have signal loads of total 5008W [10].

Table 1 Test results of red, green, yellow LEDs used in the self de-icing LED signals

Type of LED	Lens Materials	Lens gap (inch)	Ambient Temp.(°F)	RH %	Air velocity (m/s)	Lens temp.(°F)		Connected to the traffic control cabinet		Wattage (W)
			Avg.			Avg.	STD	Time On (Sec)	Cycle Time (Sec)	Avg.
Red	Plastic	0.125	44.9	68.8	0.000	102.8	1.8	N/A	N/A	48.0
	Glass	N/A	84.4	38.8	0.012	122.7	6.4	N/A	N/A	48.0
	Plastic	0.125	8.9	44.8	0.012	51.2	1.7	N/A	N/A	42.0
	Plastic	0.125	9.3	47.4	0.012	38.6	1.0	N/A	N/A	21.0
	Plastic	0.125	9.3	49.1	0.012	30.0	0.9	N/A	N/A	13.0
	Plastic	0.125	7.3	39.8	N/A	56.4	3.5	N/A	N/A	31.6
	Plastic	0.125	4.0	40.4	N/A	25.5	1.7	N/A	N/A	12.5
	Plastic	0.125	8.0	41.8	0.012	32.3	2.2	N/A	N/A	16.9
	Plastic	0.125	8.7	54.8	0.012	34.0	2.4	44	82	20.7
Green	Plastic	0.125	24.0	47.7	0.012	75.6	5.7	N/A	N/A	47.8
	Plastic	0.125	50.3	62.8	0.012	150.6	5.2	N/A	N/A	87.5
	Glass	N/A	80.0	49.5	0.012	164.6	12.4	N/A	N/A	52.5
	Glass	N/A	78.6	58.9	0.012	142.6	7.0	N/A	N/A	52.5
	Plastic	0.125	21.6	38.9	0.012	94.5	5.3	N/A	N/A	71.0
	Plastic	0.125	19.5	38.3	0.012	57.4	2.5	N/A	N/A	33.0
	Plastic	0.125	19.5	40.3	0.012	45.7	1.7	N/A	N/A	17.0
	Plastic	0.125	9.9	40.0	N/A	49.1	2.5	N/A	N/A	26.6
	Plastic	0.125	4.7	35.0	N/A	19.4	1.4	N/A	N/A	11.0
	Plastic	0.125	9.3	33.3	N/A	39.4	1.8	N/A	N/A	20.1
	Plastic	0.125	7.7	32.0	N/A	18.3	1.1	N/A	N/A	8.9
	Plastic	0.125	9.9	39.8	0.012	31.5	1.8	N/A	N/A	18.1
	Plastic	0.125	11.5	59.2	0.012	32.5	1.5	35	82	22.1
	Plastic	0.125	10.5	58.9	0.012	28.2	1.4	10	82	50.7
Yellow	Glass	N/A	15.3	58.1	0.012	93.9	10.9	N/A	N/A	60.0
	Plastic	0.125	25.9	44.1	N/A	103.4	6.4	N/A	N/A	61.0
	Glass	N/A	53.0	56.5	0.012	114.5	8.3	N/A	N/A	57.0
	Glass	N/A	78.8	50.6	N/A	159.5	7.8	N/A	N/A	57.0
	Plastic	0.125	77.8	50.6	N/A	153.8	2.7	N/A	N/A	57.0
	Plastic	0.125	5.5	55.2	N/A	94.4	4.5	N/A	N/A	62.0
	Plastic	0.125	5.4	50.3	N/A	53.1	2.3	N/A	N/A	32.0
	Plastic	0.125	4.5	52.2	N/A	30.1	1.2	N/A	N/A	13.0
	Plastic	0.125	9.7	41.4	0.012	39.0	3.0	N/A	N/A	25.4
	Plastic	0.125	3.6	38.8	0.012	13.8	1.9	N/A	N/A	11.3
	Plastic	0.125	8.7	35.1	0.012	34.1	2.7	N/A	N/A	20.8
	Plastic	0.125	6.6	35.3	0.012	13.5	1.3	N/A	N/A	8.7
	Plastic	0.125	9.9	45.8	0.012	31.8	2.3	N/A	N/A	17.3
	Plastic	0.125	19.3	51.5	0.012	32.6	1.9	3	82	47.8

