Black Ice Detection Technology

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Background

- Road icing kills more people in US than all other weather events combined (severe thunderstorms, tornadoes, hurricanes and lightning).
  - Bridges and elevated roads freeze first.
  - Even thin layers of ice can be very slippery.

- Slippery black ice can be distinguished from water and other types of ice by simple, self-calibrating, multispectral measurements.

Objectives

- To monitor road conditions and detect ice on roads, bridges and parking areas.
- To warn drivers and maintenance crews so that accidents can be prevented.

Our Patent Protected Optical Detection Technique

- Water and ice can be distinguished from road surfaces and each other by measurements of radiance at a few specific spectral bands.

- Photodetectors, thermopiles and cameras with band-pass filters at appropriate wavelengths can be used to make these measurements.

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(12) **Patent Application Publication**
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(54) **ICE AND SUPERCOOLED WATER DETECTION SYSTEM**

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Related U.S. Application Data

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Publication Classification

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B60T 7/12 (2006.01)
B64D 15/22 (2006.01)
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(52) **U.S. Cl.**
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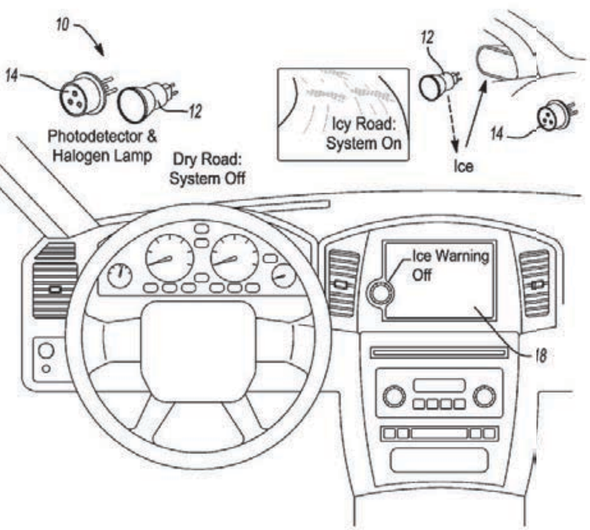
(57) **ABSTRACT**

A system for detecting ice or supercooled large droplets within an area of interest having a detection system measuring radiance or reflectance of the area of interest when exposed to shortwave infrared radiation having a wavelength in the range of about 2.05 μm to about 2.30 μm. The detection system measures the radiance or reflectance in a first band having a wavelength in the range of about 2.05 μm to about 2.15 μm and outputting a first band signal, and further measures the radiance or reflectance in a second band having a wavelength in the range of about 2.15 μm to about 2.30 μm and outputting a second band signal. A processing unit determines a ratio of the first band signal and the second band signal and compares the ratio to a predetermined critical ratio and outputs a determination signal indicating presence of ice or supercooled water droplets.



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(54) **ICE AND WATER DETECTION SYSTEM**

(71) Applicant: **THE REGENTS OF THE UNIVERSITY OF MICHIGAN**, Ann Arbor, MI (US)

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Publication Classification

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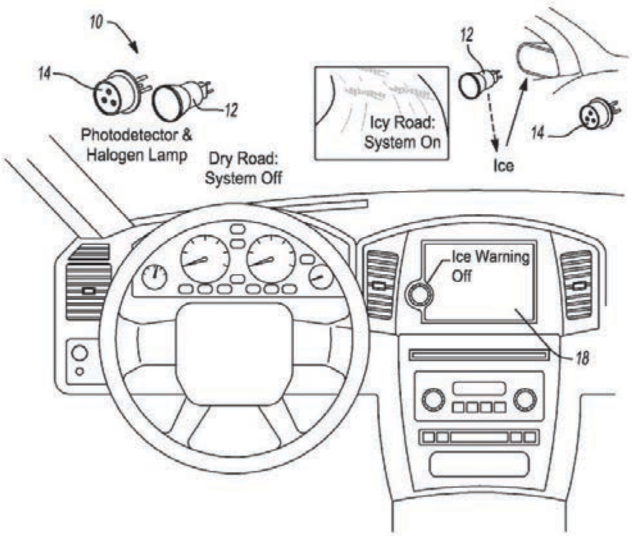
G01N 21/59 (2006.01)

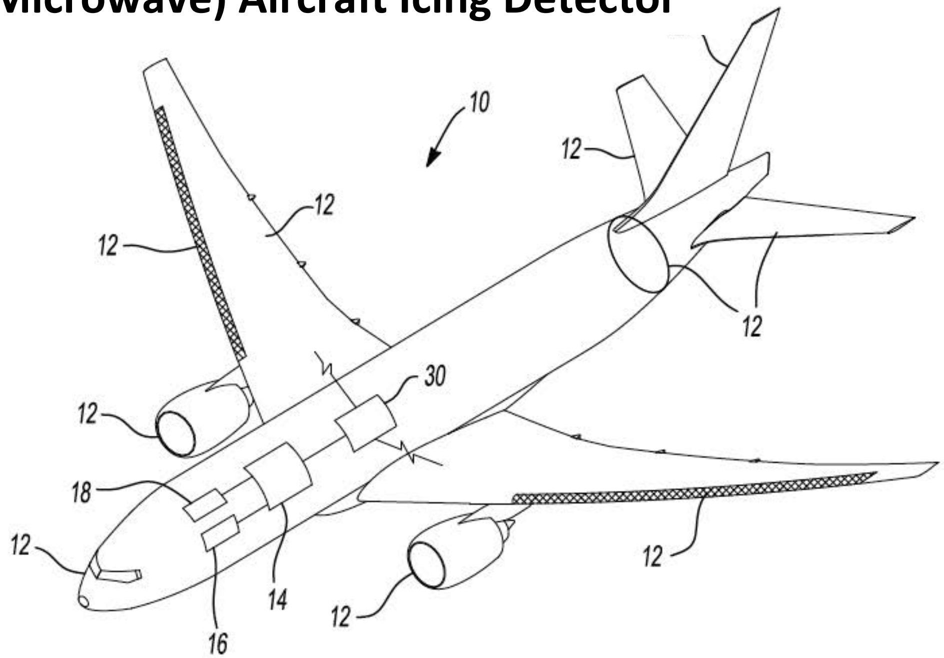
(52) **U.S. Cl.**
CPC ***G01N 21/55*** (2013.01); ***G01N 21/59*** (2013.01); ***B64C 19/00*** (2013.01); ***B60T 7/12*** (2013.01)

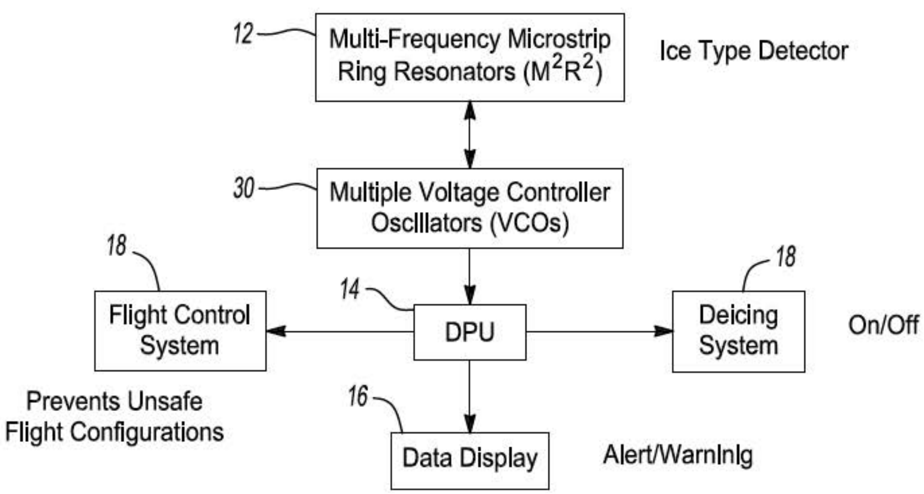
(57) **ABSTRACT**

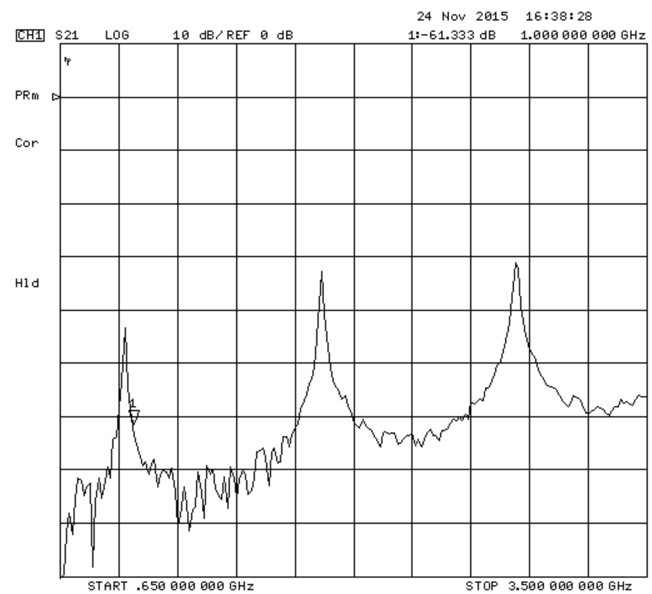
A system for detecting ice or water within an area of interest having a detection system measuring radiance or reflectance of the area of interest when exposed to shortwave infrared radiation having a wavelength in the range containing a cross-over point between the curves representing the absorption of electromagnetic radiation by ice and water. The detection system measures the radiance or reflectance in a first band having a wavelength in a spectral band on a first side of the crossover point and outputting a first band signal, and further measures the radiance or reflectance in a second band having a wavelength in a spectral band on a second opposing side of the same crossover point and outputting a second band signal. A processing unit determines a ratio of the first band signal and the second band signal and compares the ratio to a pre-determined critical ratio and outputs a determination signal indicating presence of ice or water.



