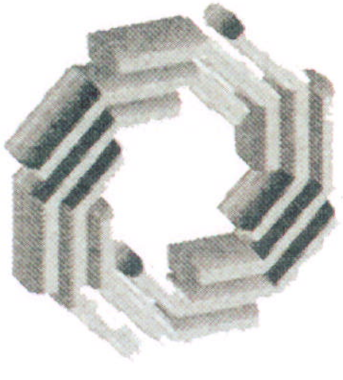
EICCT TECHNOLOGY

FINAL COAT MODULE

TEST SUMMARY



CC Technologies

WITHOUT PREJUDICE

REPORT ON TESTING OF FINAL COAT MODULE

I. INTRODUCTION

This report describes testing conducted on a device named the "Final Coat Module" (the "Module") supplied in Canada by Canadian Auto Preservation Inc. ("CAP Inc."). The testing was conducted under the direction of Dr. Digby Macdonald, Distinguished Professor of Materials Science and Engineering and Director, Center for Electrochemical Science and Technology at the Pennsylvania State University. The experiment was conducted at the facilities of CC Technologies Laboratories, Inc., a third party testing laboratory located in Dublin, Ohio. Dr. Macdonald was retained by counsel for CAP Inc. to provide expert advice and to conduct the tests described below in connection with potential litigation between CAP Inc. and the Commissioner of Competition.

The experiment described below is intended to examine the efficacy of the Module over a surface in the absence of an electrolyte film between the point of application of the electrical signal from the Module and the area being protected and to indicate to the extent possible, the mechanism by which the Module provides protection against corrosion. One of the principal problems in assessing the effectiveness of the Module lies in ascertaining exactly how the device achieves corrosion control, since it is not a classical impressed current cathodic protection system in which current is projected through a ionically conducting (aqueous) phase from an anode to the component that needs to be protected, such that the potential of the component is displaced in the negative direction. The testing described below measures the Module's effect on the potential of a scribed region (exposed steel) on a test panel in the absence of an electrolyte film (aqueous phase) between the point of application of the electrical signal from the Module and the area being protected. Under these circumstances, classical, impressed current cathodic protection is impossible, because a return path for the current from the scribe to the anode through an electrolyte film does not exist. Accordingly, a positive result from this experiment will demonstrate that the:

- Module is effective in protecting steel automotive body panels, as evidenced by a shift in the potential of the exposed steel at the scribe in the negative direction.

- Mechanism of protection provided by the Module is not that of classical, impressed current cathodic protection.

Additionally, as indicated below, the current or voltage applied to a panel by the Module is in the form of a repetitive pulse and not as a direct current that is employed in impressed current cathodic protection systems, again demonstrating a vital difference between the latter and the Module.

II. TEST METHODOLOGY

For each round of the experiment, two standard automobile stock galvanized steel panels each measuring 4 feet by 3 feet were coated on both sides with DUPONT WA5111 and then clear-coated on one side only with DUPONT 72400 by Northwest Campus Auto Body located in Columbus, Ohio. This is a standard coating system for exterior automobile bodies. The panels were identical in all material respects.

The panels were scribed to cut through the clear coat, paint and galvanized layer, thereby exposing the bare steel. A reference electrode was placed at the location of the scribe on each panel to monitor the corrosion potential of each panel. The reference electrode was composed of Ag/AgCl+KCl(sat) and employed a Luggin capillary connected to the panel from the back side. Electrolytic communication between the scribe and the liquid junction of the Luggin capillary was affected by a small diameter (1/16-inch) hole through the panel. The potential of the exposed steel at the scribe, as measured against the reference electrode, was recorded using a high impedance voltmeter/data logger. The configuration of the reference electrode is described in Figure 1 below:

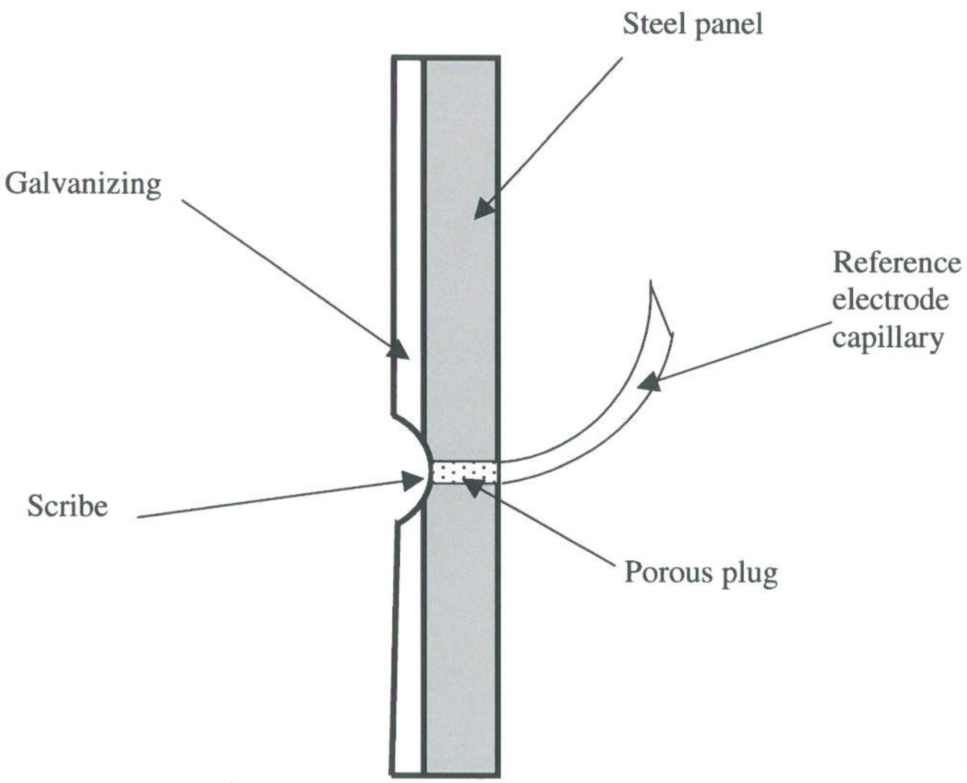


Figure 1. Reference electrode connection schematic.

One of the panels (the "Test Panel") was connected to the Module. Specifically, the Module was placed on the back side of the Test Panel with the lead wire being also attached to the back side of the Test Panel. In this way any possibility of the inadvertent development of an electrolyte path between the module connection to the panel and the scribe was eliminated. The connection of the Module to the backside of the Panel is shown below at Figure 2.