To benchmark the thermal performance of the self de-icing LED signals, the latest GE red light LED traffic lights (10.4 watts) and the traditional light bulb traffic lights (60 watts) were tested in the laboratory. The results are summarized in Table 2. The GE red light LED traffic lights failed to maintain the lens surface temperature above the freezing temperature of 32° F at an ambient temperature of 10° F, which the obsolete light bulb signal lights succeeded in doing. However, the traditional light bulb signal lights also failed to keep their lens surface temperature above freezing when the signal ON time was only 3 seconds.

Table 2 The test results of the GE red light LED and incandescent light bulb traffic lights

Type of light sources	Lens Materials	Lens gap (inch)	Ambient Temp.(°F)	RH %	Air velocity (m/s)	Lens temp.(°F)		Connected to the traffic control cabinet		Wattage (W)
			Avg.			Avg.	STD	Time On (Sec)	Cycle Time (Sec)	Avg.
GE red LED signal	**Plastic**	**N/A**	**2.1**	**72.1**	**0.012**	**9.1**	**3.1**	**N/A**	**N/A**	**10.4**
	Plastic	**N/A**	**39.6**	**90.3**	**0.012**	**49.4**	**1.4**	**N/A**	**N/A**	**10.4**
	Plastic	N/A	80.6	54.3	0.012	85.8	0.8	N/A	N/A	10.4
	Plastic	N/A	77.9	57.3	0.012	87.1	1.8	N/A	N/A	10.4
Incand. Light Bulb signal	Glass	N/A	44.0	75.4	0.012	122.5	25.1	N/A	N/A	60.0
	Glass	N/A	80.8	55.2	0.012	126.0	14.8	N/A	N/A	60.0
	Glass	N/A	80.0	53.9	0.012	163.1	23.3	N/A	N/A	60.0
	Glass	N/A	23.5	52.3	0.012	105.7	24.6	N/A	N/A	60.0
	Glass	**N/A**	**8.3**	**62.6**	**0.012**	**33.0**	**4.3**	**10**	**82**	**60.0**
	Glass	**N/A**	**9.2**	**54.8**	**0.012**	**25.1**	**1.8**	**3**	**82**	**60.0**

Potential Payoff for Practice

a. Overall User Cost Savings and Payback Period Calculations

Once validated in this proposed project, the self de-icing LED signal light is expected to be a viable replacement of the existing "cool" LED signal lights, the obsolete incandescent signal lights, and other emerging LED signal lights using additional heat generators and control sensors. Table 3 lists the estimated annual cost savings for replacing every 1000 incandescent signal lights with the self de-icing LED signal lights, or for comparison, with the existing GE "cool" LED signal lights [11]. The calculated payback time is 2.19 years for the self de-icing LED signal lights versus 2.79 years for the existing "cool" LED signal lights, when they are used to replace the old incandescent signal lights. Compared to the existing "cool" LED signal lights, the self de-icing LED signal lights consume a bit more energy at an annual cost of $2.50 / signal light. However, the self de-icing LED signal lights could save an annual maintenance cost of approximately $30.60/signal light. As a result, replacing the existing "cool" LED signal lights with the new self de-icing LED signal lights can gain an annual overall user cost saving of $28.10 / signal light with a payback period of 4.51 years. For example, for a large community such as New York City that has 12,460 signalized intersections, the estimated total annual user cost savings are approximately 8.4 million dollars. Given a lot of cities in the snowy regions in North America, a significant increase in community savings could be seen.

Table 3 The estimated annual savings per 1000 signals (R, G, B) and the payback period.