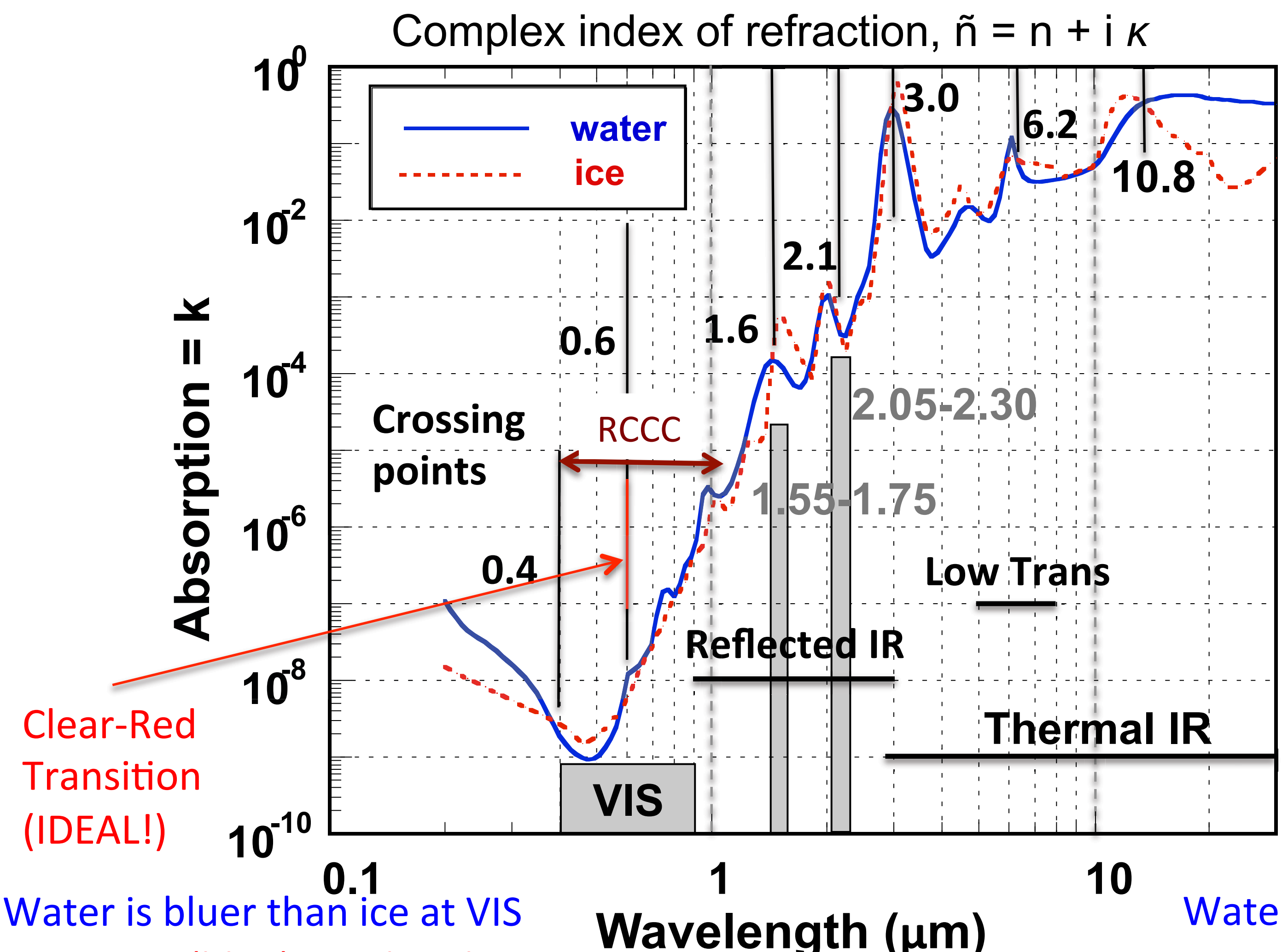
Another Patent Protected Technique:
(Microwave) Aircraft Icing Detector







Absorption Spectra of Water Substance



The 2.05-2.30 µm band is ideal because it is in a water vapor window region **illuminated** by solar radiation. Moreover, water and ice are **strongly absorbing** in this band which is located in the **reflected portion** of the IR spectrum.

Water is bluer than ice at VIS

At 0.5 µm (blue) ice absorbs twice as much radiation as water.

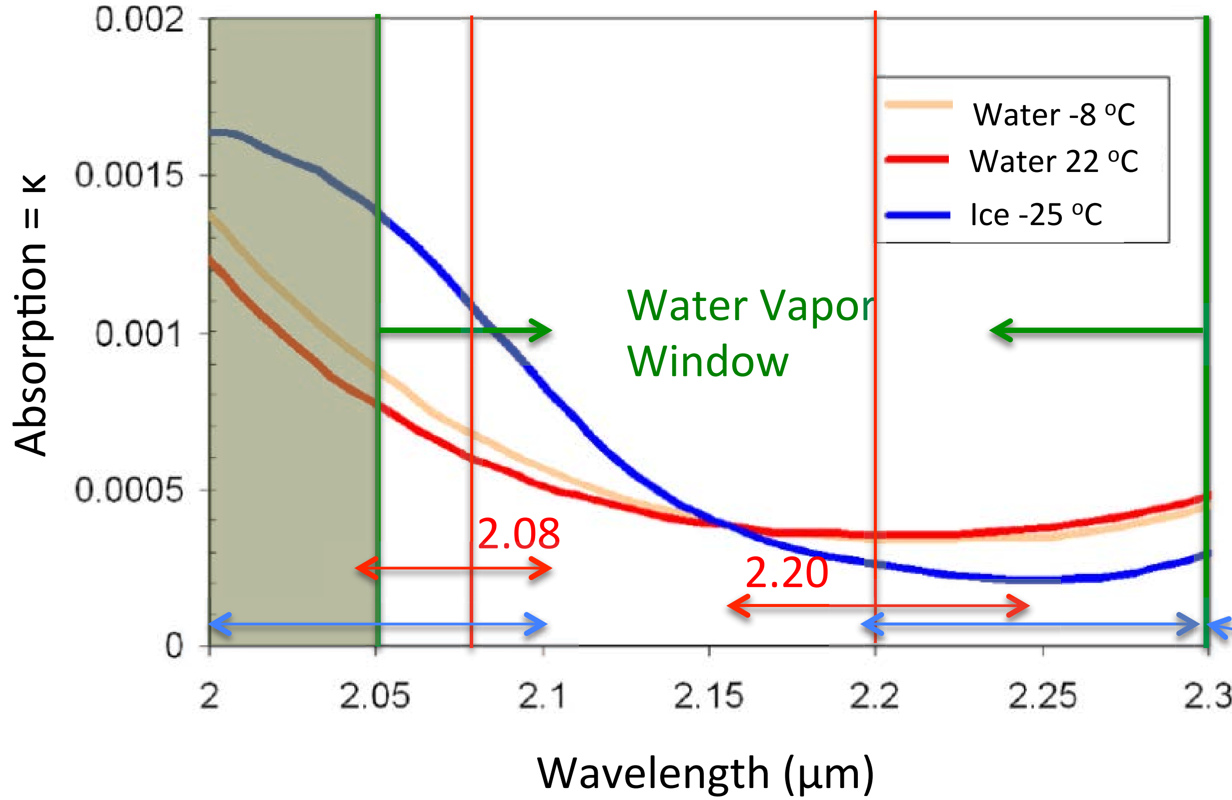
Water is less red than ice at VIS

At 0.7 µm (red) water absorbs more radiation than ice.

The 2.05-2.30 μm Band

Water is “less red” than ice

Complex index of refraction, $\tilde{n} = n + i\,\kappa$



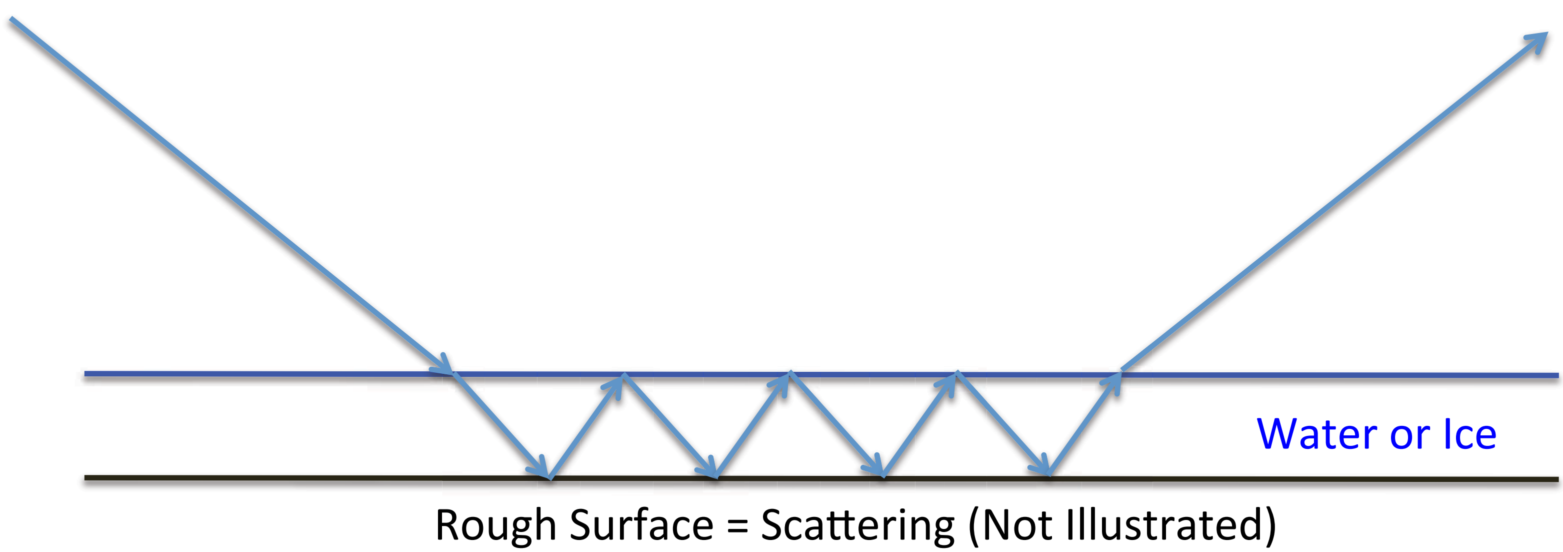
$n = c/v_{ph}$
where v_{ph}
phase speed

κ = absorption

Possible for
increasing
the signal

$\varepsilon = \varepsilon_R + i\,\varepsilon_i$ where $\varepsilon_R = n^2 - \kappa^2$ and $\varepsilon_i = 2\,n\,\kappa$

The Transmittance Signal



Our Spectrogon filters

Filter Number	Crossover Point (µm)	Filter CWL (µm)	Filter HBW (nm)
1	2.15	2.0835	77.5
2	2.15	2.2029	90.3
3	1.6	1.5363	88.3
4	1.6	1.7070	97.6
5	3.0	2.8047	50.6
6	3.0	3.0735	142.4

