

Accuracy and Characteristics of 2012 Honda Event Data Recorders from Real-Time Replay of Controller Area Network (CAN) Traffic

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ABSTRACT

Prior EDR testing methodologies required setting events in the airbag control module in the vehicle during controlled driving behavior. Duplicating events was nearly impossible, and it was difficult to separate how much differences in recorded speeds to reference speeds was due to measurement error, wheel slip, reporting time delays, or data truncation within the EDR. Recording thresholds have also increased making non-deployment and deployment events closer in magnitude, increasing the risk of accidentally exceeding the deployment threshold while setting events. The new methodology eliminates the risk of accidentally deploying airbags while gathering GPS and CAN bus data in the test vehicle. The techniques presented in this paper also allows gathering of data in vehicle without tampering with the airbag control module, which reduces the potential liability to testers using rental or borrowed test vehicles. The new methodology allows for repeatable testing and mapping the transfer function between the vehicle CAN bus data and the EDR. Should a manufacturer make a design change to an ACM EDR, identical inputs can be given to exemplar ACM's from before and after the changes to document any change in the transfer function. This methodology allows researchers the ability to re-create events of interest in a low-cost, repeatable manner.

The accuracy of the 2012 Honda CR-V and 2012 Honda Civic event data recorders were tested using this new two part methodology.

First, the test vehicles were instrumented with both a Racelogic VBOX differential GPS speed measurement system and a Vector CAN data logger. The measurements from the VBOX were transmitted onto the vehicle's Controller Area Network (CAN) bus that also contained messages reflecting indicated vehicle speed, brake status, accelerator pedal position, steering wheel angle, individual wheel speeds and other signals. This put the GPS speed data on the same time base as the vehicle CAN speed signal such that no additional synchronization was required. This permitted analysis of the accuracy and update rate of the vehicle speed CAN signal, which is the source for speed data used in the Event Data Recorder (EDR).

Second, a system was developed to replay the recorded CAN data to an exemplar airbag control module in the laboratory, such that the exemplar was receiving data exactly as if it were in a moving vehicle. A pneumatic fixture with a slide was built to allow the exemplar module to be accelerated to nearly 10 km/h (6 mph) and then stopped in about 80 msec. to create a non-deployment event that met the minimum 5 mph delta-V over 150ms threshold. Actuation of the event setting fixture was computer controlled (using LabVIEW) and synchronized with the CAN replay system so that the desired test condition could be replicated precisely. An external accelerometer was mounted to the airbag control module to mark when the ACM began recording and the accelerometer data was matched to the acceleration and delta-V data in the EDR. The desired test conditions were replayed to the airbag control module and a series of non-deployment events were set. Each event on the EDR data was read using the Bosch Crash Data Retrieval system.

The EDR data was compared to the inputs, and it was determined that the two byte vehicle CAN bus signal was truncated to the next lower whole km/h when recorded in the EDR. Under steady state conditions the speed data was accurate within 2%. The vehicle CAN signal published new values every 0.1 seconds, and the CR-V updated values every 0.1 seconds, but the Civic only updated every 0.6 seconds during hard brake events. During hard ABS braking events the

expected wheel slip led to the vehicle speed signal under-reporting ground speed, but the delay in the CAN bus update rate resulted in over-reporting ground speed in many of the tests.

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INTRODUCTION

The objective of this paper is to describe the methods and results of assessing the accuracy of the Event Data Recorder (EDR) information on two new Honda vehicles, shown in [Figure 1](#) and [Figure 3](#). The EDR data is stored on the supplemental restraint system (SRS) modules that are shown in [Figure 2](#) and [Figure 4](#). The SRS module gets its information from external Controller Area Network (CAN) bus messages and from its internal sensor system.



Figure 1. 2012 Honda Civic with VIN 2HGFB2F55CH585517



Figure 3. 2012 Honda CR-V with VIN 2HKRM4H78CH622194.



Figure 4. SRS module located to the right of the accelerator pedal in the CR-V.



Figure 2. SRS module in the 2012 Civic located in the fore section of the center tunnel.