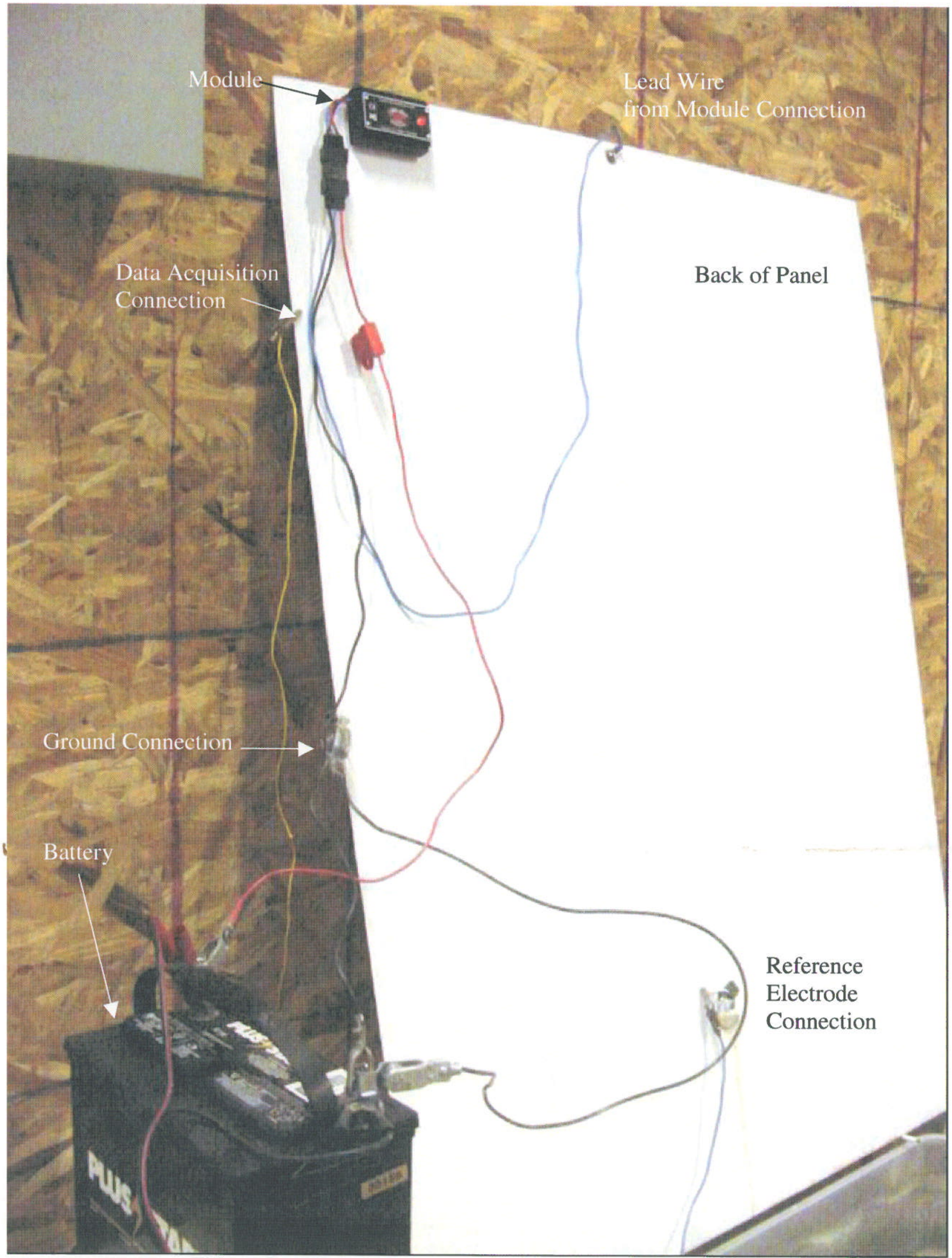


Figure 2 – View of Module Connection at Back of Panel

The other panel (the "Control Panel") was not connected to a Module. Both panels were inclined at approximately 25 degrees to the vertical with the scribed surface facing outward and with the scribe being located approximately 3 feet down from the top edge. The scribed surfaces of the panels were continuously sprayed with a 3.6 wt.% NaCl (salt) solution to simulate road salt exposure. Only the surface of the panel in the vicinity of the scribe was inundated with the electrolyte (see Figure 3); the remainder of the panel surface was dry. In fact, the distance between the top of the spray zone and the location where the Module was connected to the Test Panel was approximately 2 feet. In addition, as noted above, the lead wire for the Module was connected to the back of the Test Panel, which was not in contact with the electrolyte plume.

With the exception of the presence of the Module on the Test Panel, the configuration of the Test Panel and Control Panel was identical in all material respects. The configuration of the Test Panel is described in the schematic diagram found at Figure 3 below:

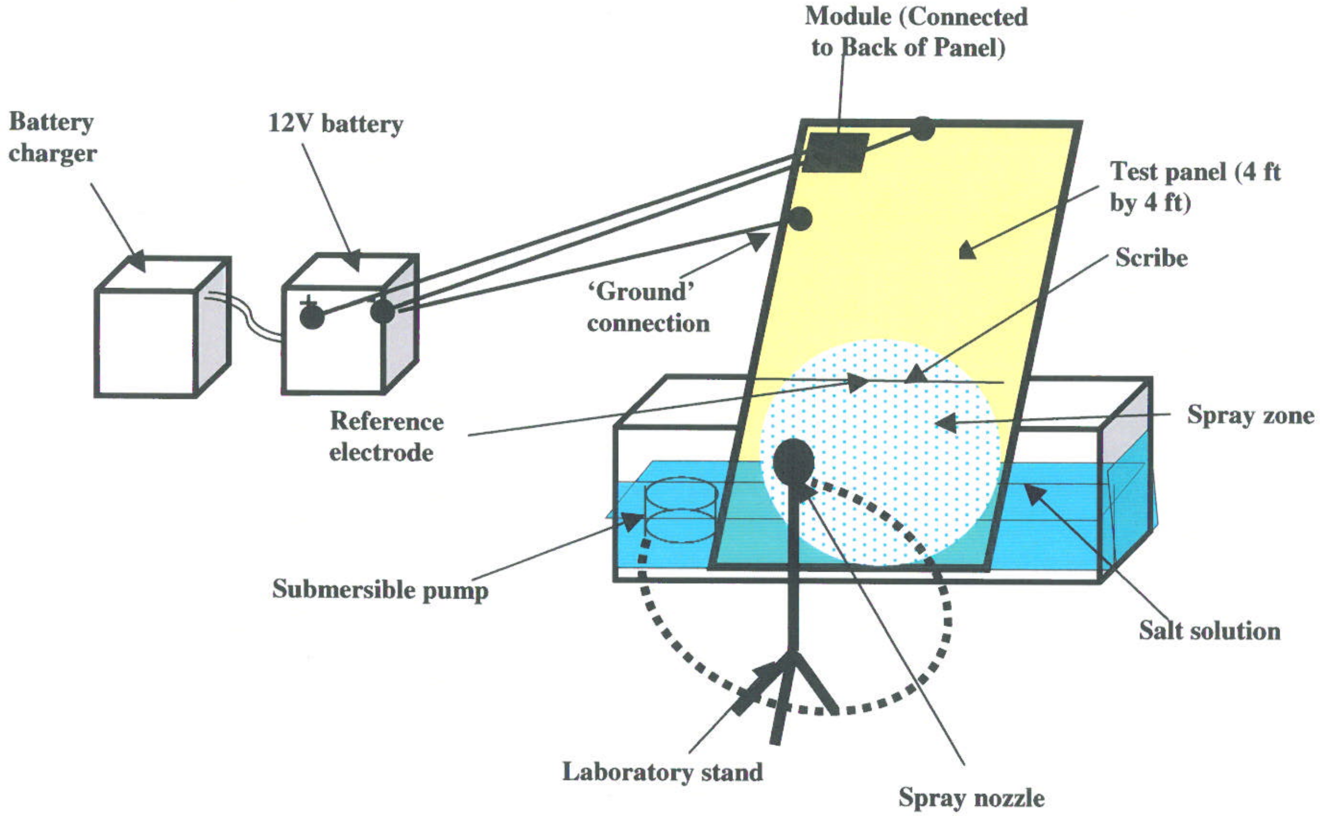


Figure 3. Schematic of the test arrangement.