Theoretical Transmittance Ratios

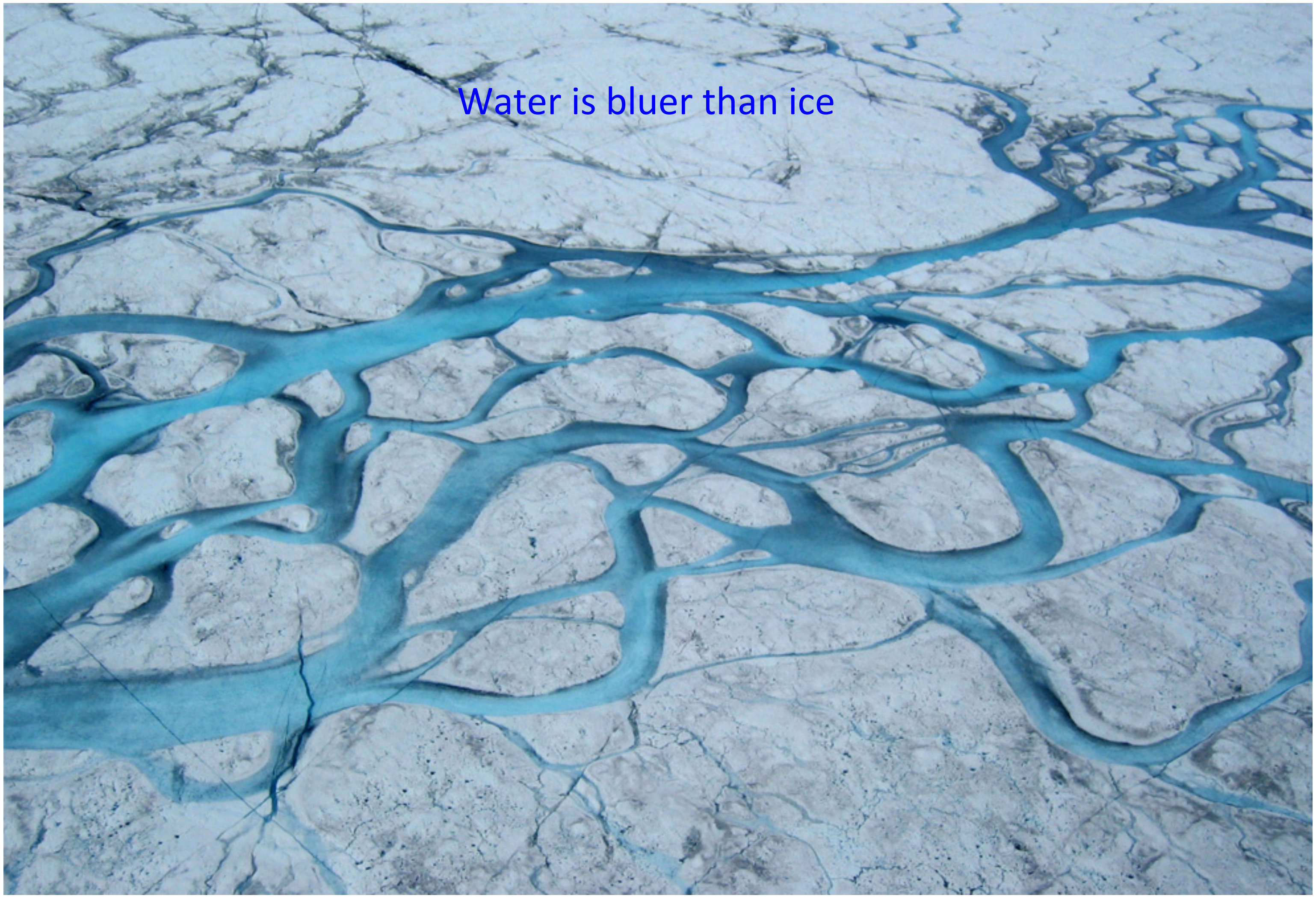
Crossover Point	$(I_{Red}/I_{Blue})_{Water}$	$(I_{Red}/I_{Blue})_{Ice}$	Comment
0.6 µm	0.83 (1 m)	0.95 (1 m)	Water is bluer than ice
1.6 µm	0.50 (1 mm)	0.05 (1 mm)	Water is redder than ice
2.15 µm	0.08 (1 mm)	0.008 (1 mm)	Water is redder than ice

$$\frac{I_{\mathrm{Red}}(z)}{I_{Blue}(z)} = \frac{\exp(-\dfrac{4\pi\kappa_{\mathrm{Red}}z}{\lambda_{\mathrm{Red}0}})}{\exp(-\dfrac{4\pi\kappa_{Blue}z}{\lambda_{Blue0}})} = \exp\left(4\pi(\frac{\kappa_{Blue}}{\lambda_{Blue0}} - \frac{\kappa_{\mathrm{Red}}}{\lambda_{\mathrm{Red}0}})z\right)$$

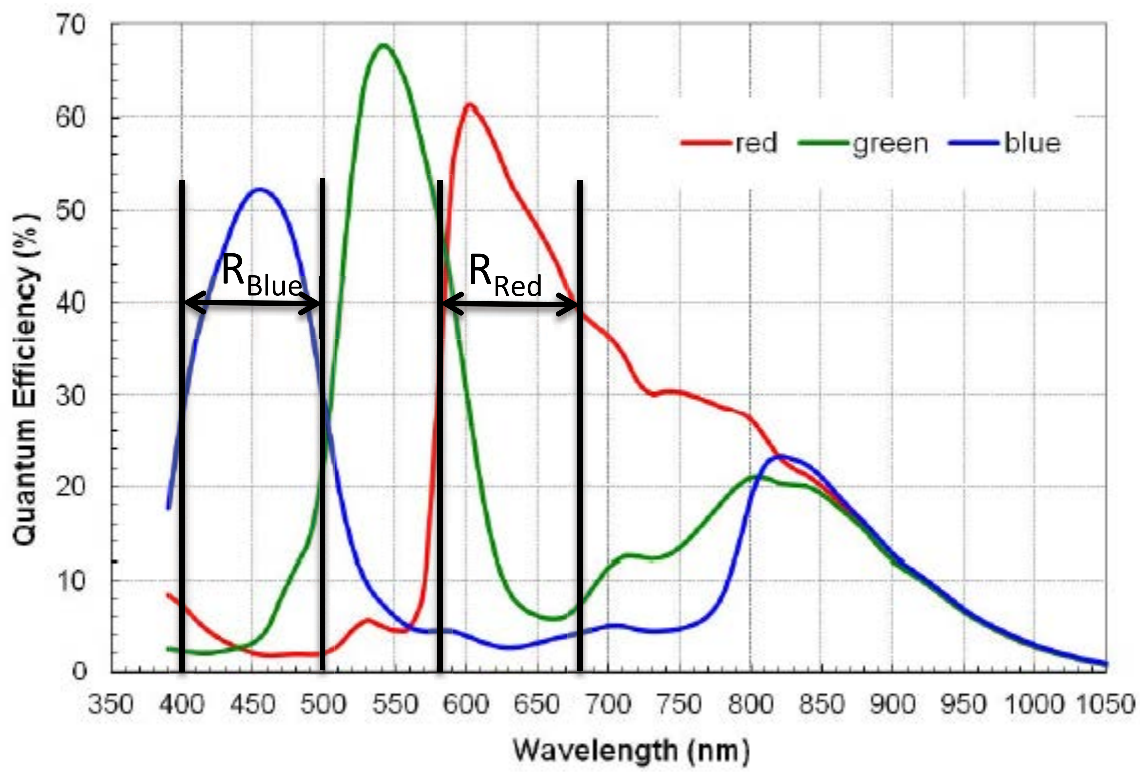
***I* = transmitted signal**, z = path lenght.

At 0.6 µm and 1.6 µm increases in the light path length increases the redness because around these crossover points absorption increases with wavelength. At around 2 µm, the opposite behavior is observed because absorption decreases with wavelength.

Sea Ice



Typical Visible Camera Specs



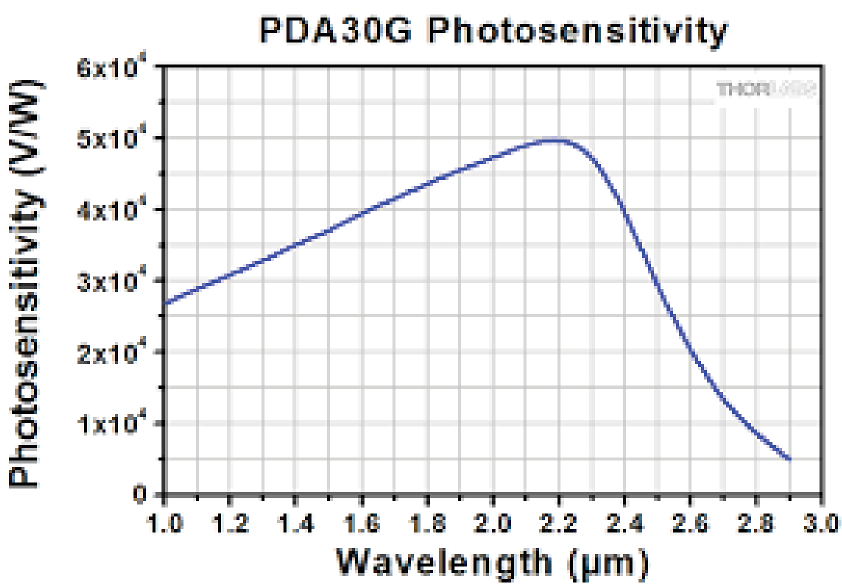
At 1 nm the absorption of light by ice and water is 1000 stronger than in the blue portion of the spectrum...

RCCC Cameras are ideal for detection!

The spectral bandwidth of the Red and Blue bands is about 100 nm.
The QE is about 40% or 0.4.