LITERATURE REVIEW

While the Bosch CDR tool help file and the Data Limitations section in CDR reports contain useful information about accuracy limitations, actual test data is needed to quantify and verify the information. EDR precrash speed data was first recorded by General Motors beginning in some 1999 models and the first paper to address precrash EDR speed data accuracy was by Chidester in 1999 [1]. Chidester's team included General Motors personnel, and the paper listed the accuracy of speed data as $\pm 4\%$ of the recorded value, implying that differences between EDR recorded values and ground speed may be higher at greater speeds. This paper was written before the start of 1999 model-year production, and the 4% articulated a design tolerance that could include tread wear, tire pressure variations, and other design variations. Test data was not yet available. The paper noted that the various data elements were recorded asynchronously, raising the issue that the

timing labels associated with precrash data may not be precise regarding when the data was actually recorded. Data points labeled “-1” may actually be recorded any time during the second before algorithm enable (AE).

In 2003, Lawrence [2] created artificial crash signals during normal driving and published data finding the GM EDR speed to be under reported by 1.5 km/h (about 1 mph) at low speeds and over reported by 3.7 km/h (about 2.3 mph) at high speed when compared to reference instrumentation, under steady state conditions. This paper raised the concern that differences between recorded speed values and speeds obtained with external instruments may not only have some relationship to vehicle speed, but that there may be some type of offset since the sign of the difference changed between low speed and high speed.

In 2005, Niehoff reported the recorded pre-crash speed from 28 NHTSA crash tests of GM and Toyota vehicles [3]. The crash tests were at speeds of 48 and 64 km/h (30 to 40 mph) and the data was reported as “within 1 mph”. The precrash EDR data was typically reported in whole miles per hour and the reference instrumentation was reported with either one decimal place or no decimal places. Data was not reported as a percentage of speed, which was appropriate given the combination of resolution of the data and the relatively low speed of the test.

In 2006, Wilkinson reported on the timing of EDR data in General Motors sensing and diagnostic modules, indicating that the actual time between labeled data points may vary from the interval suggested by the labels [4]. In 2011, Bare et al. reported on precrash data timing of the GM SDM-DS module, indicating that the timing of the last data point recorded can vary from the label “-1” that is placed on that last data point [10]. This work addresses some of the same type of timing issues as Wilkinson but used more sophisticated instrumentation and was on a more recently designed EDR. Bare also suggested that data timing was far closer to the reported “1 second” interval than reported by Wilkinson.

In 2008, Gabler [5] reported on the accuracy of precrash speed data for 33 crash tests ranging from 40 to 56 km/h (25 to 40 mph) on 2004-2007 model year vehicles. 32 of the tests were on GM vehicles and one was on a Toyota. The paper states that all of the speed data was within 3%, except for test 5310 on a 2005 Buick Rendezvous that reported low by 22% (27 mph vs 35mph actual). Gabler did not explain the anomaly.

Takubo and Ishikawa et al. reported on Japanese New Car Assessment Program (NCAP) tests and additional tests intended to mimic real world crashes [6, 7, and 8]. They published two SAE papers and one Enhanced Safety of Vehicles (ESV) paper, with each successive paper including some additional tests. As such, the most complete data set as of this writing can be found in the latest, though the earlier papers contain some minor details which are not reproduced in the most recent paper. They reported that the cars were mostly 2007 and 2008 Toyota Corollas (00/02 EDR), and that

“the pre-crash velocities [reported by the] EDR were highly accurate and reliable but generally lower than the optically derived velocities.” In 14 full overlap barrier tests the EDR speed data was -2.0% different than the reference instrumentation, with a range of -6.3 to +1.9%, and an RMS of 2.6%. For the 14 Offset Deformable Barrier (ODB) tests, the EDR averaged -2.1% different than the reference instrumentation, with a range of -4.1% to 0.0% and an RMS of 2.7%. The negative average value is consistent with the CDR Data Limitations which state the speed data is truncated to the next lower even km/h value.

In 2009, Ruth [20] reported on the speed data accuracy of Chrysler vehicles. In 113 km/h steady state conditions the 2008 Jeep Commander EDR reported from -1.18 to +0.32 km/h different than GPS, and Dodge Dakota EDR reported from -3.09 to -0.98 km/h different from the GPS reference instrumentation, with the average error being below zero due to truncation of any fractional km/h to the next lower whole number in the EDR. In 2010, Bortolin [21] reported that a 2008 Dodge Caravan EDR reported from -1.74 to +0.63 mph of GPS reference speeds from 11 to 61 mph

In 2008, Ruth [22] reported on the steady state speed data accuracy of Ford Powertrain Control Module event data recorders at speeds from 48 km/h to 113 km/h (30 to 70 mph). For the 2005 Ford Crown Victoria, the data was accurate within 1.0%. In 2010, Ruth reported on the accuracy of the 2009 Ford Crown Victoria Powertrain Control Module (PCM) EDR in steady state and heavy braking [16]. The Crown Victoria vehicle speed sensor is on the transmission output shaft, and during heavy ABS controlled braking wheel slip results in the speed being under reported by an average of 5% at 97 km/h. This recognized that the “vehicle indicated speed” on the speedometer or CAN bus obtained from a sensor measuring proportional to wheel speed may not represent the ground speed of the vehicle under heavy braking conditions.

