Development of Imbedded Sensors and Techniques for Chloride Determinations in Steel Reinforced Bridge Deck Structures

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Abstract:

Chloride ions, found in deicing chemicals, penetrate concrete causing corrosion of reinforcing steel. Corrosion in bridge deck and post-tensioned structures poses a great safety risk to the public. Furthermore, corrosion monitoring is very expensive.

Time domain reflectometry is a method in which a high velocity pulse is sent down the length of a transmission line. Any imperfections along the line are reflected back, and the exact location of the imperfection can be determined. For our purposes, a sensor consisting of two parallel electrodes is placed at the end of a transmission line. The sensor is placed in differing chloride concentrations (0.1M, 0.5M, 1.0M NaCl) and reflected waveforms are analyzed and correlated using LabVIEW software.

In our experiments, one electrode receives pulses from the time domain reflectometer (TDR) while the other electrode is held at ground. In order to study the initial redox chemistry of the electrodes, our focus has been on developing high-speed switching devices and software to accommodate the switches.

Purpose:

The goal of this project is to develop and implement low-cost sensors into bridge deck and post-tensioned structures that can accurately determine chloride concentration relating to corrosion of rebar and steel cables.

Sensor Characteristics:

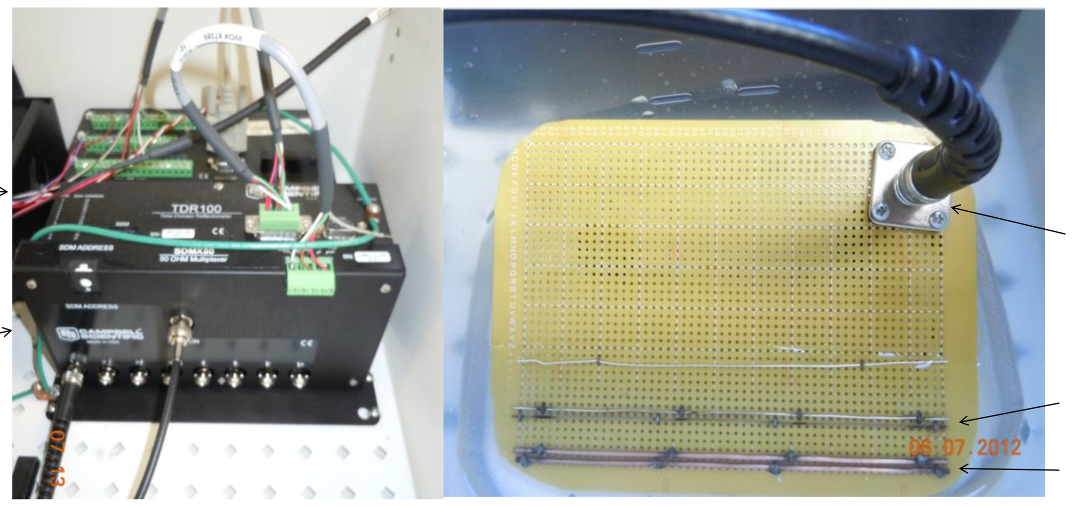
- Effective: Sensors must be reliable in measurement of chloride concentration.
- Inexpensive: Sensors will provide an inexpensive alternative to current chloride monitoring techniques.
- Durable: Sensors will be placed during bridge construction and must have a long lifetime.
- Accessible: Multiple sensors may be placed in one bridge. Data can be collected and analyzed at one central location.

Sensor Design and Experimental Testing:

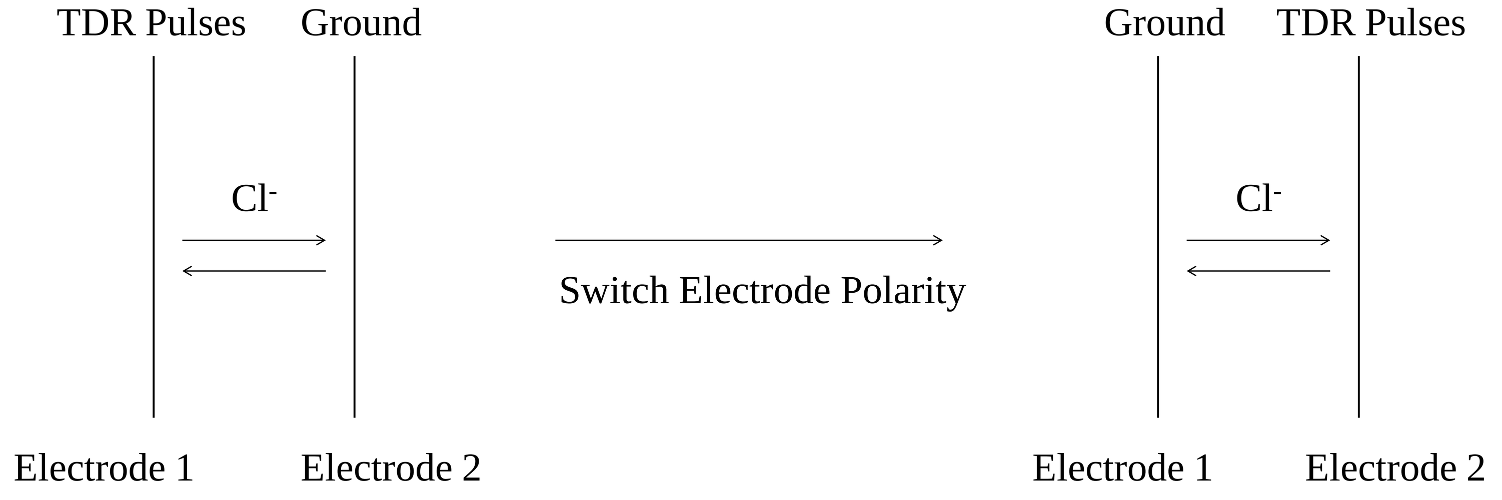
Three sensor types have been developed and tested in 0.1M, 0.5M and 1.0M NaCl:

- Copper electrodes
- Silver electrodes
- Silver Chloride electrodes

  -Silver electrodes are anodized in slightly acidified 0.3M KCl for 1 minute to form silver chloride electrodes



Experimental Design:



While performing experiments with silver and silver chloride it is hypothesized that one electrode will be oxidized (silver oxidized to silver chloride) while the other electrode is reduced (silver chloride reduced to silver). It is our goal to monitor this behavior, and as such, the electrode polarity is switched at the middle of each experiment.

Software Design and Switching Devices:

Using Loggernet, TDR pulses are applied every 30 seconds. Each pulse lasts for a duration of 14 microseconds. Experiments usually run for 30 minutes with15 minutes of pulses applied to electrode 1, E1, and 15 minutes of TDR pulses applied to electrode 2, E2. Each pulse results in a reflected waveform that is saved in chronological order in Microsoft Excel. Each waveform can then be accessed later for analysis. LabVIEW software is used to analyze and correlate the waveforms that have been saved in excel.