A Good Performing Detector

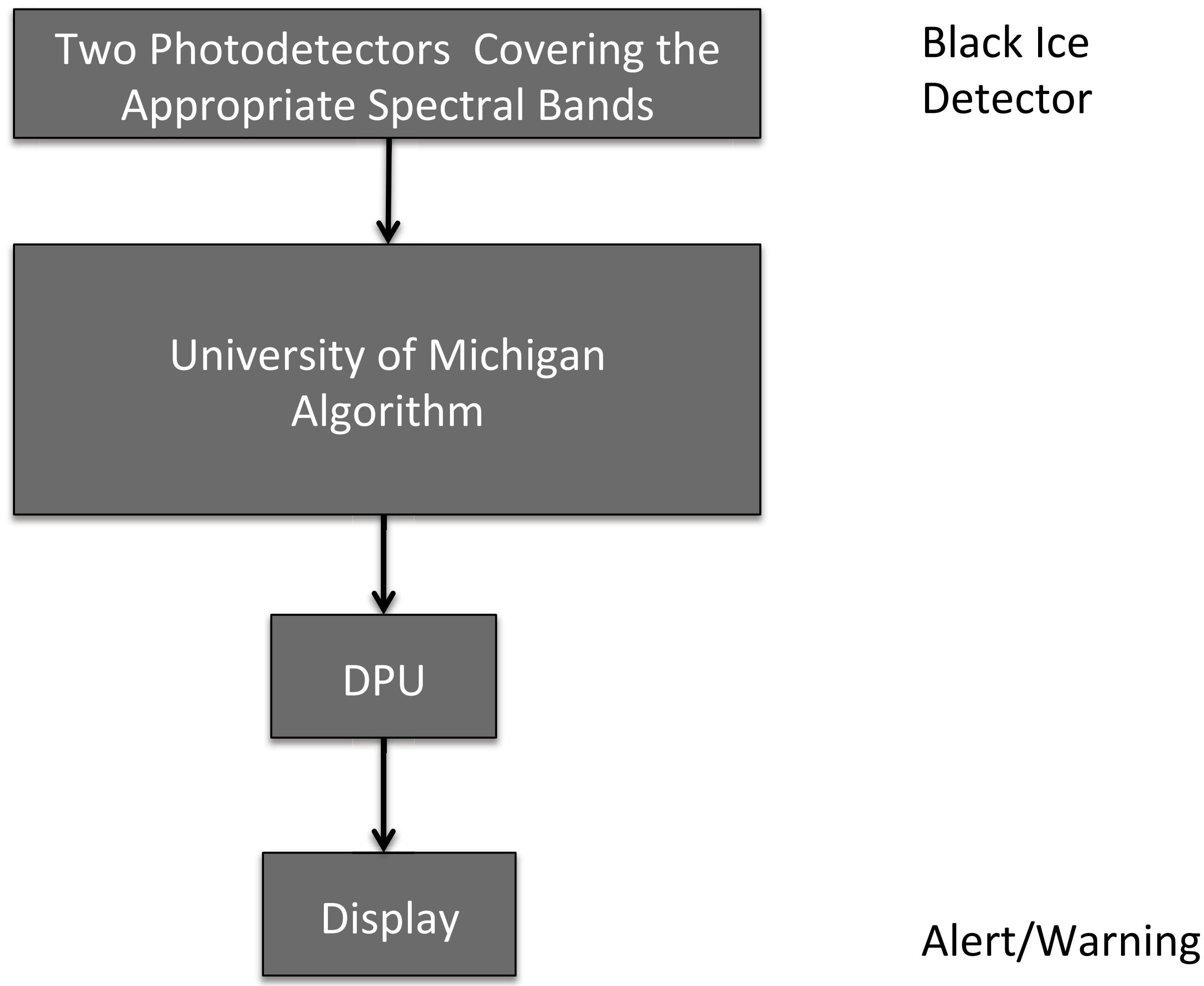
- The PbS Photodetector (PDA30G) sensor



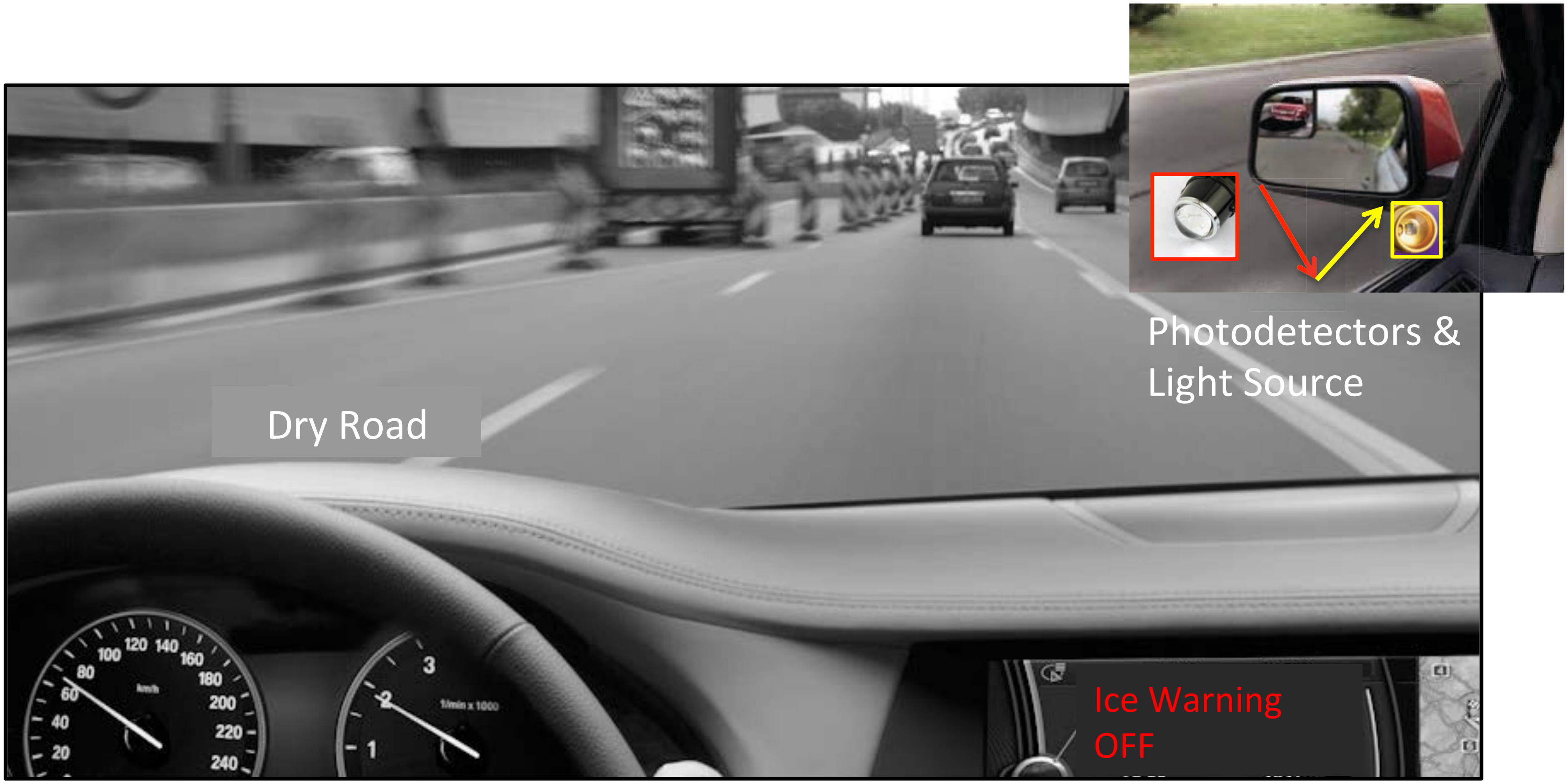
Halogen Automotive Light Source

Brand	CEC Industries
Energy Used	70 Watts
Volts	24
Base	PK22s
Bulb Shape	T-3 1/4
Candle Power	146
Bulb Finish	Clear
Bulb Technology	Halogen
Average Rated Life	150 hs
Class and Filament	C-6
Length	1.65 in
Diameter	0.45 in

System Block Diagram

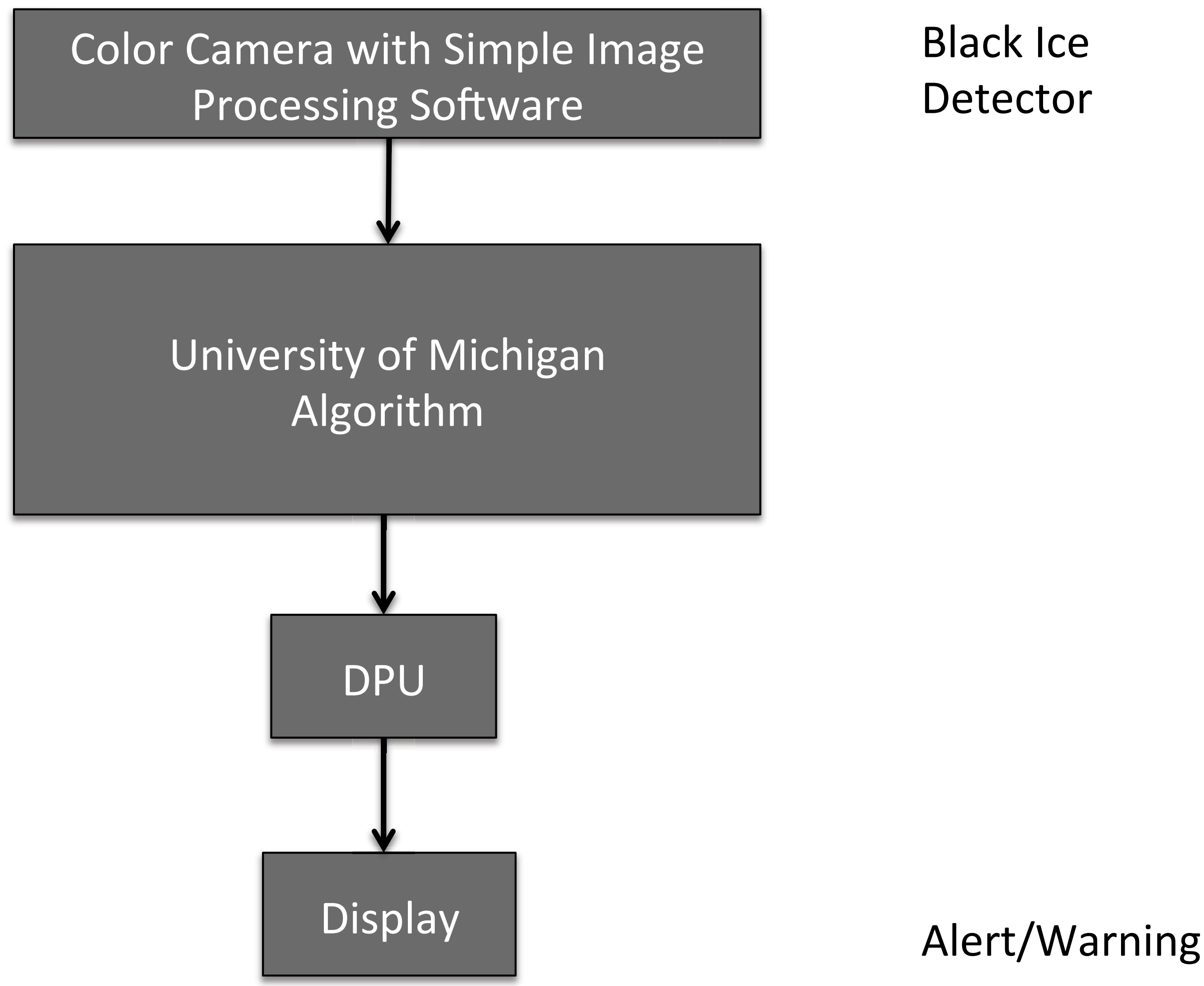


The Detection of Black Ice with Photodetectors



The invention allows the detection of slippery black ice. The black ice is detected via multispectral measurements of a scene illuminated by the sun, by an halogen lamp, or by appropriate LEDs.

System Block Diagram: Another Implementation



The Detection of Black Ice with Cameras

The invention allows the detection of slippery black ice. The black ice is detected via multispectral measurements of a scene illuminated by the sun, by an halogen lamp, or by appropriate LEDs.