In 2011, NHTSA conducted an evaluation of Toyota pre-crash data accuracy [9]. The paper reports 28 staged events using two 2007 Camrys (04/06 EDR) and a 2008 Highlander (04/06 EDR) as bullet vehicles striking the back of a 2006 Tacoma (00/02 EDR) target vehicle with a 3 to 8 km/h (2-5 mph) closing speed in order to create a nondeployment event the EDR would capture. NHTSA defined the vehicle speed tolerance as ± 2.3 km/h (1.5 mph), and was aware that the recorder temporary buffer only refreshed speed data every 0.5 seconds. Around each EDR data point they created a “window of acceptance” of ± 2.3 km/h (1.5 mph) that extended back in time 0.5 seconds. If the GPS speed data crossed anywhere in the window, then it was deemed within the acceptable tolerance. NHTSA concluded that 100% of the precrash speed data fell within the tolerance and time window. The ± 2.3 km/h window was wider than the ± 0.2 km/h range expected from the data resolution cited in the CDR Data Limitations.

In 2011 Comeau [11] reported on Toyota crash tests conducted by Transport Canada, comparing their measured

impact speed to the EDR-recorded speed “at $-1s$ ”, just prior to the impact. They compiled data from 14 full frontal rigid barrier tests at 40, 48, and 56 km/h (25, 30 and 35 mph), 11 with speed data. They showed that the EDR-reported speed ranged from -2.27 to $+0.2$ km/h below the GPS measured speed, with the reported speed consistent with the recording resolution of the next lower even km/h stated in the CDR Data Limitations.

In 2012, Ruth [17] reported on 2010 and 2011 Toyota Camry EDR speed data. Data limitations stated that the Toyota truncated speed data to the next lower even number of km/h, such that the difference between EDR and GPS would be expected to from -2.0 to 0 km/h in the absence of other calibration or random measurement errors. For steady state conditions, differences for the 2011 Camry at 113 km/h (70 mph) ranged from -3.0 to -0.4 km/h (-1.9 to -0.2 mph). For the 2010 Camry, for the 113 km/h (70 mph) tests the difference ranged from -2.1 km/h to $+0.2$ km/h. The best fit line has a slight slope indicating a larger difference would be expected at a higher speed, but the slope was not statistically significant. During maximum ABS braking, Ruth identified that in addition to the wheel slip under reporting phenomena, data recorded for the last point prior to impact may be up to 0.5 seconds old, resulting in over reporting speed. This research reinforced that for speed at impact calculations, the timing of the last speed data point recorded was important.

In 2012, Brown [18, 19] reported on 2010 Toyota Camry speed data. The CAN speed data under steady state conditions was found to under report by 2.7%. Under steady state speed conditions the standard deviation ranged from 0.21 to 0.73 km/h.

To summarize the literature, EDR speed data was first published at $\pm 4\%$ in 1999 in a paper specifically addressing GM recorders. Since then specific GM, Ford, Chrysler and Toyota EDR's have been tested and the data has been found to be more accurate than the previously published 4% under steady state conditions. Tests have evaluated a vehicle at a point in time, and most indicate the EDR data is on average under-reported due to some form of truncation of the raw data to the next lower integer or even integer number. Tire wear over the life of the vehicle has not been addressed since the original 1999 paper. The more recent literature also documents that under maximum ABS braking conditions, the EDR will accurately report the average drive wheel speed it is measuring, but it will under-report the true ground speed. Tests on 2010/2011 Toyotas indicated the CAN bus updated only every 0.5 seconds, and during braking the reporting delay could lead to the last speed data point being over-reported.

As of this writing no other published research on the accuracy of the Honda EDR is available.