Items	Self de-icing LED signal lights			Existing "cool" LED signal lights			Incandescent signal lights
Wattage	25* (R)	26* (G)	55* (Y)	14.5 (R)	16.5 (G)	26.5 (Y)	60 (R, G, Y)
$/KWh	$0.20	$0.20	$0.20	$0.20	$0.20	$0.20	$0.20
Number of signal lights	1000	1000	1000	1000	1000	1000	3000
Unit price	$60.00	$60.00	$70.00	$40.00	$42.00	$43.00	N.A.
Average TimeOn %/cycle	53.66%	42.68%	3.66%	53.66%	42.68%	3.66%	100.00%
Total capacity installed (KW)	9.73			5.43			15.79
Annual energy costs	$17,046.96			$9,513.36			$27,664.08
Maintenance costs per lamp	$0.00			$15 (cleaning off snow and ice)			$26.67 (relamping)
Annual maintenance costs	$0.00			$91,800.00			$163,220.40
Annual operating costs	$17,046.96			$101,313.36			$190,884.48
Total initial investment	$380,000.00			$250,000.00			N.A.
Energy saved per year (KW)	6.06			10.36			N.A.
CO2 emissions avoided (tons)	33.52			57.30			N.A.
Annual energy savings	$10,617.12			$18,150.72			N.A.
Annual maintenance savings	$163,220.40			$71,420.40			N.A.
Payback time	**2.19 years** if replacing incandescent signal lights; **4.51 years** if replacing the existing "cool" LED lights			**2.79 years** if replacing incandescent signal lights			N.A.

*It is presumed, based on the laboratory tests, that the self de-icing red LED signal light consumes 25 watts, the self de-icing green signal light consumes 26 watts, and the self de-icing yellow signal light consumes 55 watts, to maintain their lens surface temperature above freezing at an ambient temperature of below 10° F when the signal ON time is 44 seconds (red), 35 seconds (green), and 3 seconds (yellow) in a cycle length of 82 seconds.

b. Expected Benefits to Transportation Agencies if Implementing the Innovation

If the self de-icing LED signals are implemented in practice, the research team expects to have three significant benefits to the transportation agencies, districts and cities, the railroad companies, and the driving public in the snow-belt states, including:

Safety and efficiency. The self de-icing LED signals can promote safer and more efficient railroad and highway operations in inclement weather than the existing "cool" LED signals. They can enhance safety for the motoring public and reduce vehicle crashes at highway intersections and railroad at-grade crossings, and allow companies to continuously move goods and services through winter conditions safely. Wayside signals not covered in snow can reduce the chances for a derailment or rear-ending another train.

Cost savings. Being swappable with the existing signal lights, the self de-icing LED signal light can avoid the high cost of replacing an entire system with new equipment. The labor costs of traffic signal crews to sweep off the snow and ice on the signal lens can be avoided. The maintenance costs can also be reduced at a rate of approximately $30.60/signal light/year over a long service life (11.4 years). Additionally, a reduction in delay or preventing an at-grade crossing crash will not only save lives, but also potentially save millions of dollars in operations and maintenance costs by avoiding a disruption in highway and rail freight service.

Environmental sustainability. The self de-icing LED signal light harvests both the light and the heat generated by the same LED. There is no waste of energy. It is more energy efficient than the existing signal lights. Thus, the emissions of CO_2 and other greenhouse gases to the atmosphere can be continuously reduced. There is also no need to paint de-icing chemicals on the signal lens, which may be harmful for the lens and local environments.

Investigative Approach

a. Literature Review

Current solutions to the snow-clogged signal lights include manual labor of brushing snow off of the signal lens and spraying de-icing chemicals on the lens to prevent the buildup of snow and ice. These manual methods are laborious, adding an annual maintenance cost of $30.60 /signal light. Chemicals may also be harmful to the signal lens and the local environment.

To solve this problem, LED signal manufacturers (e.g, GE and Leotek Electronics) and LED signal suppliers (e.g., Traffic Control Corporation) have been trying to develop new technologies. A couple of products have been tested for roadway intersection applications, including the Fortan "snow sentry" cover and the McCain "snow scoop" visor [12]. Nonetheless, those tests have mixed conclusions, lacking of a thoroughly research study. Additional heat generators are added on the existing "cool" LED signals, such as resistance wires on the lens (e.g., patent No. US 20070114225A1, 2007) and infrared LEDs mounted on the circuit board for radiating additional heat to the lens (e.g., Patent No. US8246205B2, 2012). Unfortunately, the heat generators demand additional power consumption from the signal controller cabinet, resulting in additional wiring and energy costs. Resistance wires on the lens may decrease the visibility of the signal light. The heat generators also need sensors to control their activation and deactivation, resulting in additional failing points in inclement weather conditions.