The actual test arrangement is also shown in the photographs found at Figures 4 and 5 below.

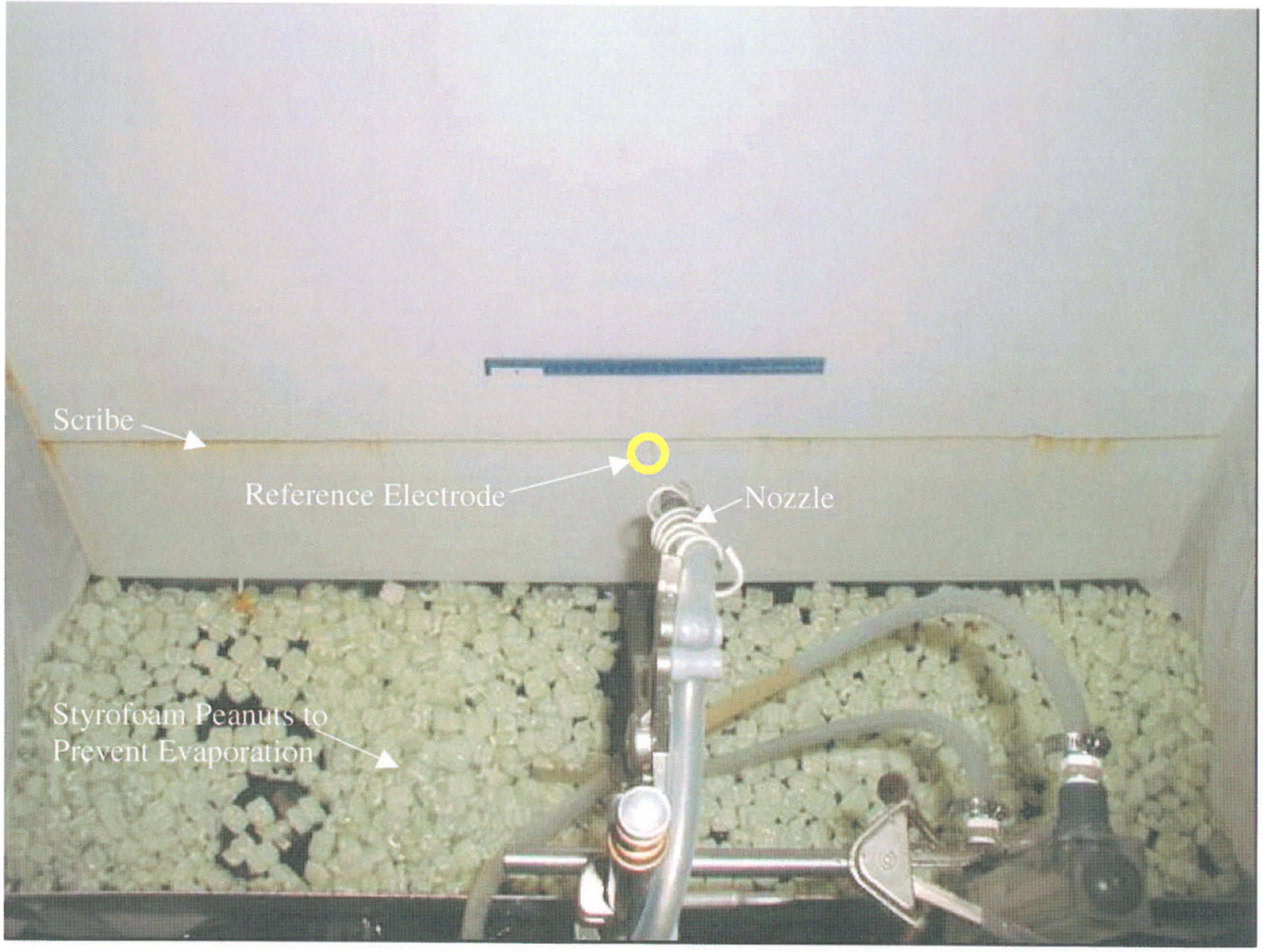


Figure 4 – View of Test Arrangement from Above Nozzle Stand

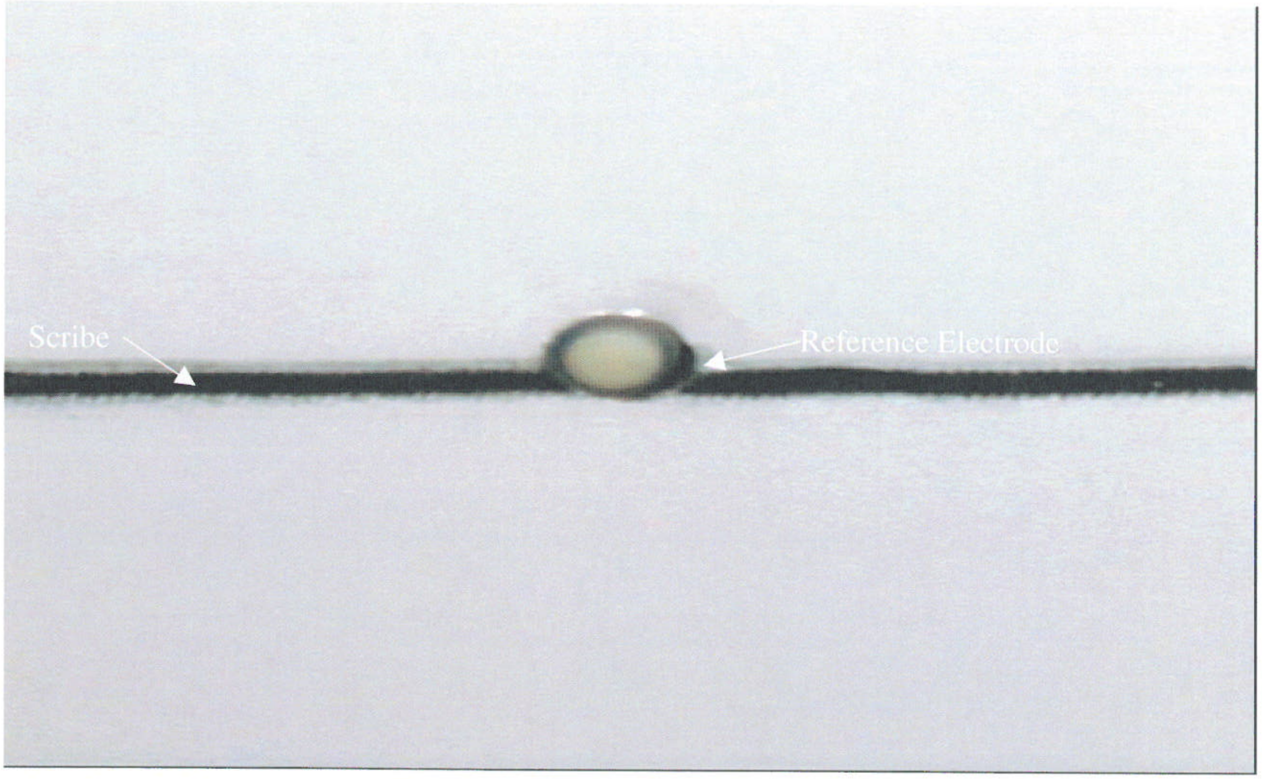


Figure 5 – Close-Up of Reference Electrode

The progression of corrosion was quantified by measuring the corrosion potentials and was also characterized visually by examining the rust stains emanating from the scribes.