METHODOLOGY

The data stored on the Honda SRS module can come from one of two places: 1) the internal sensor circuits or 2) the

messages existing on the Controller Area Network (CAN) bus. The source for pre-crash information typically comes from the CAN messages and the SRS internal accelerometer provides the data source for the delta-V data. Therefore, if the CAN message data is known at the time of recording, then the data storage mechanism can be systematically studied by comparing the retrieved event data to the known data on the CAN bus. Also, if an external reference is known for a particular CAN bus message value, then the data on the CAN bus can be assessed. A graphical depiction of the methodology used for this paper is presented in Figure 5 as a flow chart and this section describes the methodology in detail.

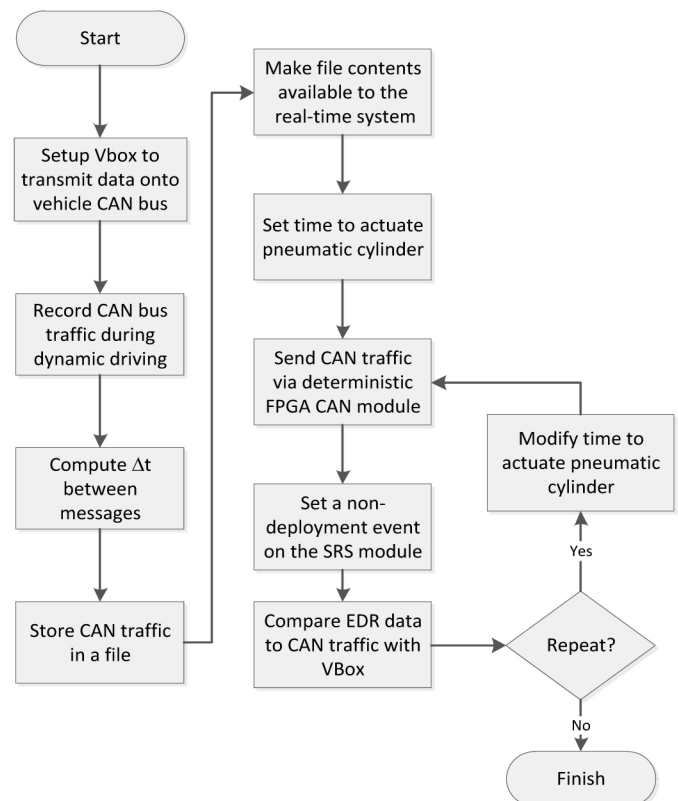


Figure 5. Methodology overview.

Data Collection

Data was collected from the two test vehicles under a variety of driving conditions including steady state, maximum ABS braking, acceleration, figure 8's, yaws, and normal driving. For the maximum ABS braking condition, multiple test runs were made from a highway speed (approximately 113 km/h or 70 mph) and multiple runs from a lower starting speed (80 km/h or 50 mph). These data were archived so they could be used as sources to replay the data back to the SRS module in the lab.

Each car was instrumented with a Racelogic VBox 3i and a Vector CANCaseXL logging device. The VBox was programmed to transmit 100 Hz GPS-based vehicle speed on

CAN ID 0x302 and time on CAN ID 0x301 over the vehicle's CAN bus according to the VBOX 3i User's Manual. To ensure that no data would be lost because of this transmission, CAN data was logged before the addition of the VBOX and it was determined IDs 0x301 and 0x302 were not used by the Honda CAN network, making them available for VBOX data. An example of CAN data from a hard-brake test for the Honda Civic is shown in Figure 6. It contains CAN data that show the engine speed in RPM, indicated vehicle speed, accelerator pedal position, and brake status. Additionally, it shows the VBOX speed that was transmitted onto the CAN network. This is fundamental to this research, because it enables all data to be synchronized by using the same data bus. While injecting the VBOX data onto the CAN, the busload hovered around 40%, thus no issues regarding normal CAN bus behavior and timing were suspected.