Consequently, the research team believes that a viable retrofit has not been developed or tested by the signal manufacturers and suppliers to melt ice and snow accumulated on the signal lens but not compromise the efficiency, brightness, and/or operational complexity of the system.

b. Research Tasks and the Plan of Work

This proposed research project will develop and test different types of prototype self de-icing LED signals over a project period of three years. Such a long project period is needed because the prototypes need to be tested first in a closed-course setting and then in the field in sequence of two cold winter seasons. The prototypes will cover all types of the existing LED signals used in highway signalized intersections and railroad signaling applications, including highway intersection traffic signals (8" and 12"), repeater signals (100 mm), arrow signals (12"), pedestrian signals (12", 16"x18"), railroad wayside signals (5 ½", 8", 12"), rail transit signals (12"), rail level crossing signals (6", 8", 12") in red, green, yellow, lunar, and white light colors.

The plan of work includes nine tasks divided into four stages: (i) laboratory development and tests of the prototype self de-icing LED signals, (ii) tests of the prototypes on the roof of the engineering complex and refinements, (iii) field tests of the prototypes on identified highway signalized intersections and rail track sections as well as on-site demonstration, and (iv) project briefing and final report. Fig. 7 is the schedule chart showing the timing of the tasks, quarterly progress reports, and two milestones. The nine tasks are listed below in more detail.

Project stages	Laboratory development and tests														Tests on the roof						Field tests and on-site demonstration											Final report				
Month	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20	M21	M22	M23	M24	M25	M26	M27	M28	M29	M30	M31	M32	M33	M34	M35	M36
Task 1	■	■	■	■																																
Task 2	■	■	■	■	■	■	■	■													■	■	■	■	■	■	■	■	■	■	■					
Task 3			■	■	■	■	■	■	■	■	■	■	■	■																						
Task 4															■	■	■	■	■																	
Task 5																	■	■	■	■																
Task 6																					■	■	■													
Task 7																												■	■	■	■					
Task 8																																■				
Task 9																																	■	■	■	■
Progress report				X			X			X			X			X			X			X			X			X			X			X		
Milestones																				M1											M2					

M1: Prototypes of the self de-icing signal lights ready for field tests
M2: Field demonstrations of the prototypes under inclement weather conditions

Fig. 7 The schedule chart showing the timing of all nine tasks with two milestones.

<u>Task 1 (Months 1-4): order equipment, components and materials</u>, including high-power LED modules in green, yellow, red, and white light with approximate wattages and lumen output, LED drivers, passive heat exchangers custom made of pure aluminum or aluminum-copper alloy, custom made light collectors (with integrated convex lens) mounted on top of the LEDs, bundles of light fiber cables and light diffusers (with optional mini lens), lens of the signal lights, housing of the signal lights, electricity monitors, waterproof security video cameras for monitoring the performance of the prototypes in the field, other mounting accessories and materials, etc..

<u>Task 2 (Months 1-8, 21-31): collaborate with the project partners.</u> The research team will then work with the Kansas Department of Transportation (KDOT), the Colorado Department of Transportation (CDOT), and all other participating state DOTs, cities and counties (e.g., the Saint Louis County in Minnesota), the Union Pacific (UP) Railroad, the Burlington Northern and Santa Fe (BNSF) railroad, the Leotek Electronics, and the Quanzhou HuaTian Measurement Equipment Company to determine the desired specifications of the prototype signals to be developed and identify the field test sites. Later in Months 21-31, the project partners will further assist the research team in the installation and tests of the prototypes of the self de-icing LED signals in the field to be conducted at Steps 6 and 7.