Example of Applications: Onboard Warnings and Activation of Road Signs

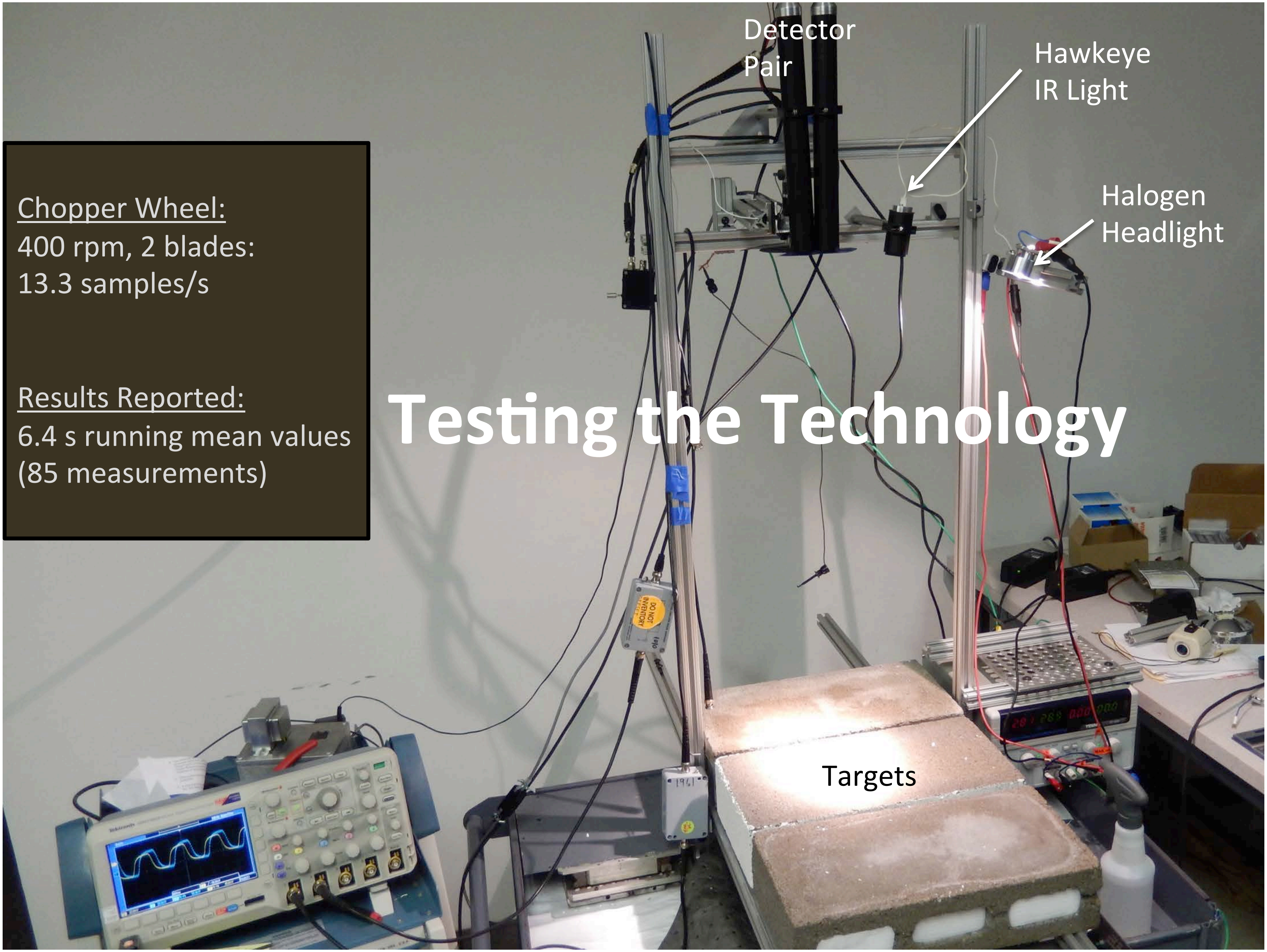
The proposed black ice detector is ideal for detecting slippery conditions on roads and bridges. The detection of black ice can be used to alert drivers as soon as slippery conditions are encountered ahead of the vehicle, on roads, bridges and parking lots.

Detection with a Off-the-Shelf Visible Camera

Testing the Technology

Chopper Wheel:
400 rpm, 2 blades:
13.3 samples/s

Results Reported:
6.4 s running mean values
(85 measurements)



Summary of Results

PbS Detector Signal (V)
Halogen Bulb: LumenFlow Reflector

10 V, 1.57 A Placed about 30° from the vertical

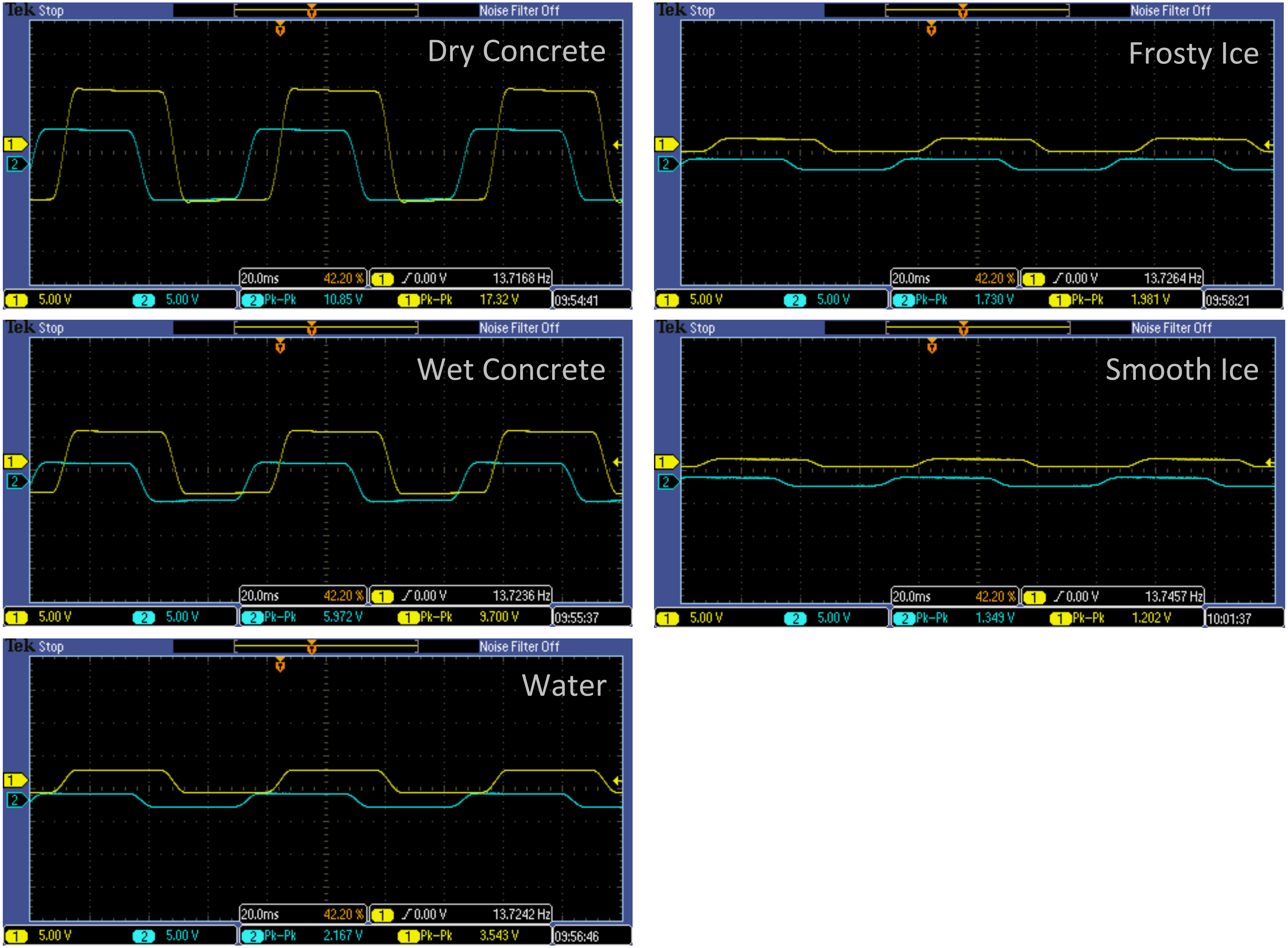
06/19/15

	1. Blue (V)	2. Maize (V)	R_1/R_2
Dry	10.85	17.32	0.63
Wet	5.972	9.700	0.62
Water	2.167	3.543	0.61
Frosty Concrete	1.730	1.981	0.87
Black Ice –Smooth	1.349	1.202	1.12

400 rpm
1.2 m from target

1. Blue Channel = 0.624 µm
2. Maize Channel = 0.450 µm

As expected water is bluer than ice.


Dry Concrete
Tek Stop
Noise Filter Off
20.0ms 42.20 % 1 0.00 V 13.7168 Hz
1 5.00 V 2 5.00 V 2 Pk-Pk 10.85 V 1 Pk-Pk 17.32 V 09:54:41
Frosty Ice
Tek Stop
Noise Filter Off
20.0ms 42.20 % 1 0.00 V 13.7264 Hz
1 5.00 V 2 5.00 V 2 Pk-Pk 1.730 V 1 Pk-Pk 1.981 V 09:58:21
Wet Concrete
Tek Stop
Noise Filter Off
20.0ms 42.20 % 1 0.00 V 13.7236 Hz
1 5.00 V 2 5.00 V 2 Pk-Pk 5.972 V 1 Pk-Pk 9.700 V 09:55:37
Smooth Ice
Tek Stop
Noise Filter Off
20.0ms 42.20 % 1 0.00 V 13.7457 Hz
1 5.00 V 2 5.00 V 2 Pk-Pk 1.349 V 1 Pk-Pk 1.202 V 10:01:37
Water
Tek Stop
Noise Filter Off
20.0ms 42.20 % 1 0.00 V 13.7242 Hz
1 5.00 V 2 5.00 V 2 Pk-Pk 2.167 V 1 Pk-Pk 3.543 V 09:56:46

PbS Detector Signal (V)
Halogen Bulb: LumenFlow Reflector

19 V, 2.23 A Placed about 30° from the vertical

06/19/15

	1. Blue (V)	2. Maize (V)	R_1/R_2
Dry	Sat	Sat	---
Wet	14.26	21.28	0.67
Water	5.045	6.991	0.72
Frosty Concrete	4.952	5.176	0.96
Black Ice –Smooth	2.957	2.398	1.23

400 rpm
1.2 m from target

1. Blue Channel = 0.624 µm
2. Maize Channel = 0.450 µm

As expected water is bluer than ice.