III. RESULTS AND DISCUSSION

As outlined in greater detail below, the Test Panel (which was connected to the Module) showed marked differences in corrosion potentials when compared with the Control Panel. The experiment was conducted on three occasions using three different sets of panels. In each case, the panels were prepared and tested in accordance with the methodology described above. Each of the three runs of the experiments yielded broadly consistent results. Specifically, the potential for the Test Panel eventually became more negative than that for the Control Panel by approximately 150 mV. In addition, the difference in corrosion potential was also supported by the difference in the rust staining characteristics of the Test Panel when compared with the Control Panel.

During the first run of the experiment, the corrosion potentials measured at the scribes on both panels were approximately the same until the test had been conducted for approximately 60 hours. The potentials then diverged, with that for the Test Panel eventually becoming more negative than that for the Control Panel by approximately 150 mV. This significant difference in corrosion potential continued until the experiment was terminated following 550 hours of exposure. A chart showing the corrosion potential versus time over the duration of the entire experiment for the Test Panel and Control Panel is set out below in Figure 6:

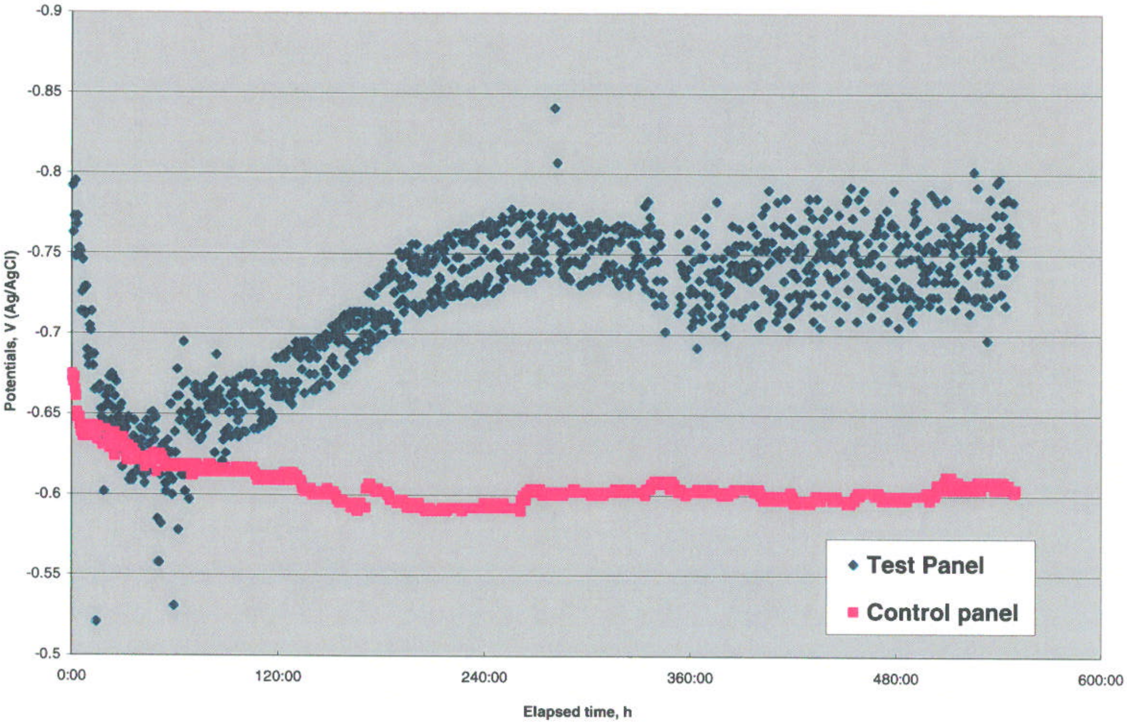


Figure 6. Potential –versus-elapsed time curve

In this figure, it is seen that, after about 60 hours of exposure, the potentials of the two panels diverge with that of the panel controlled by the Module becoming more negative by about 150 mV. It is also noted that the "noise" in the Test Panel potential is significantly greater than that for the Control Panel. The fluctuations in the Test Panel potential are to be expected, because the panel is under active electrochemical control, in which the efficacy of the Module may vary from time-to-time as the local conditions change (e.g., the growth and detachment of gas bubbles). In any event, the efficacy of the Module in displacing the potential of the scribed area in the negative direction is clear.

The difference in corrosion potential is also supported by the difference in the rust staining characteristics of the Test Panel, when compared with the Control Panel. Photographs of the two sets of panels are shown below in Figures 7 and 8. These tests showed marked differences in the extent of rust staining from the scribes on the Test Panel and the Control Panel from very short times.

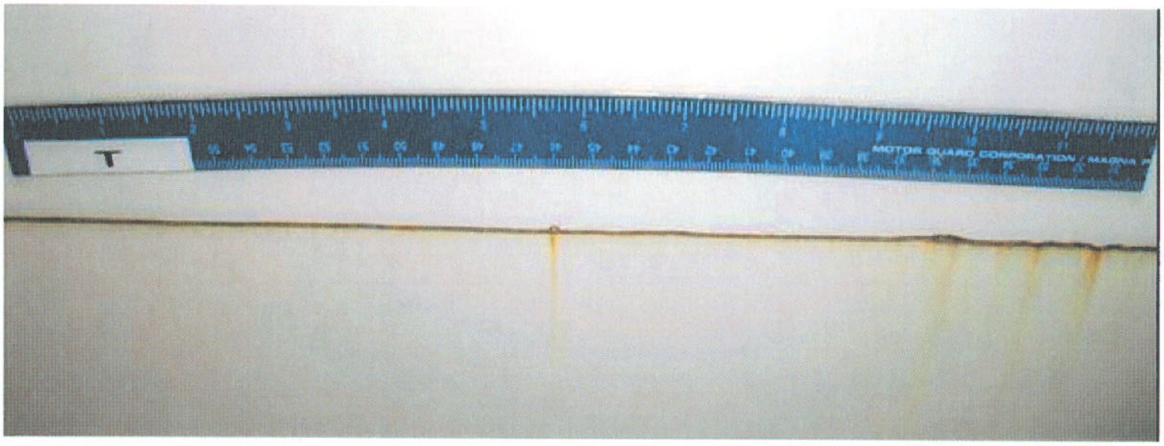


Figure 7. Test panel appearance (Experiment One)