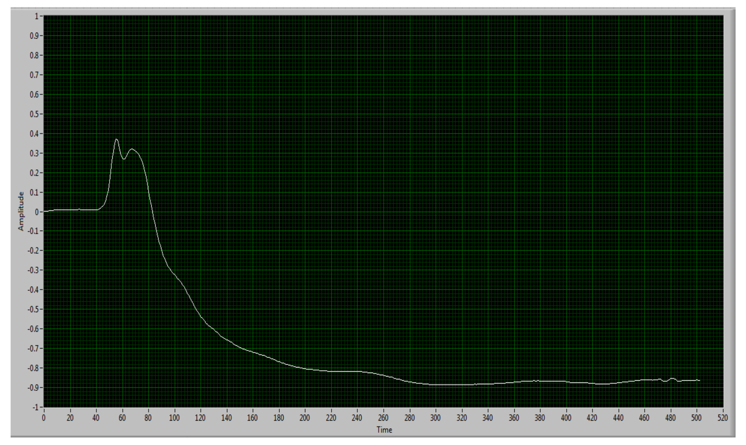


Figure 1: Raw reflected waveform of silver chloride electrode in 1.0M NaCl

Derivative

Savitzky-Golay Filter

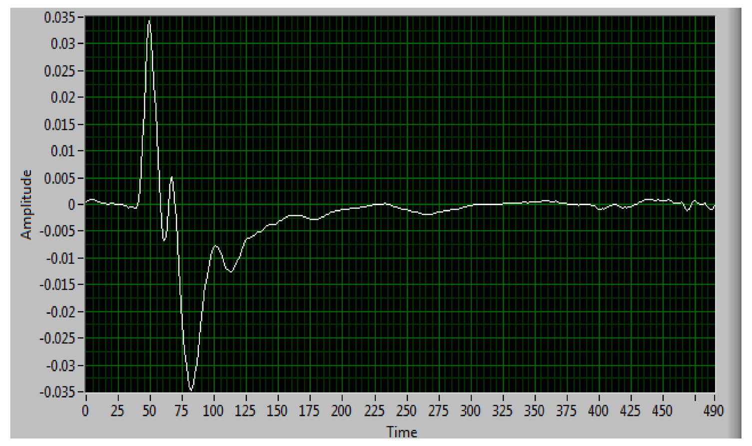


Figure 2: Modified waveform after derivative and Savitzky-Golay filtering has been applied.

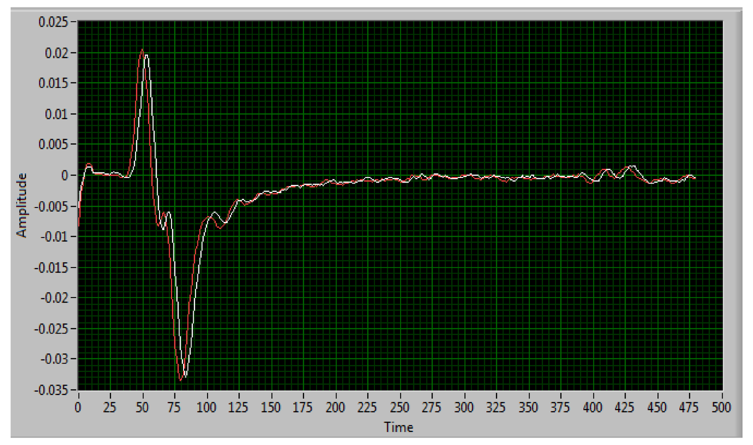


Figure 3: Comparison of sample (Red) and Standard (White) waveforms in LabVIEW.
Total correlation: 2.57359

Peak Alignment

Correlate

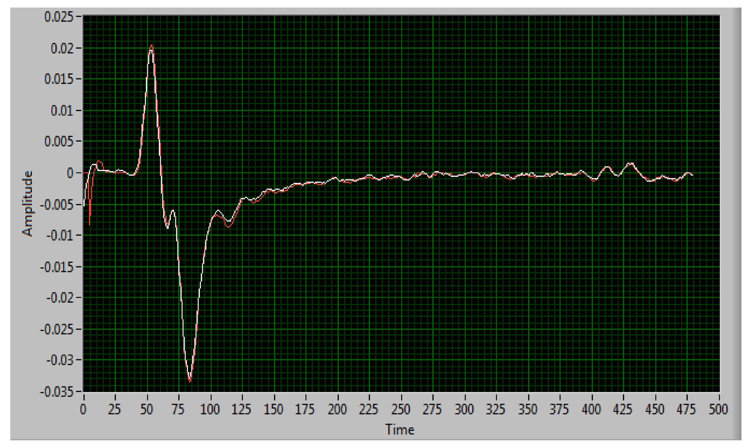


Figure 4: Comparison after sample waveform (Red) has been shifted accordingly to most closely match standard waveform (White), determined by threshold peak heights.
Total correlation: 2.97062

Current LabVIEW programs differentiate, filter, align and correlate waveforms. The correlation accounts for the trended, de-trended and differentiated waveforms. The sum of the correlation results help determine the concentration of chloride.

Problem:

At the middle of each experiment sensor polarity must be switched. To do this, wires connected to electrodes must be de-soldered and re-soldered at each switch.