PbS Detector Signal (V)
Hawkeye IR Light: Si-217-p-1

24 V, 1.30 A Placed about 10° from the vertical

06/19/15

	1. Blue (V)	2. Maize (V)	R_1/R_2
Dry	3.599	5.816	0.61
Wet	1.850	3.071	0.60
Water	0.710	0.797	0.89
Water Drying	1.925	3.032	0.64
Frosty Concrete	0.645	0.705	0.91
Black Ice –Smooth	0.319	0.248	1.29

400 rpm
1.2 m from target

1. Blue Channel = 0.624 µm
2. Maize Channel = 0.450 µm

As expected water is bluer than ice.

PbS Detector Signal (V)
Halogen Bulb: LumenFlow Reflector

24 V, 2.53 A   Placed about 30° from the vertical

06/19/15

	1. Blue (V)	2. Maize (V)	R_1/R_2
Dry	3.965	5.916	0.67
Wet	2.365	3.326	0.71
Water	0.896	0.562	1.59
Frosty Concrete	0.527	0.640	0.82

400 rpm
1.2 m from target

1. Blue Channel = 1.705 µm
2. Maize Channel = 1.535 µm

As expected water is redder than ice at around 1.6 µm.

PbS Detector Signal (V)
Hawkeye IR Light: Si-217-p-1

24 V, 1.25 A   Placed about 10° from the vertical

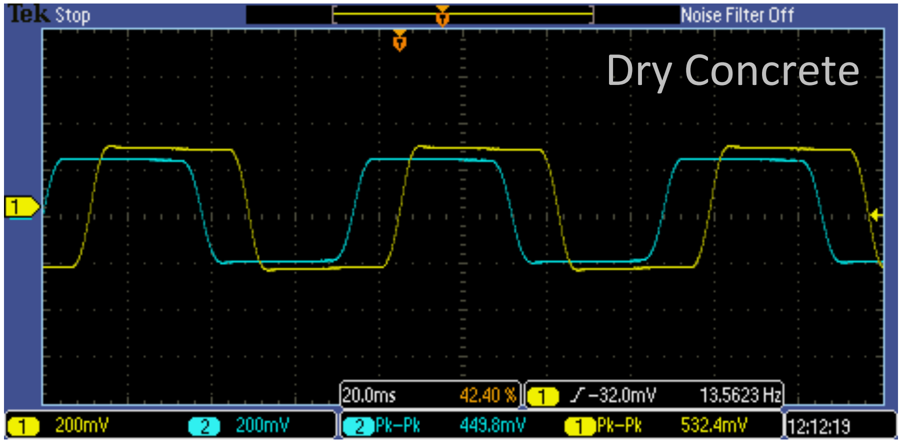
06/19/15

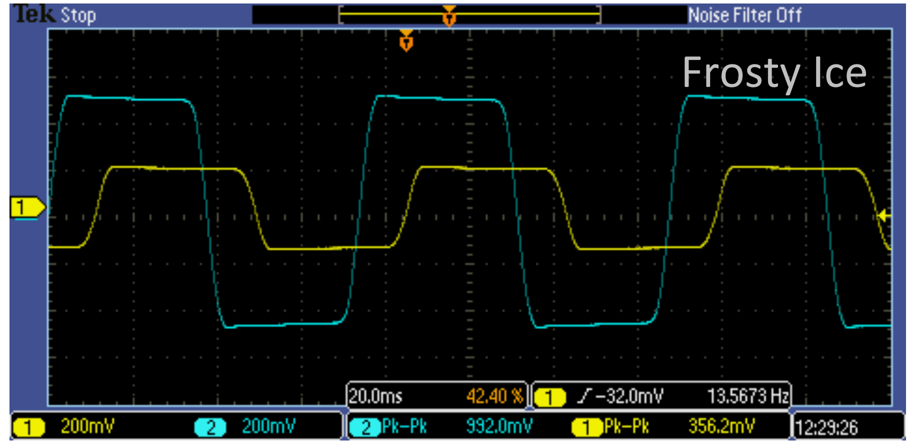
	1. Blue (V)	2. Maize (V)	R_1/R_2
Dry	0.450	0.532	0.85
Wet	0.256	0.285	0.90
Water	1.165	0.337	3.46
Frosty Concrete	0.992	0.356	2.79
Black Ice –Smooth	0.600	0.421	1.43

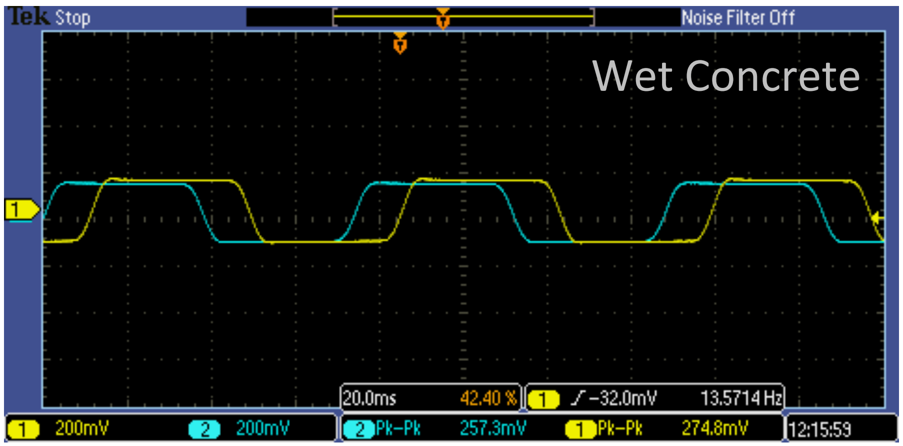
400 rpm
1.2 m from target

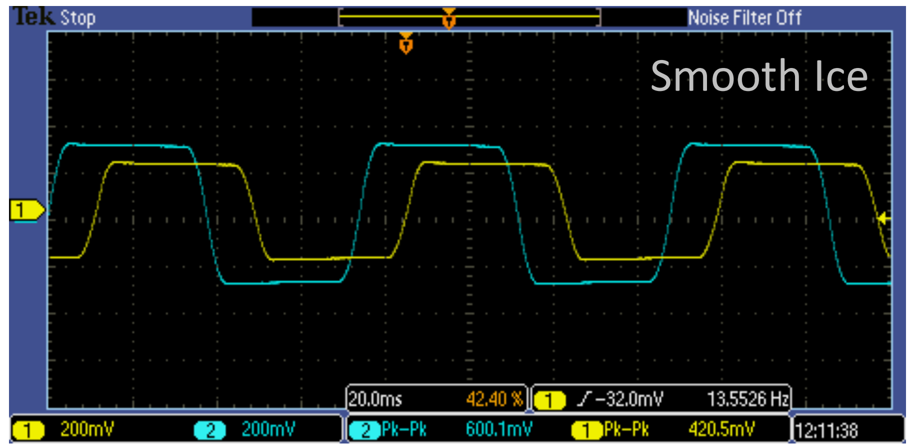
1. Blue Channel = 1.705 µm
2. Maize Channel = 1.535 µm

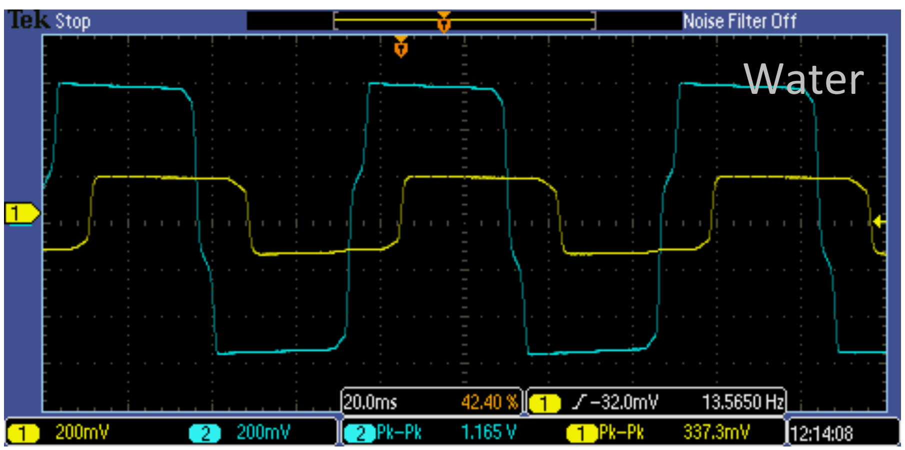
As expected water is redder than ice at around 1.6 µm.


Tek Stop
Noise Filter Off
Dry Concrete
20.0ms 42.40 %
1 ∕ −32.0mV 13.5623 Hz
1 200mV
2 200mV
2 Pk−Pk 449.8mV
1 Pk−Pk 532.4mV
12:12:19


Tek Stop
Noise Filter Off
Frosty Ice
20.0ms 42.40 %
1 ∕ −32.0mV 13.5673 Hz
1 200mV
2 200mV
2 Pk−Pk 992.0mV
1 Pk−Pk 356.2mV
12:29:26


Tek Stop
Noise Filter Off
Wet Concrete
20.0ms 42.40 %
1 ∕ −32.0mV 13.5714 Hz
1 200mV
2 200mV
2 Pk−Pk 257.3mV
1 Pk−Pk 274.8mV
12:15:59


Tek Stop
Noise Filter Off
Smooth Ice
20.0ms 42.40 %
1 ∕ −32.0mV 13.5526 Hz
1 200mV
2 200mV
2 Pk−Pk 600.1mV
1 Pk−Pk 420.5mV
12:11:38


Tek Stop
Noise Filter Off
Water
20.0ms 42.40 %
1 ∕ −32.0mV 13.5650 Hz
1 200mV
2 200mV
2 Pk−Pk 1.165 V
1 Pk−Pk 337.3mV
12:14:08