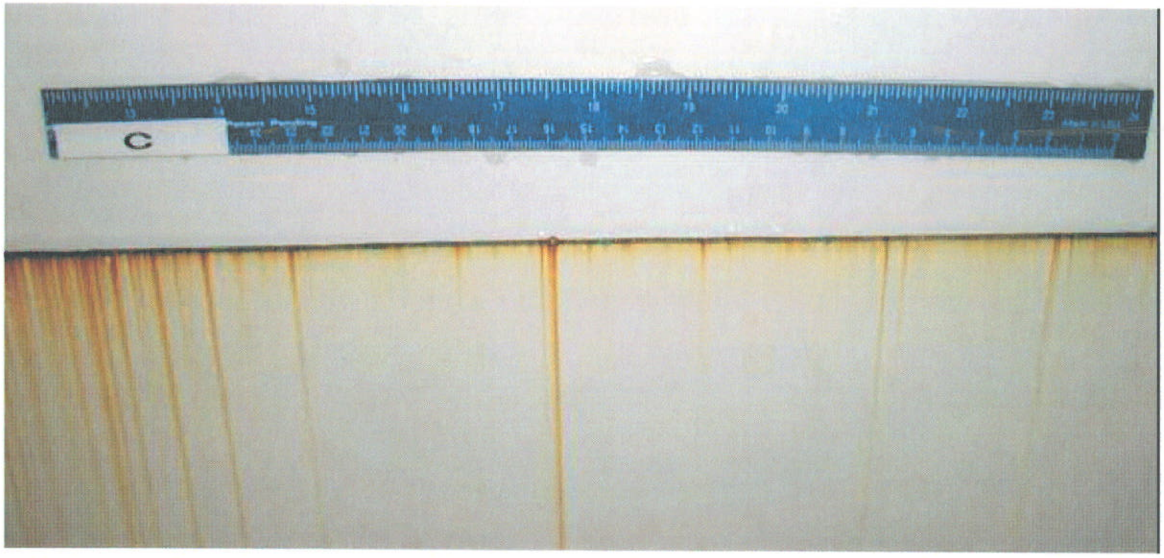


Figure 8. Control panel appearance (Experiment One)

The fact that *any* staining is observed on the Test Panel can be attributed to the fact that an induction period exists for the efficacy of the Module to develop. Thus, with reference to Figure 6, the impact of the Module on the corrosion potential of the scribe is evident only after about 100 hours of exposure, during which time rust would have accumulated on the Test Panel to the same extent that it accumulated on the Control Panel. In other words, we postulate that the rust that accumulates on the Test Panel did so during the induction period. After that time, very little corrosion, if any, occurs as the Module takes effect. Because, in automobile protection, we are concerned with long term effects (> 100 hours), we conclude that the module is effective to the extent that little or no additional rust staining would have been observed after the initial 100-hour exposure period. Clearly, any staining that would have occurred during the induction period might reasonably be expected to be cleaned from the automobile body early in the life of the vehicle. The present data suggest that, thereafter, the accumulation of rust staining on a vehicle protected by the Module should be minimal if not non-existent.

As noted above, the experiment was repeated on three separate occasions, with broadly consistent results. The time required to establish a significant difference in corrosion potential was longer and visual evidence of rust staining was greater than in the first run of the experiment. This is consistent with the existence of an induction time for the Module to begin to exert control over the corrosion process, as noted above, and it is the goal of future work to understand the processes that control the length of the induction period. However because long-term protection is the goal of automobile corrosion mitigation, the initiation period is of no practical significance. The results of the second and third round of the testing are shown in Figures 9 to 14 below.

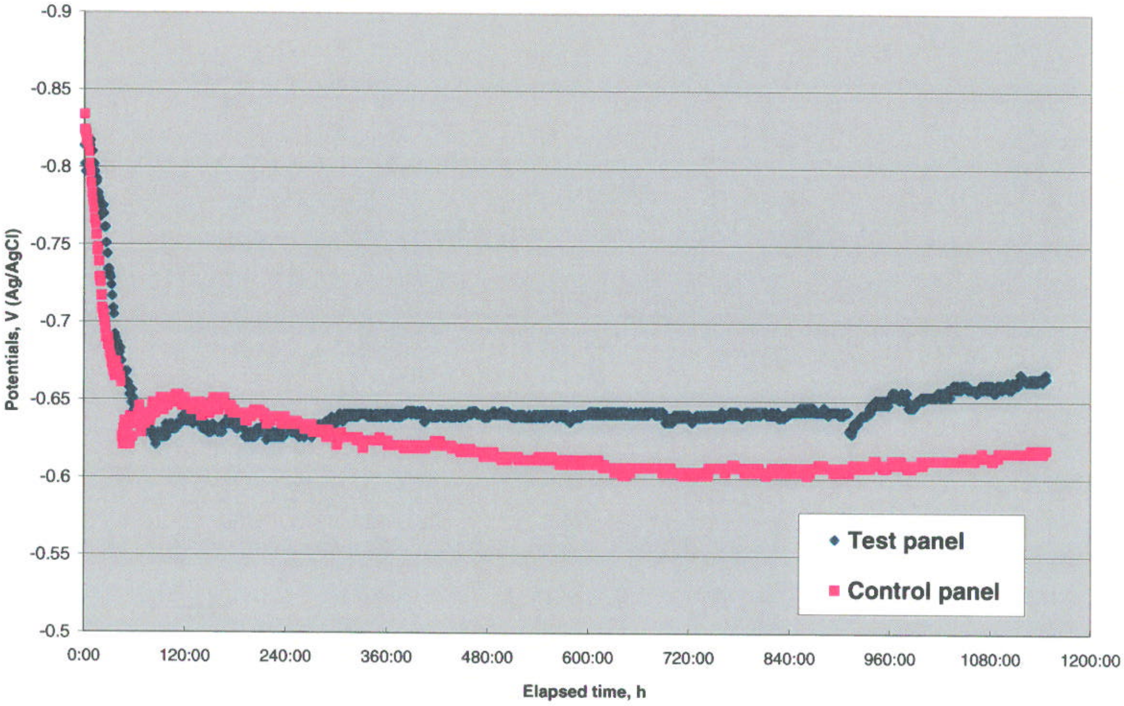


Figure 9 - Potential –versus-elapsed time curve (Experiment Two)