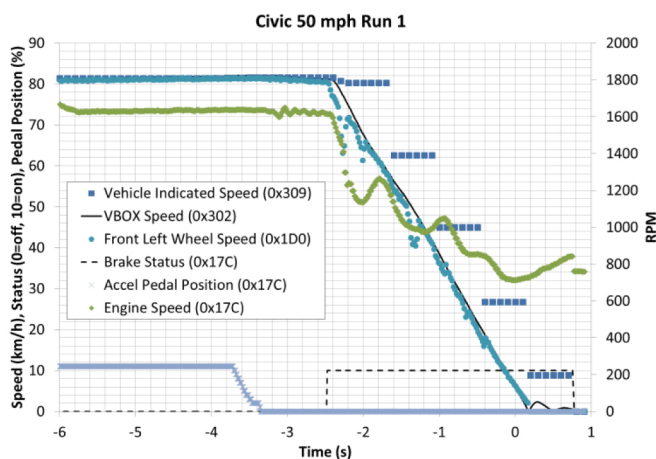


Figure 6. CAN data showing a hard brake on the Civic from 50 mph

By injecting varying CAN data under different message ID's it was determined the EDR was recording speed from message 0x309 bytes 4 and 5 (counting from zero). This message was also perceived to track with the display on the digital speed indicator in the instrument cluster. The methodology for determining CAN sources is discussed in the "CAN Identifier maps" section of this paper. The graph shown in Figure 6 demonstrates that the indicated vehicle speed can be nearly 0.8 seconds late in reporting the value. The front left wheel speed found from the message 0x1D0 bytes 0 and 1 show that wheel speed tracks the VBOX speed appropriately during a tire slip with the ABS system engaged. Based on this observation and the fact that the data were synchronized using the CAN bus, the timing delays found in message 0x309 are real. Furthermore, the indicated vehicle speed message updates every 0.1 seconds but changes value every 0.6 seconds in this test. Therefore, it is expected that the Honda Civic will likely have a repeated data point on the 0.5 second intervals shown in the EDR records. However, not all data gathered show the 0.6 second wait to change, which

suggests there is some manipulation of a primary speed source before it is formed into an indicated vehicle speed value.

The observed repeated values could not be properly explained without knowledge of the design and intent. Based on private communication with representatives from Honda, it was learned that:

"The data element 'Speed, Vehicle Indicated' is received over the CAN bus from the combination meter (Honda's name for the Speedometer and Odometer together), and is sampled every 500ms by the EDR. It is a direct representation of the pointer position, or in the case of the Civic, digital display, indicating vehicle speed."

All combination meters apply some level of filtering, hysteresis control, and with digital display, a hold timer so that the displayed speed can be visible and understood by the driver. These parameters can vary for each model based on the mechanism applied. The CAN value output will match the speedometer displayed value."

Based on this research, it appears the 2012 Honda Civic is calibrated such that new values are held 0.6 seconds to allow the driver to have time to focus on it and see it. The displayed value is formed into a CAN message and presented to the CAN bus by the combination meter (as opposed to an engine controller or some other instrument). As a result, values sampled by the EDR every 0.5 seconds may occasionally repeat a speed value during hard braking conditions. If this is observed, this explanation is confirmation that the most recent speed value is relatively fresh, between 0 and 0.1 seconds old, and the older value is 0.5 to 0.6 seconds old. If there is a time series of speed data points during hard braking, the relative age of each point could be inferred by where in the series it is relative to the data point that was repeated. Similarly, if there were no repeated data points, the age of those points can also be inferred.

The data shown in Figure 7 show the CR-V indicated speed updates and changes every 0.1 seconds. The speedometer on the CR-V used a dial gage as opposed to a digital display. There were no repeated CAN buss messages for indicated vehicle speed detected for the CRV. The wheel speed signal drops as the braking commences and periods of higher slip are shown. The indicated speed tends to follow a subdued path when the wheel speed drops, indicating an averaging effect for the indicated speed. With no wheel slip, the indicated vehicle speed closely matches the VBOX speed.

All CAN data were logged to a Vector CANCaseXL Log device that recorded time, message spacing, ID, Data Length Code, Data entries, and Bus statistics. These binary files were converted to a text based log file and parsed to extract the data of interest. Because these files contained all the CAN

data, the file sizes were large. Therefore, the runs used for replay were trimmed to nearly 7 seconds so the hard brake events were captured along with the steady-state speed section proceeding as shown in [Figure 6](#) and [Figure 7](#). Also, some of the non-interesting CAN messages were removed from the dataset since they had no meaning to the SRS module.