PbS Detector Signal (V)
Halogen Bulb: LumenFlow Reflector

24 V, 2.54 A   Placed about 30° from the vertical

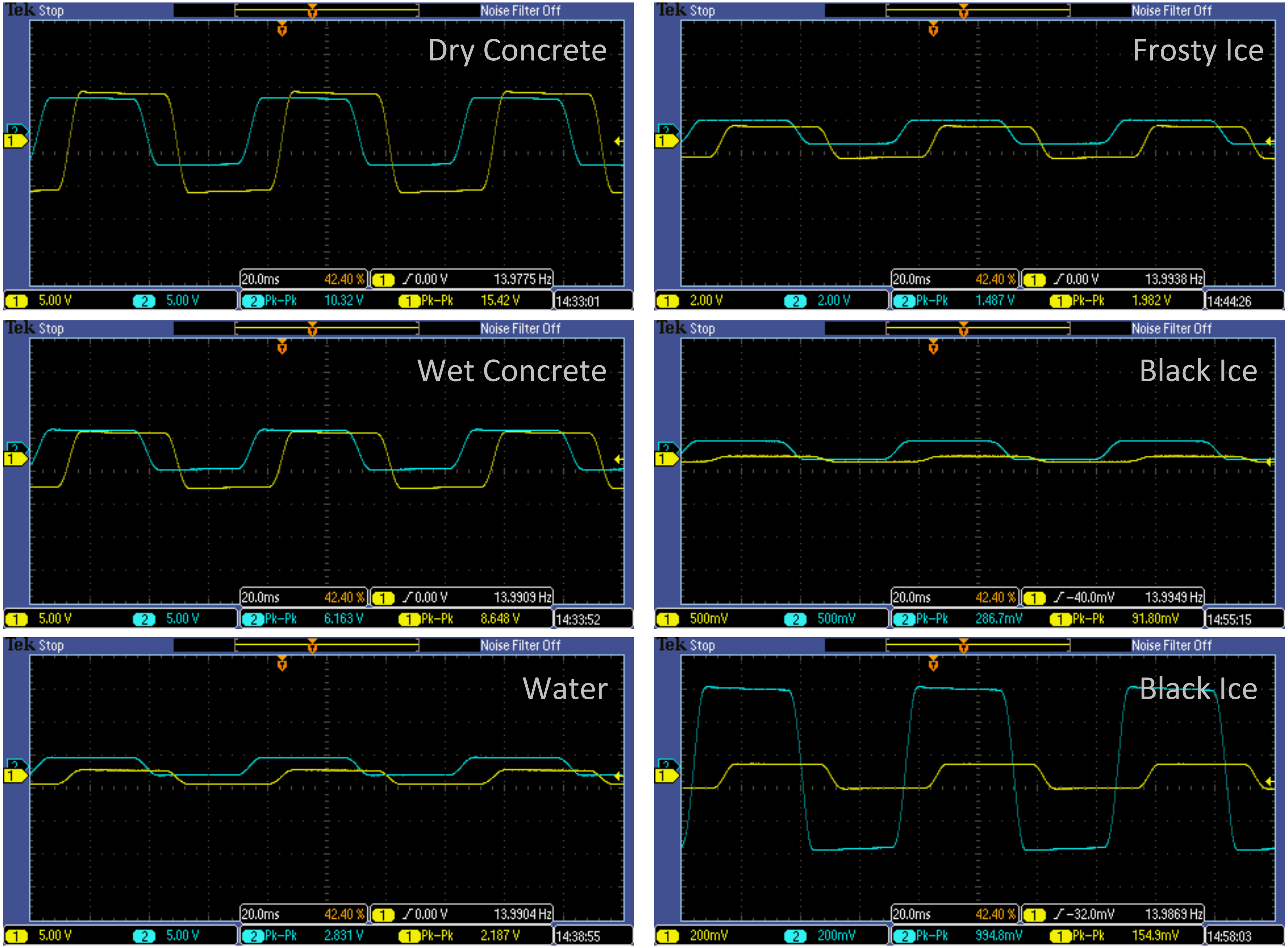
06/24/15

	1. Blue (V)	2. Maize (V)	R_1/R_2
Dry	10.32	15.42	0.67
Wet	6.16	8.65	0.71
Water	2.83	2.19	1.29
Frosty Concrete	1.49	1.98	0.75
Black Ice -Heterogeneous	0.287	0.092	3.11
Black Ice -Heterogeneous	0.995	0.155	6.42

400 rpm
1.2 m from target

1. Blue Channel = 1.705 µm
2. Maize Channel = 1.535 µm

Water is expected to be redder than ice at around 1.6 µm.
(a larger light path length in ice might explain the results)



Dry Concrete
Tek Stop
Noise Filter Off
20.0ms 42.40 %
1 0.00 V 13.9775 Hz
1 5.00 V 2 5.00 V
2 Pk-Pk 10.32 V
1 Pk-Pk 15.42 V
14:33:01
Frosty Ice
Tek Stop
Noise Filter Off
20.0ms 42.40 %
1 0.00 V 13.9938 Hz
1 2.00 V 2 2.00 V
2 Pk-Pk 1.487 V
1 Pk-Pk 1.982 V
14:44:26
Wet Concrete
Tek Stop
Noise Filter Off
20.0ms 42.40 %
1 0.00 V 13.9909 Hz
1 5.00 V 2 5.00 V
2 Pk-Pk 6.163 V
1 Pk-Pk 8.648 V
14:33:52
Black Ice
Tek Stop
Noise Filter Off
20.0ms 42.40 %
1 −40.0mV 13.9949 Hz
1 500mV 2 500mV
2 Pk-Pk 286.7mV
1 Pk-Pk 91.80mV
14:55:15
Water
Tek Stop
Noise Filter Off
20.0ms 42.40 %
1 0.00 V 13.9904 Hz
1 5.00 V 2 5.00 V
2 Pk-Pk 2.831 V
1 Pk-Pk 2.187 V
14:38:55
Black Ice
Tek Stop
Noise Filter Off
20.0ms 42.40 %
1 −32.0mV 13.9869 Hz
1 200mV 2 200mV
2 Pk-Pk 994.8mV
1 Pk-Pk 154.9mV
14:58:03

PbS Detector Signal (V)
Hawkeye IR Light: Si-217-p-1

Measurements made on June 22, 2015

24 V, 1.23 A   Placed about 10° from the vertical

06/22/15

	1. Blue (V)	2. Maize (V)	R_1/R_2
Dry	0.454	0.269	0.59
Wet	0.252	0.162	0.64
Water	0.174	0.564	3.24
Frosty Concrete	0.116	0.103	0.89
Black Ice –Smooth	0.409	0.238	1.72

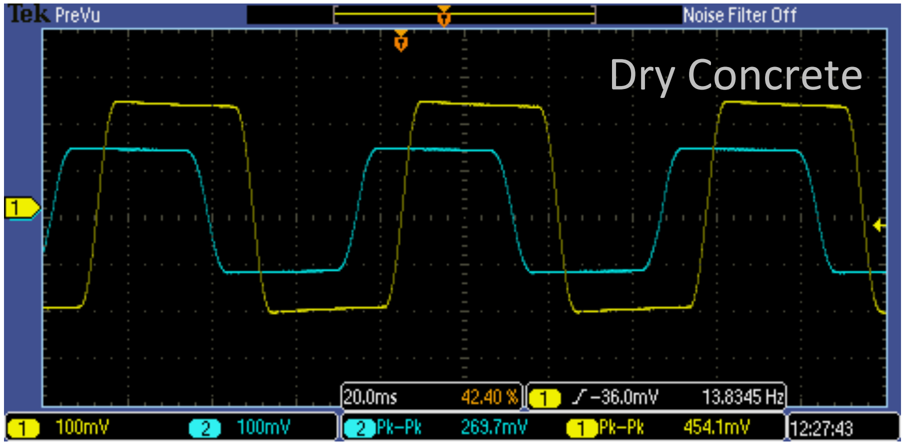
The 2 μm band is the best for detecting water.

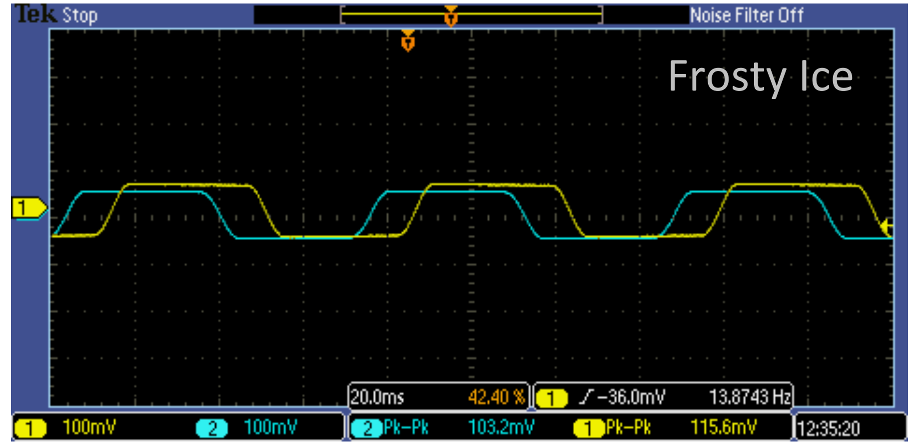
400 rpm
1.2 m from target

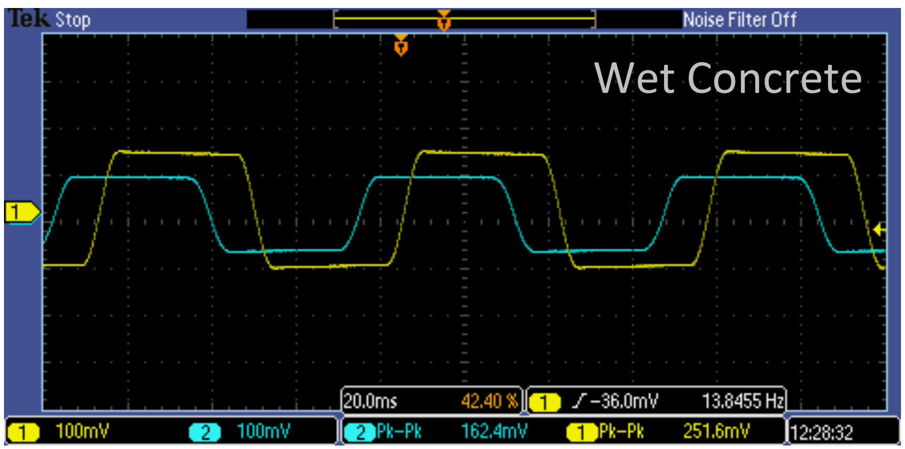
1. Blue Channel = 2.200 μm
2. Maize Channel = 2.090 μm

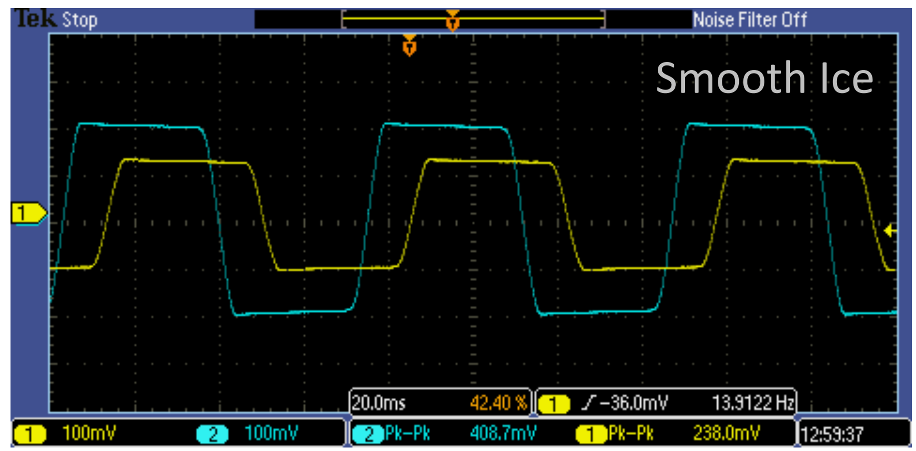
As expected around 2 μm water is redder than ice.