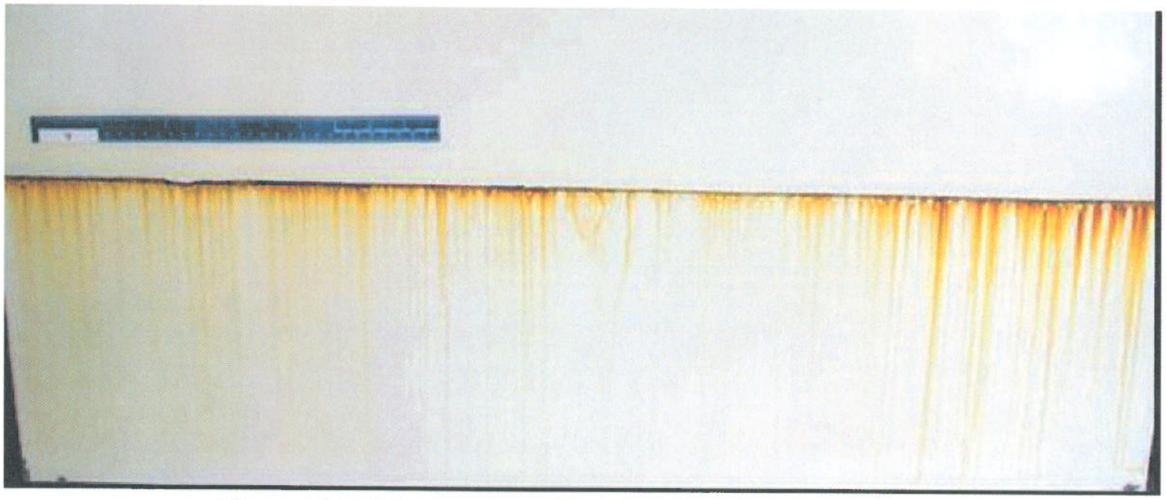


Figure 10 - Test panel appearance (Experiment Two)

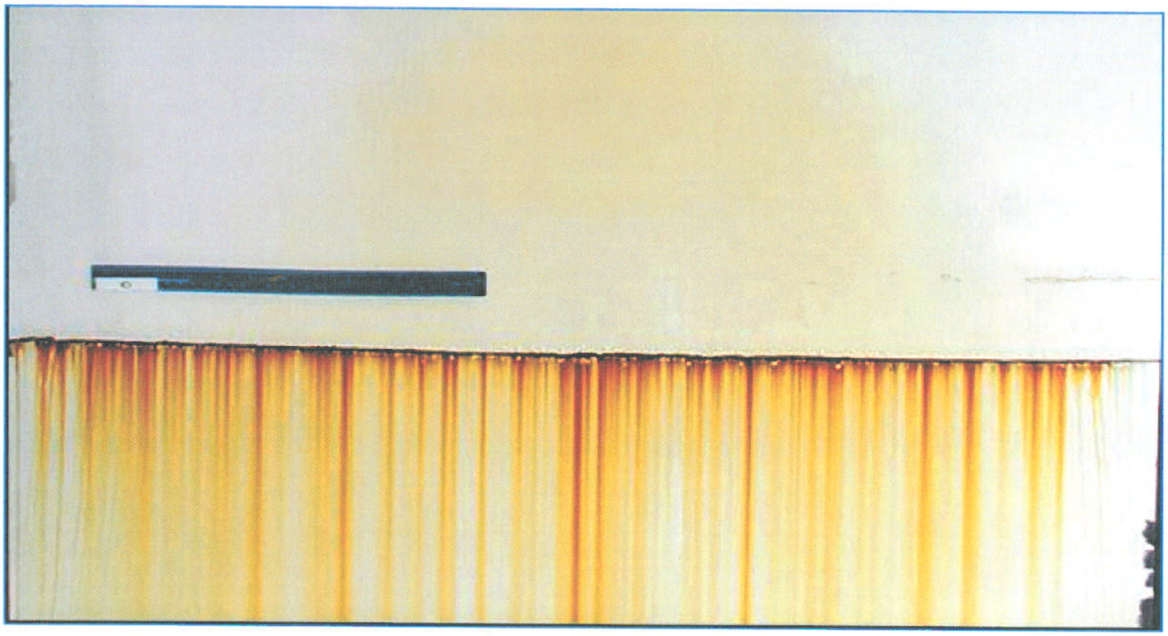


Figure 11 – Control Panel Appearance (Experiment Two)

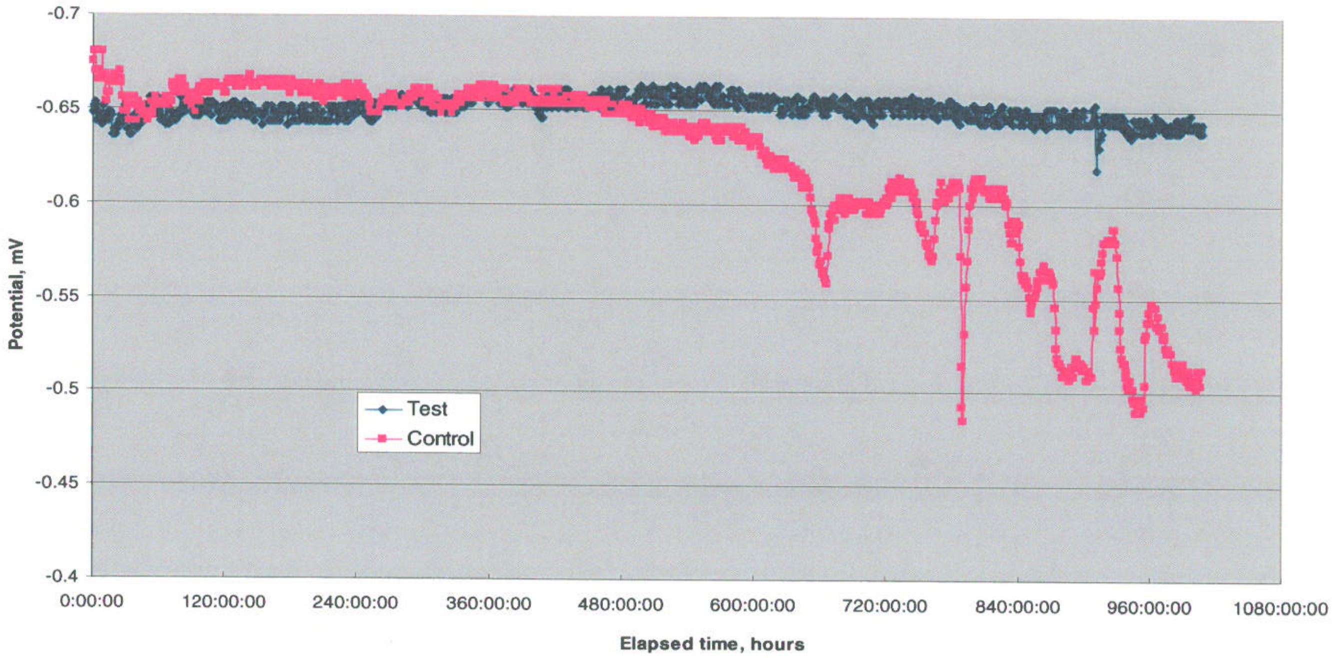


Figure 12. Potential –versus-elapsed time curve (Experiment Three)