<u>Task 3 (Months 3-14): laboratory development and tests.</u> Next, the team will build the prototypes in the KU Lighting Research Laboratory. Research and development will be conducted to test different prototypes for their best thermal and lighting performance. Once a prototype is assembled, it will be connected to the traffic controller cabinet to test its thermal performance in a chest freezer in simulated cold and humid harsh environments. The lens surface temperature will be measured using remote sensors wired to HOBO data loggers. The light output and brightness of the signal lens will be measured using light meters, an integrating sphere system, and high dynamic range imaging technology. The sight lines of the lens will also be tested at different viewing angles -90° - 90°, both horizontally and vertically. The prototypes will be improved based on the test results. <u>The judging criteria include</u>: (i) the lens surface

temperature must remain above freezing (32° F) at an ambient temperature 0-10° F; (ii) the peak minimum light intensity of the lens must be higher than the threshold values (365 cd for red light, 910 cd for yellow light, 475 cd for green light) of the ITE requirements [9] or to meet the regulated safety requirements of UP or BNSF railroad corporations.

Task 4 (Months 15-19): closed-course performance and reliability tests. The research team will evaluate the thermal and lighting performance of the prototypes in winter season in a closed-course setting to avoid interruption on people and ground traffic. The prototypes will be mounted on the roof of the engineering complex at KU and powered by the signal controller cabinet. Data to be collected include (i) ambient temperature, humidity, air velocity, lens surface temperature (measured every 10 minutes, 24 hours a day, using remote sensors wired to the HOBO data loggers connected to a computer); (ii) light intensity and lens surface brightness (once every night, using light meters); and (iii) power consumption of each prototype from the controller cabinet (real time, using electricity monitors wired to the signal controller cabinet). The judging criteria include: (i) the lens surface temperature remains above 32° F over the entire testing period in cold wintertime; (ii) no visible buildup of ice, sleet, and snow on the signal lens; (iii) the brightness of the signal light lens is higher than the threshold values designed to meet the regulated safety requirements of the ITE and the UP or BNSF railroad corporations; and (iv) minimum power consumption from the signal controller cabinet.

Task 5 (Months 17-20): refine the prototypes for field tests. Based on the test results on the roof, the prototypes may be further improved and re-tested on the roof if necessary. The refined prototype self de-icing LED signal lights will then be ready for the field tests.

Task 6 (Months 21-23): field trips to the test sites in summer, to set up the field tests on identified highway intersections and rail track sections. Assisted by the project partners, the validated prototypes in the closed-course setting will be installed on pole-mounted signals as backup to the existing primary signals. Backup system will not increase the risk of highway and railroad operations or put anyone or property in harm's way in the real world situation. The research team will commission the prototype signals and conduct a measurement of their initial thermal and lighting performance under the summer conditions. In addition, at each test site, a security video camera will be mounted on a pole top facing the prototype signals at a close distance to monitor their real-time performance for melting snow and deicing in upcoming wintery conditions. The video camera will be set up to record 1 frame per second (FPS), 24 hours a day, for the whole year. The video clips data would better be uploaded online for real-time sharing by the research team and the local project partners. Alternatively, the storage space of the video camera should be at least 100 Gigabytes for continuous recording over 12 months.

Task 7 (Months 28-31): field trips to the test sites in winter. The research team will visit the test sites again to conduct a real-time performance measurement of those prototype signals under wintery conditions with heavy snow and ice. The video data will be retrieved for data analyses. The research team will also hold an on-site demonstration of the prototype signals to the project partners for open discussions on further improvements of the self de-icing LED signals and their future implementation in practice.

Task 8 (Month 32): project briefing. The research team will then visit the state DOTs and the TRB NCHRP Highway IDEA and Rail Safety IDEA committees for a project briefing.

Task 9 (Months 33-36): final report. The research team will write the final project report, including the performance data measured on the roof and in the field, the video files, the on-site demonstrations, and the improved prototypes of the self de-icing LED signals.

Key Personnel and Facilities

Principal Investigator: Hongyi Cai, Ph.D., Assistant Professor in the Department of Civil, Environmental, and Architectural Engineering (CEAE) at KU. Cai holds a Ph.D. from the University of Michigan with expertise in lighting, especially energy efficient LEDs and innovative applications. He worked in the industry as a lighting designer and R&D engineer for new products for several years in New York and China. Cai established the KU Lighting Research Laboratory in 2010 as the PI of a research team. Cai has secured over $420,000 research funds, published 16 journal papers, and presented 22 conference papers. Cai designed and developed multiple innovative LED application technologies and new research instruments for patent applications (with one pending approval). His research group received several international and national awards, including the Besal Scholarships, the IES Young Professionals Scholarships; and the IALD scholarships. Professionally, Cai is a member of the Illumination Engineering Society and the Human Factors and Ergonomics Society. In 2014, Cai received the honor of Miller Scholar at the KU School of Engineering.