Solution: High Speed Switching Devices

ADG407

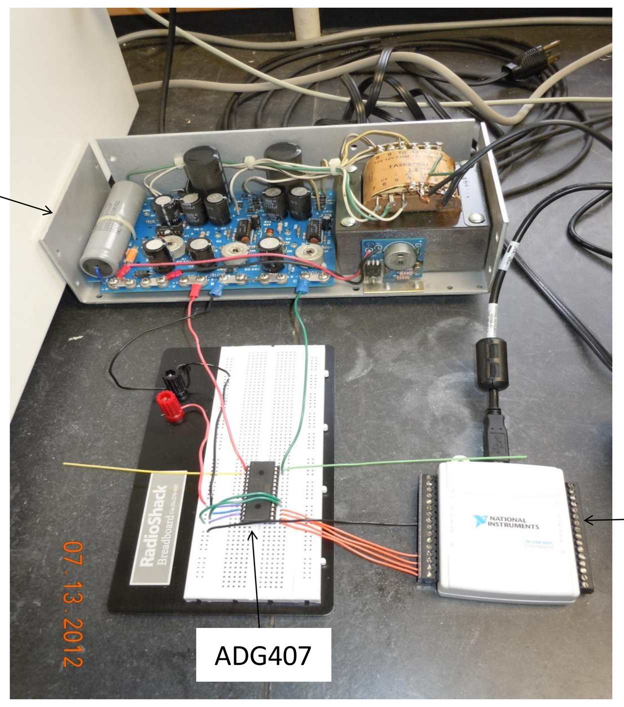
- High speed analog switching device
- Eight differential inputs, one common differential output
- All channels can be enabled or disabled (EN)
- 3-bit binary address lines A0, A1 and A2 determine channel switching (defined in Table 1)

USB6501

- Communicates with ADG407
- Twenty four I/O channels
- Low voltage (~0.03V) or high voltage (~4.9V) signal
- Low voltage signal corresponds to channels EN, A0, A1 and A2 in off state (0 in binary code)
- High voltage signal corresponds to channels EN, A0, A1 and A2 in on state (1 in binary code)

Table 1: ADG407 Truth Table

A2	A1	A0	EN	On Switch Pair
X	X	X	0	None
0	0	0	1	1
0	0	1	1	2
0	1	0	1	3
0	1	1	1	4
1	0	0	1	5
1	0	1	1	6
1	1	0	1	7
1	1	1	1	8



Musical Instrument Digital Interface (MIDI):

MIDI devices are also being explored as a switching device in this project. LabVIEW programs have been developed to communicate with the MIDI device. The MIDI device in use has eight I/O channels, and is connected to a GCX guitar audio switching device. The GCX device has eight loops, each containing in, send, return and out ports.

Figure 5: MIDISPORT 8x8/s device (bottom) and GCX guitar audio switcher (top).