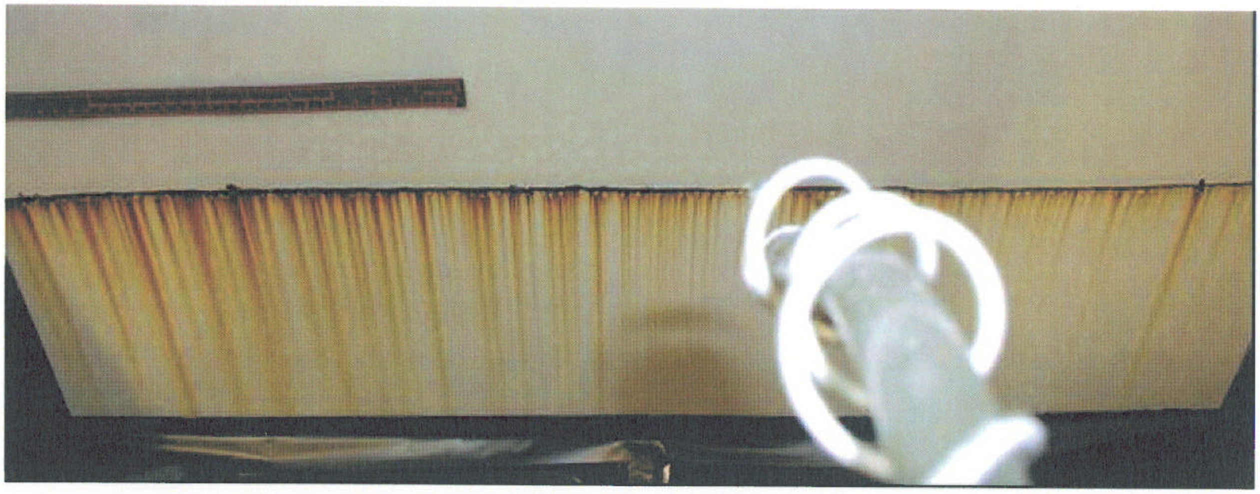


Figure 13 - Test panel appearance (Experiment Three)

Figure 14 - Control panel appearance (Experiment Three)

The effect of a 150mV difference in potential on the rate of corrosion of an automobile body panel is significant and may be determined by applying the following formula, which is derived from electrochemical kinetic (Tafel) theory:

$$CR = (CR)_0 exp\ (\alpha F E_{corr}/RT) \qquad (1)$$

where CR is the corrosion rate, $(CR)_0$ is a constant, α is the transfer coefficient, F is Faraday's constant (96,487 C/equiv.), R is the universal gas constant (8.314 J/K.mol), T is the Kelvin temperature (298.15 K), and E_{corr} is the corrosion potential. This equation holds for all values of the corrosion potential and hence we may write:

$$(CR)_{test}/(CR)_{control} = exp\{\alpha F[E_{corr/test}-E_{corr/,control}]/RT\} \qquad (2)$$

where $E_{corr/test}-E_{corr/,control} = -0.150$ V and $\alpha = 1.0$ [S. M. Sharland, C. P. Jackson, and A. J. Dier, Corrosion Science, Vol. 29, page 1149, (1989)]. Substitution of the values for the various parameters yields $(CR)_{test}/(CR)_{control} = 0.00291$. That is, the corrosion rate is reduced by 99.7 % by the Module on the Test Panel compared with the Control Panel Even if the difference in the corrosion potential is reduced to –0.100V, the ratio $(CR)_{test}/(CR)_{control} = 0.0204$ and hence the corrosion rate is reduced by 98 %. To put these numbers in perspective, imagine that a system (automobile) fails by corrosion without the Module in a time of one year. If the Module were attached, the failure time would be 343 years if the potential is displaced by 150mV in the negative direction and 49 years if the potential was displaced by only 100mV. Such results are particularly significant when one considers that the average life of a vehicle is of the order of 10 years. Accordingly, these calculations demonstrate that the reduction in corrosion rate is substantial and that the Module is an effective corrosion control device.

As discussed in greater detail in the "without prejudice" presentation made to the Competition Bureau on May 30, 2003, the Module appears to reduce the rate of corrosion by limiting the passivation of the zinc galvanizing, thereby enhancing the efficacy of galvanization in protecting the underlying steel. As evidenced by the experiment described herein, the Module does not require a continuous aqueous phase to exist between the corrosion site and the point of application of the electrical signal. The Module utilizes a high frequency AC induced current that operates on the surface similar to an antenna. During our earlier meeting with the Competition Bureau, we were requested to produce a graph showing the current profile for the Module. Please see the graphs at Figure 15 below:

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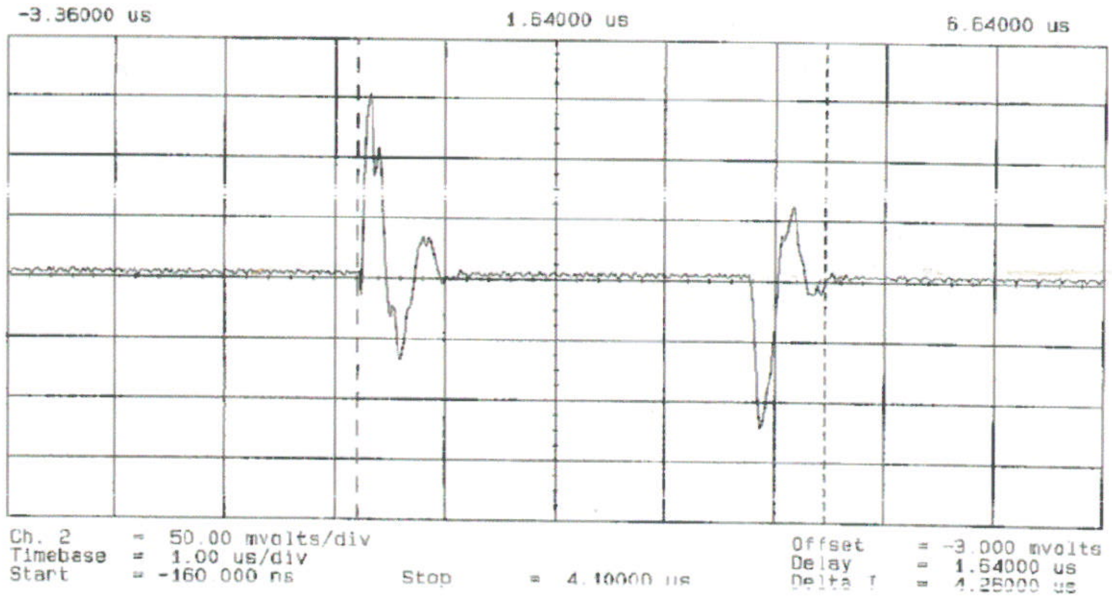

Ch. 2 = 50.00 mvolts/div
Timebase = 1.00 us/div
Start = -160 000 ns
Stop = 4.10000 us
Offset = -3.000 mvolts
Delay = 1.64000 us
Delta T = 4.26000 us