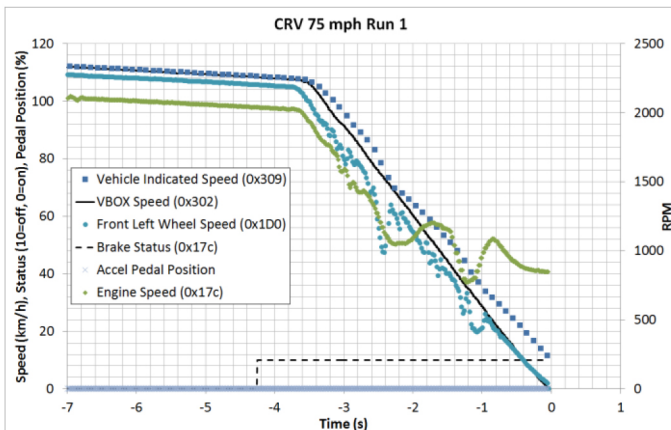


Figure 7. CAN data showing a hard-brake on the CR-V from 75

Non-Deployment Event Generation

The SRS modules need to experience an event that will enable the recording algorithm. According to the Data Limitations of Version 8.1 of the Bosch CDR report: "A non-deployment event is recorded if the change in longitudinal or lateral velocity equals or exceeds 8 km/h over a 150 ms timeframe..." Since multiple tests were desired, only non-deployment events were generated to enable recording. This was achieved using a linear sled and a pneumatic cylinder that was designed to provide a delta-V around 10 km/h in less than 150 ms. This deceleration occurs as the carrier with the SRS module reaches the end of the motion and comes to a stop. An external accelerometer was used to measure the accelerations and independently determine the delta-Vs. An annotated photograph of the test setup is shown in [Figure 8](#).

The actuator is a pneumatic cylinder with a stroke of approximately 10 cm. The air sent to the pneumatic cylinder was controlled using a pressure regulator in series with a solenoid valve. This solenoid valve is normally closed and is opened in one of two ways: (1) a manual switch located near the rail or (2) the output from the National Instruments NI 9478 digital output (DO) module. The DO module switch is controlled from the FPGA program and was engaged based on a user specified time, which enabled an event to be repeatedly generated during a specific section of the CAN history. Another switch was used as a start/stop switch that began and ended the program. It ensured the cylinder was only actuated when the user was ready and the area was safe.

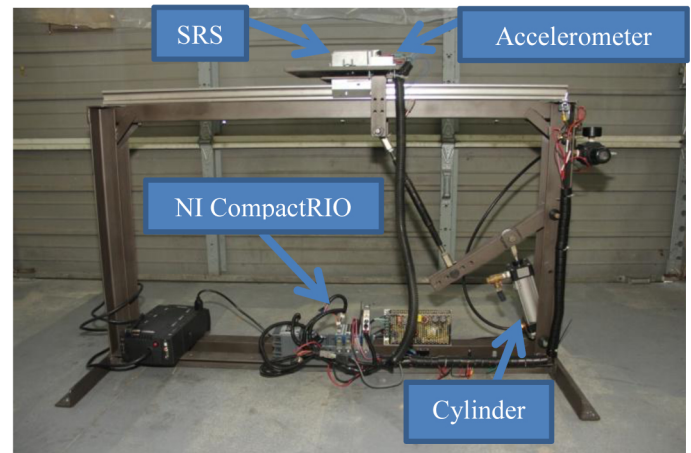


Figure 8. Non-deployment event generation mechanical test setup.

A Spectrum 15200B ± 35 g accelerometer with a DC-400 Hz response was used to measure the acceleration the SRS unit. The acceleration trace was time correlated to the CAN message transmission. This synchronization allows Algorithm Enable (t0) to be established in the external CAN data sent to the SRS module.

The electronic communication schematic of the test apparatus is shown in [Figure 9](#). The CAN network connects both CAN ports of the NI 9853 high speed CAN module, OBD II port, SRS module, and the female banana plug test points. The CAN information is transmitted from the CAN0 port of the high speed CAN module and recorded by multiple devices (SRS module, CAN1 port, and possibly the banana plug test points). The Honda SRS module requires an additional wire, the K-Line, to be connected for communications with the Bosch CDR tool. The SRS connector pin-out is shown in [Table 1](#).

Table 1. 2012 Honda SRS Connector A and OBD-II pin out.