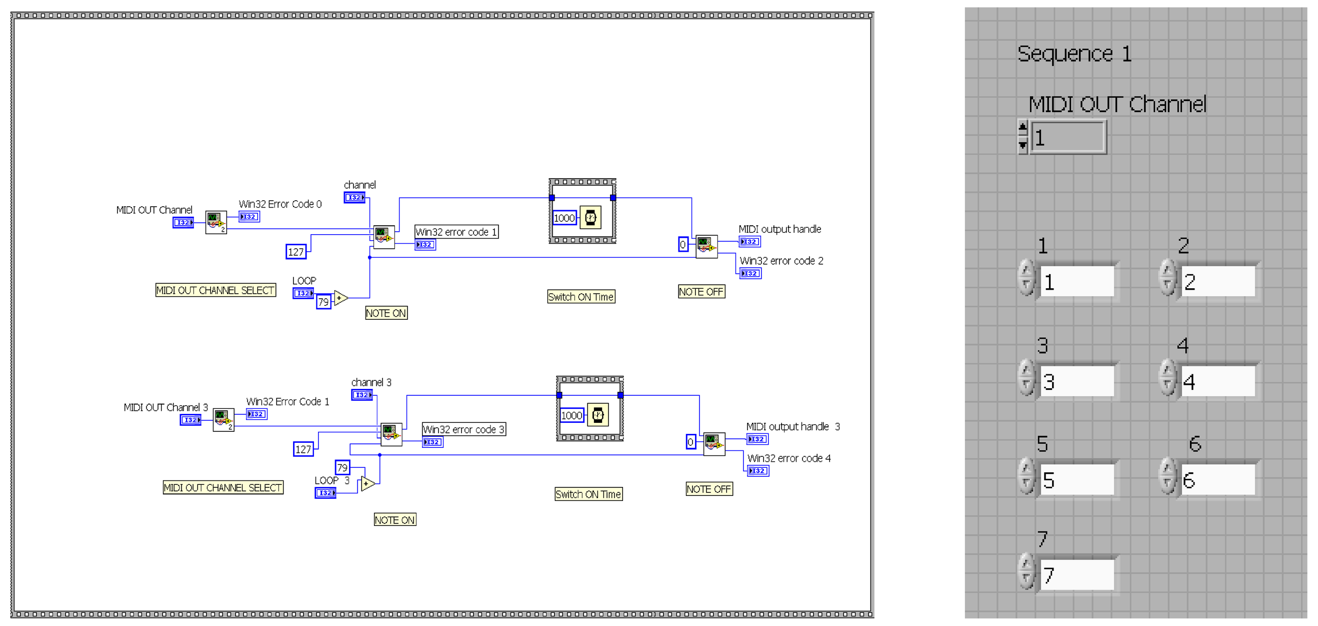


Figure 6: LabVIEW block diagram (left), and front panel (right). This program controls which MIDI output is on, and which loop(s) are on/off on the GCX device. Binary, hexadecimal and decimal values can be used as byte values in LabVIEW. Our program was made to accommodate decimal values, making the program simpler and easier to understand for other users.

Conclusion:

Chloride concentrations are differentiated according to correlation values, however further testing is required. Furthermore, switching devices are still in progress.

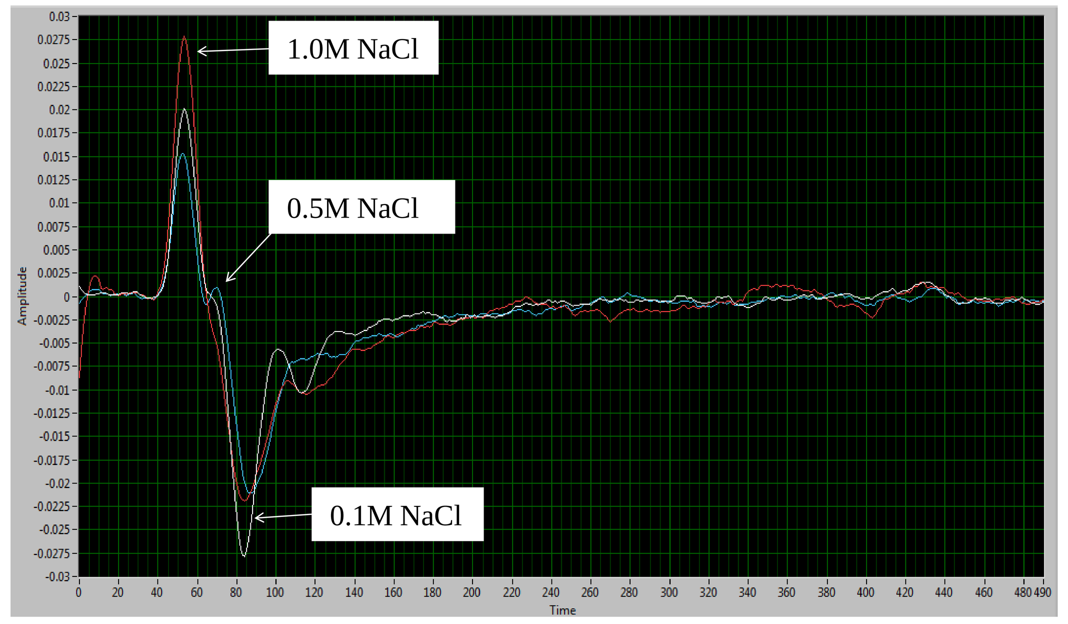


Figure 7: Silver electrode comparison in 1.0M, 0.5M and 0.1M NaCl after waveforms have been differentiated and filtered in LabVIEW.

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