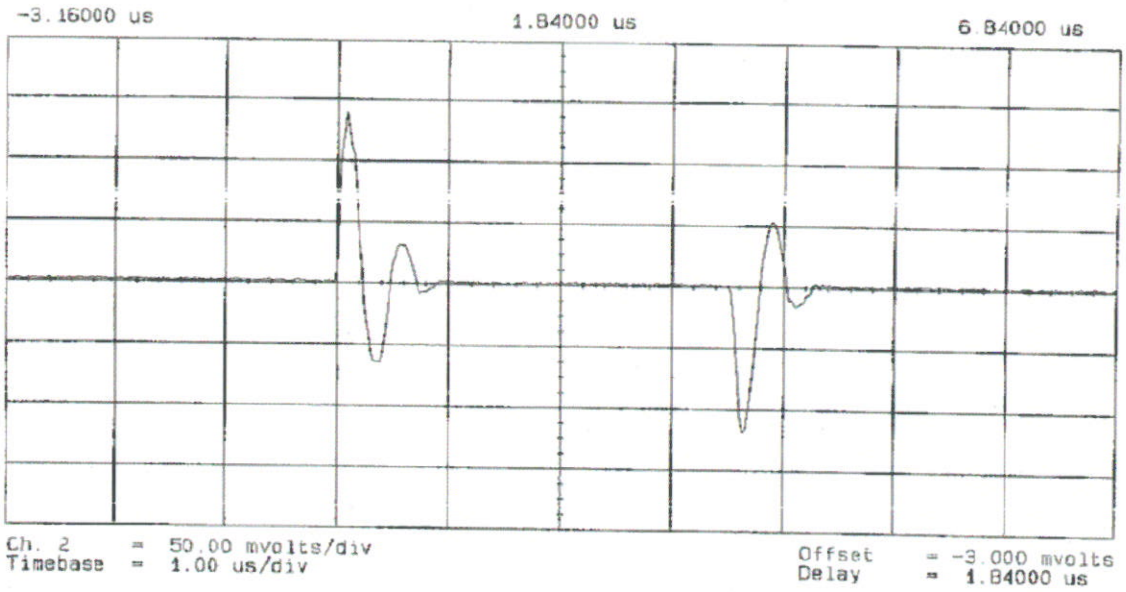

Figure 15 – Current Profile for Module

The data for the above current profile was recorded using an HP 54100D Digitizing Oscilloscope. The current shown is the current in the blue wire of the Module that is connected to the Test Panel. From the plots provided it is clear that the current pulse is not a DC type but is a pulsed AC type.

As one can see, the current rises predominantly in the positive direction at the leading edge of the voltage pulse, followed by a pulse of current predominantly in the negative direction. This is to be expected, since the current in the blue wire is passed through a capacitor and is related to the time derivative of the voltage across the capacitor, as given by:

$$I = C\frac{dV}{dt}.$$

where I is the current through the capacitor and hence through the blue wire (the capacitor is connected to the blue wire), C is the capacitance, V is the voltage pulse across the capacitor (shown in a graph in the presentation), and t is time. At the leading edge of the voltage pulse, the time derivative dV / dt is strongly positive resulting in a positive current, while at the trailing edge of the pulse the time derivative is strongly negative resulting in a negative current. Neither current pulse is entirely positive or negative, because neither the leading edge nor the trailing edge of the voltage pulse V monotonically increases or decreases. This is due to the fact that there are ripples on both the leading edge and trailing edge caused by ringing of the voltage waveform, which itself is due to resonances caused by parasitic inductances, such as those due to the wires themselves. Also, the time between the current pulses is 4.26 μS. This is in keeping with the nominal pulse width of the rust inhibitor unit of 4.0 μS

Unlike impressed current cathodic systems, the Module's effect is not limited to the region where a continuous electrolyte film exists between the point of application of the electrical signal (the anode) and the area being protected. Rather, similar to an antenna, the current from the Module covers the entire surface and does so instantly. As such, the Module is effective in reducing the rate of corrosion over the entire surface of a vehicle. For further discussion of the theory of operability of the Module, please see the comments made in the "without prejudice" presentation made to the Competition Bureau on May 30, 2003.

IV. SUMMARY AND CONCLUSIONS

The work described in this report was designed to establish the efficacy of the Module in reducing the development of corrosion damage on automobile panels and to indicate, to the extent possible, the mechanism by which protection is accomplished. The results of this study may be summarized as follows:

- The Module is effective in protecting steel automotive body panels, as evidenced by a shift in the potential of the exposed steel at the scribe in the negative direction;

- The mechanism of enhanced protection appears to be that the Module renders the galvanizing (a sacrificial anode) more effective than when a Module is not connected to the system;

- The mechanism of protection is not that of classical, impressed current cathodic protection. This is shown by the fact that the current or voltage applied to the panel by the Module is in the form of a repetitive pulse and not a direct current that is employed in impressed current cathodic protection systems, again demonstrating a vital difference between the latter and the Module;

- Unlike impressed current cathodic systems, the Module's effect is not limited to the region where a continuous electrolyte film exists between the path of application of the electrical current and the area being protected. Rather, similar to an antenna, the current from the Module covers the entire surface. As such, the Module is effective in reducing the rate of corrosion over the entire surface of a vehicle; and

- The frequency of the applied electrical signal is sufficiently high that the "skin effect", whereby current flow concentrates near the surface of a conductor, becomes a factor.

CC Technologies

SOLVING PROBLEMS THROUGH INNOVATION

CC Technologies is an engineering, research, and testing firm specializing in corrosion control, corrosion monitoring, materials evaluation and selection, asbestos analysis, and design and development of instrumentation and software.

CATHODIC PROTECTION SERVICES

Since its inception in 1985, CC Technologies has grown to a staff of nearly 100 people. We have Ph.D. scientists and engineers in a number of relevant fields including Metallurgical, Materials Science, Polymer Science, Chemical, Ceramic, Electrical, Mechanical, and Geological and Petroleum Engineering, Theoretical and Applied Mechanics and Environmental Geology.

Cathodic Protection is used to control the corrosion of a wide variety of buried and submerged metallic structures. It has been demonstrated to be a cost effective way to extend the life of a structure and to ensure integrity throughout its operating life. The engineers and researchers at CC Technologies are recognized throughout the world for their contributions in promoting and advancing cathodic protection.

Our highly qualified staff includes both registered engineers and NACE International certified specialists and technicians with training and experience to assist clients in choosing the correct application of cathodic protection technology. These specialists have designed systems to operate and control corrosion in virtually every environment where cathodic protection presents a viable solution. Our extensive knowledge of the operating parameters and long-term performance characteristics of system components, allows us to choose the most appropriate systems to achieve the technical objectives, while carefully considering the client's economic requirements .

CC Technologies has developed new methods for monitoring the effectiveness of cathodic protection for complex structures in complex environments. Our staff of engineers has even met the challenge of designing new and more effective cathodic protection systems for the Trans-Alaska Pipeline System.

Available services include:

- Corrosion Assessment
- Cathodic Protection Design
- Testing and Analysis of Existing CP Systems
- Rectifier and Remote Monitoring Maintenance and Repair
- Project Management
- Construction Management

Our research and testing division covers all aspects of cathodic protection, including:

- Fundamental Research on Cathodic Protection (e.g. Application and Criteria)
- CP System Computer Simulation
- System Component Evaluations
- Anode Testing (ASTM)
- Coating Compatibility with Cathodic Protection

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