SRS Pin	Signal	OBD-II Pin
19	K-Line	7
20	CAN H	6
21	CAN L	14
36	GND 1	5
37	GND 2	5
38	VBAT 1	16
39	VBAT 2	16

CAN Replay Experiments

The test setup and software implementation described in this section enables experiments to study the timing and accuracy of the data on the Honda SRS modules. The first set of experiments is to assess the accuracy of the CAN data compared to external references. To do this, the CAN

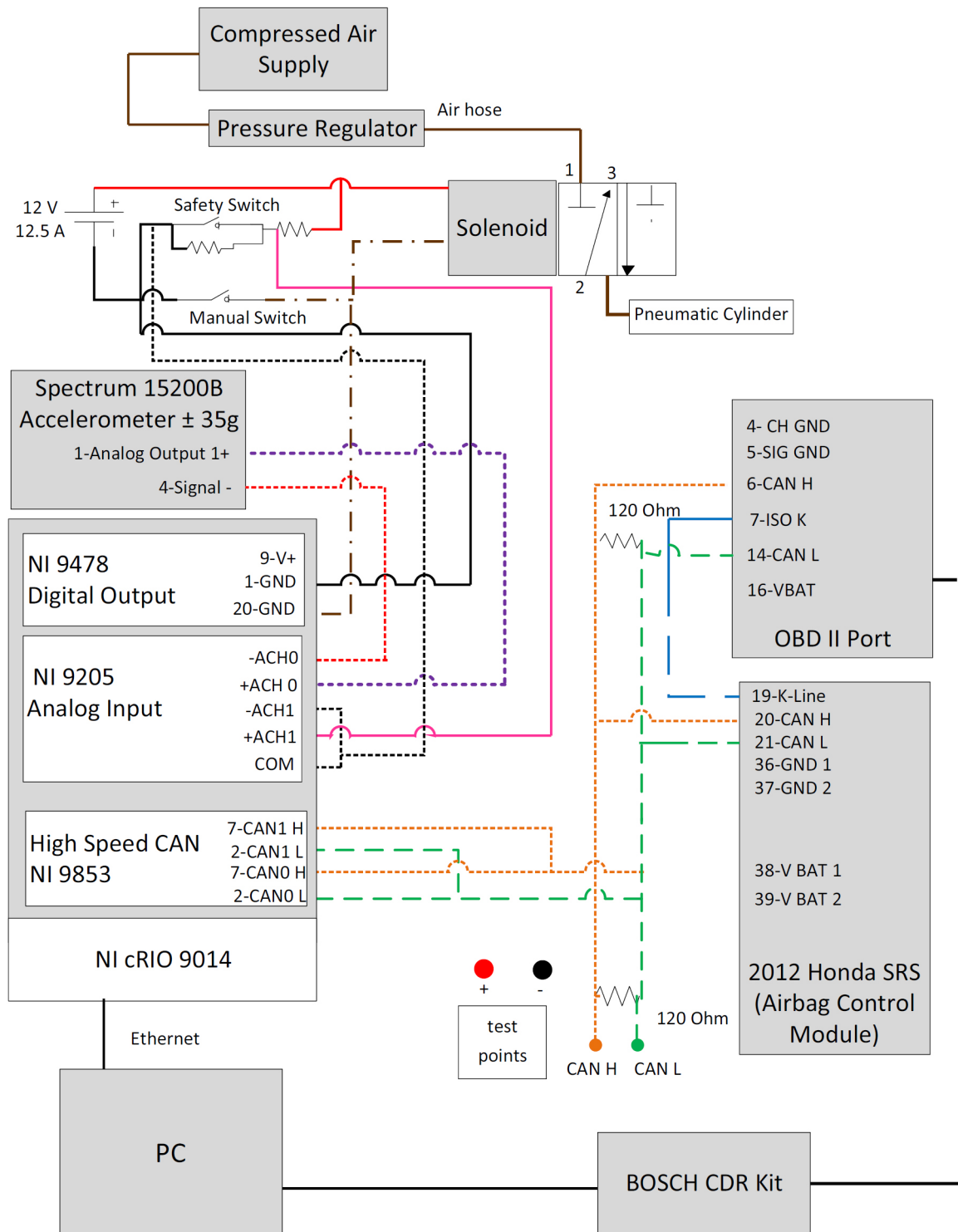


Figure 9. SRS module replay system schematic.

messages were cataloged and characterized so values shown in the CDR report can be attributed to the correct CAN messages. Once some CAN messages were known, the CAN data can be compared to external references to gain a sense of the CAN data accuracy. Finally, the timing and data storage algorithms can be evaluated through reading SRS module

data with the Bosch CDR kit after repeatedly setting non-deployment events for the same set of CAN message traffic.

For each run, the timing was verified by comparing the timestamp produced by the VBOX during the driving test to the recorded CAN from the replay. The VBOX 3i message encoding the time was also transmitted during the tests using