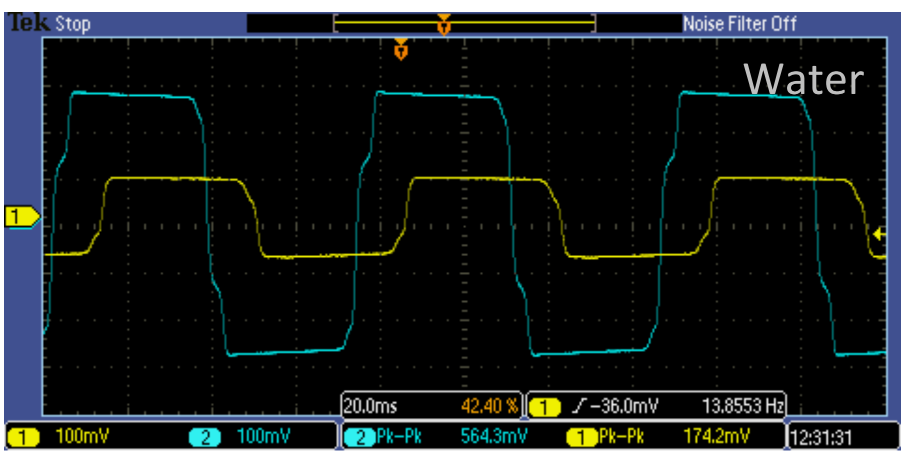
Illumination from the zenith maximizes the results.


Tek PreVu
Noise Filter Off
Dry Concrete
20.0ms 42.40 %
1 ∫ −36.0mV 13.8345 Hz
1 100mV
2 100mV
2 Pk−Pk 269.7mV
1 Pk−Pk 454.1mV
12:27:43


Tek Stop
Noise Filter Off
Frosty Ice
20.0ms 42.40 %
1 ∫ −36.0mV 13.8743 Hz
1 100mV
2 100mV
2 Pk−Pk 103.2mV
1 Pk−Pk 115.6mV
12:35:20


Tek Stop
Noise Filter Off
Wet Concrete
20.0ms 42.40 %
1 ∫ −36.0mV 13.8455 Hz
1 100mV
2 100mV
2 Pk−Pk 162.4mV
1 Pk−Pk 251.6mV
12:28:32


Tek Stop
Noise Filter Off
Smooth Ice
20.0ms 42.40 %
1 ∫ −36.0mV 13.9122 Hz
1 100mV
2 100mV
2 Pk−Pk 408.7mV
1 Pk−Pk 238.0mV
12:59:37


Tek Stop
Noise Filter Off
Water
20.0ms 42.40 %
1 ∫ −36.0mV 13.8553 Hz
1 100mV
2 100mV
2 Pk−Pk 564.3mV
1 Pk−Pk 174.2mV
12:31:31

PbS Detector Signal (V)
Halogen Bulb: LumenFlow Reflector

Measurements made on June 22, 2015

24.1 V, 2.565 A   Placed about 30° from the vertical

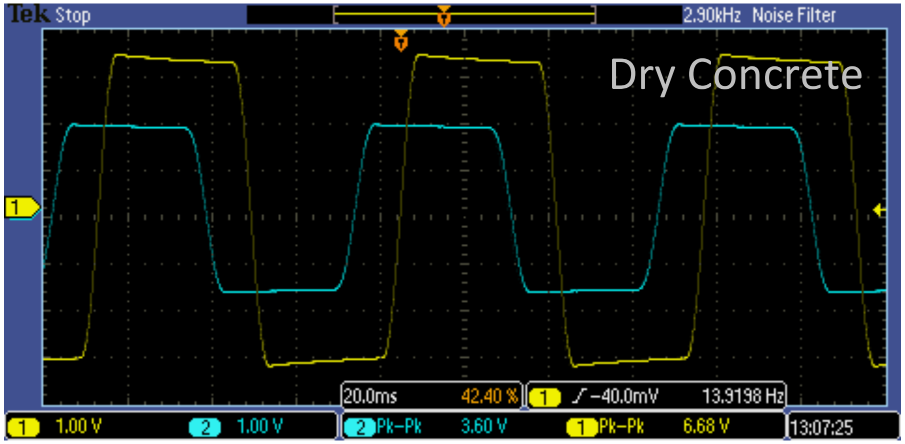
06/22/15

	1. Blue (V)	2. Maize (V)	R_1/R_2
Dry	3.60	6.68	0.54
Wet	2.20	3.76	0.58
Water	0.320	0.200	1.60
Frosty Concrete	---	---	---
Black Ice –Smooth	0.320	0.080	4.00

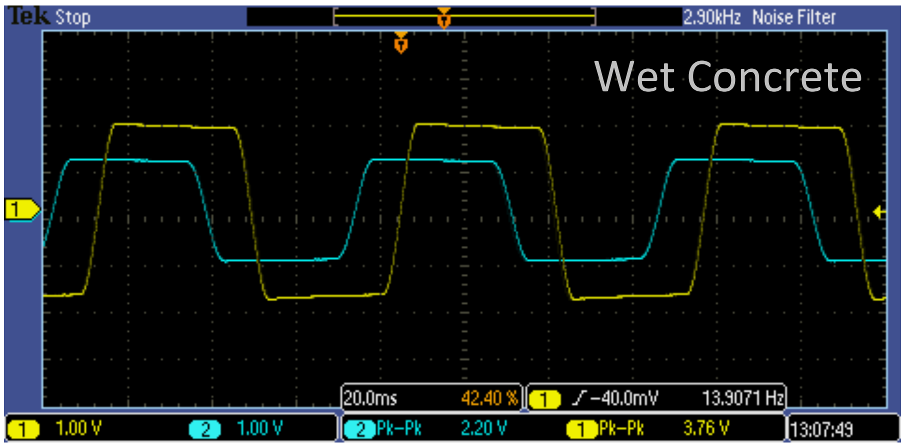
400 rpm
1.2 m from target

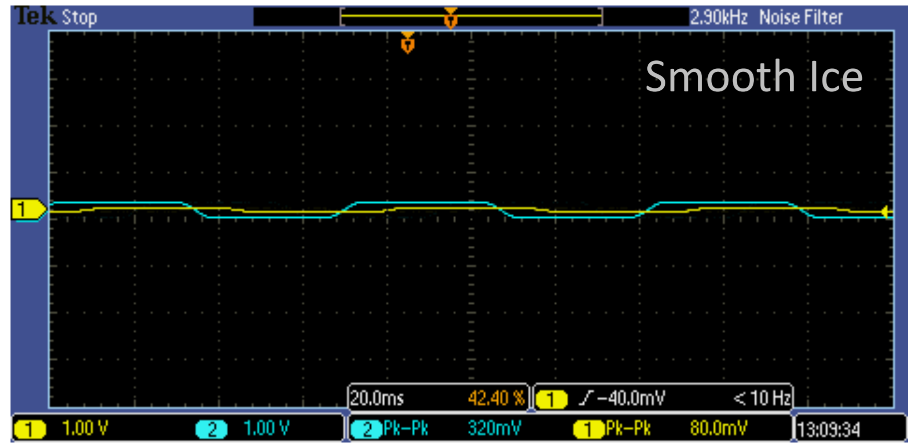
1. Blue Channel = 2.200 µm
2. Maize Channel = 2.090 µm

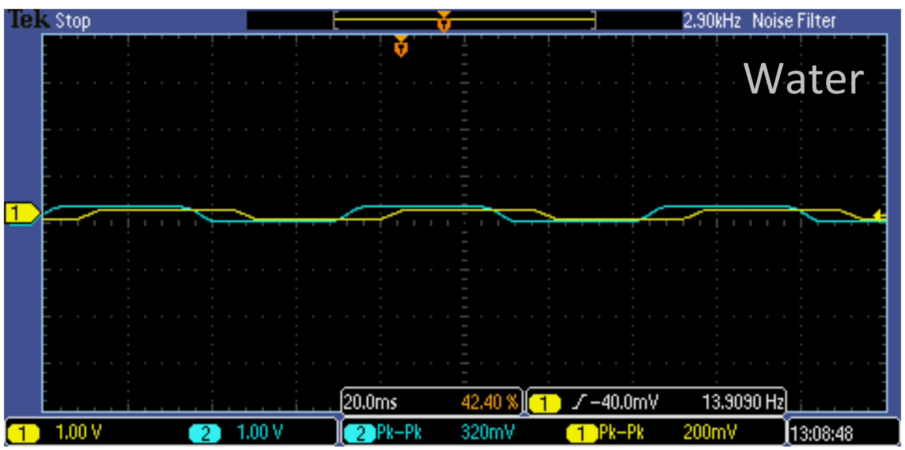
Water would be expected to be redder than ice around 2 µm (a larger light path length in ice might explain the results).
The 1.6 µm band is the best for detecting ice.


Tek Stop
2.90kHz Noise Filter
Dry Concrete
20.0ms 42.40 %
1 ∫ −40.0mV 13.9198 Hz
1 1.00 V
2 1.00 V
2 Pk−Pk 3.60 V
1 Pk−Pk 6.68 V
13:07:25

Frosty Ice


Tek Stop
2.90kHz Noise Filter
Wet Concrete
20.0ms 42.40 %
1 ∫ −40.0mV 13.9071 Hz
1 1.00 V
2 1.00 V
2 Pk−Pk 2.20 V
1 Pk−Pk 3.76 V
13:07:49


Tek Stop
2.90kHz Noise Filter
Smooth Ice
20.0ms 42.40 %
1 ∫ −40.0mV < 10 Hz
1 1.00 V
2 1.00 V
2 Pk−Pk 320mV
1 Pk−Pk 80.0mV
13:09:34


Tek Stop
2.90kHz Noise Filter
Water
20.0ms 42.40 %
1 ∫ −40.0mV 13.9090 Hz
1 1.00 V
2 1.00 V
2 Pk−Pk 320mV
1 Pk−Pk 200mV
13:08:48

Summary

- Multispectral (e.g., color) cameras, photodetectors and thermopiles can be used to detect slippery black ice.

- The system can be installed in cars to provide onboard alert to drivers.

- The system can be mounted on bridges and other areas where ice is likely to form first to alert drivers and maintenance crews.

- **The technology has been demonstrated in the laboratory and outdoors, in real road-like conditions.**