Co - Principal Investigator: Steven D. Schrock, Ph.D., P.E., F.ITE, Associate Professor in the CEAE Department at KU. Schrock holds a Ph.D. from the Texas A&M University. He has extensive research experience in transportation engineering. He is the successful PI or Co-PI on 36 research projects totaling over $2.05 million. This work has been predominantly in the areas of highway safety, some of which has included elements of pedestrian and road worker safety. He has published 39 reports, 31 conference proceedings, 13 journal papers, 5 white papers, and 56 technical presentations in the area of transportation engineering, including geometric highway design, traffic flow theory, highway safety, and pedestrian and roadway worker safety. Schrock serves in the Project Panel for NCHRP 17-61 (Work Zone Crash Characteristics and Countermeasure Guidance, National Cooperative Highway Research Program, Transportation Research Board, National Research Council of the National Academies), and Transportation Research Board Committee on Work Zone Traffic Control. Schrock received the honor of Miller Scholar at the KU School of Engineering in 2008 and 2011.

Co - Principal Investigator: Eric J. Fitzsimmons, Ph.D., EIT, Visiting Assistant Professor of Civil Engineering at Kansas State University. Previously, Dr. Fitzsimmons was on staff at KU as a Post Doctoral Researcher. Fitzsimmons holds a Ph.D. from Iowa State University with a specialization in transportation engineering. Dr. Fitzsimmons has developed an extensive knowledge base in vehicle data collection and reduction strategies by working on multiple field-data driven research projects during his graduate career with the Institute for Transportation at Iowa State University. Dr. Fitzsimmons has gained valuable information working with the rail industry on various initiatives and educational course development with Michigan Tech, University of Kentucky, and University of Illinois over the past two years. Kansas State University currently has railroad research underway with the FRA to evaluate new types of concrete ties. Professionally, Dr. Fitzsimmons currently serves as a member of the Transportation Research Board's Traffic Law Enforcement Committee, Operational Effects of Geometric Committee, and Access Management Committee.

Project Partners: the Kansas Department of Transportation (KDOT), the Colorado Department of Transportation (CDOT), other state DOTs in snowy zones, such as Minnesota, Wisconsin, Iowa, and New York, cities and counties such as the Saint Louis County in Minnesota, the Union Pacific (UP) Railroad, the Burlington Northern and Santa Fe (BNSF) railroad, and the Traffic Control Corporation (signal light supplier) will aid the research team in the development and tests of the new self de-icing LED signal light by providing test sites, necessary expertise, advice, and technical help. In addition, the Leotek Electronics (LED signal manufacturer) and the Quanzhou HuaTian Measurement Equipment Company (factory) will assist the research team in custom making the passive heat exchangers, light collectors, and mounting devices, etc. The partners will join the project implementation team to help transfer the technology to practice.

Key Facilities: the KU Lighting Research Laboratory has nearly all of the facilities and equipment that it needs for carrying out the proposed research. In addition to a solid-state-lighting workshop, an LED light measurement system using an integrating sphere, the laboratory has light meters (illuminance meter Minolta T-10/10M, luminance meter Minolta LS-100, Chroma meter Minolta CL-200A, spectrophotometer Minolta CL-500A), power meters, environmental meters (sound level, temperature, air velocity, humidity), infrared camera, Canon cameras and Sigma lenses for high dynamic range imaging, laser distance meters, data loggers and sensors (temperature, humidity), AC/DC power supplies, Onset HOBO data loggers and sensors, etc. Other facilities in the KU Civil, Environmental, and Architectural Engineering Department can also be used, such as the Transportation Engineering Analysis Laboratory in which the signal controller cabinet is stored.

Other Related Proposals

A proposal submitted to the Rail safety IDEA program in 2014 was selected for funding of $50,000. A follow-up proposal was submitted in March 2015 to the NCHRP IDEA program for additional $50,000 (pending).

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