

An Examination of Snapshot Data in Caterpillar Electronic Control Modules

2011-01-0807

Published
04/12/2011Timothy P. Austin
Wisconsin State PatrolMichael J. Farrell
Fox Valley Technical College

Copyright © 2011 SAE International

doi:[10.4271/2011-01-0807](https://doi.org/10.4271/2011-01-0807)

ABSTRACT

It has been recognized that Event Data Recorder (EDR) technology incorporated into the Electronic Control Modules (ECMs) of on-highway heavy truck engines can be a benefit to motor vehicle collision investigation and reconstruction [1,2,3,4,5,6,7]. Such beneficial features include the snapshots recorded by many Caterpillar engines. These snapshots, which are triggered by engine faults, operator input, or by what is called a “Quick Stop,” record engine operation and parameters surrounding the event. Past research has reported that while snapshot data are accurate, the documented event time may be off by 24 hours in some ECMs, notwithstanding the module’s clock settings being correct [7]. Furthermore, other research has suggested that some modules may report the time interval between data points at approximately two times the actual duration [6]. In these cases, without a formal detailed study of snapshot records, the validity of the data may be brought into question should a snapshot be shown to have occurred on a different date, or should the timing of data be off.

This study performed a detailed examination of the data recorded by Caterpillar snapshots. In particular, the research identified known issues, as well as several previously unknown anomalies that can occur with different Caterpillar ECM types. Beyond documenting snapshot data, the authors also explored whether or not multiple snapshot records can be recorded at the same time, or, when this is not possible, how much time is needed between events for multiple electronic files to be written.

INTRODUCTION

As far back as 1998, police reconstructionists and engineers have been made aware of ECM technology. That year, Meyers, et al. indicated that engines manufactured by Cummins, Detroit Diesel, and Caterpillar use computerized engine controls that may store data surrounding a collision event [1]. Later that year, Ferrone and Goebelbecker wrote that the ECM “...often answers critical questions regarding vehicle speed and the driver’s actions leading up to, during and after a vehicle accident” [2]. Two years later, Goebelbecker and Ferrone expanded on their original publication, and presented a detailed discussion on ECM technology available as of that date [3]. In terms of court acceptance, a case study discussed in the Meyers article concerned the use of Caterpillar ECM data in a 1998 criminal proceeding in Fond du Lac County, Wisconsin, Circuit Court.

With respect to Caterpillar engines, there are three different physical ECM types. These include the Advanced Diesel Engine Management (ADEM) II, the ADEM 2000 / ADEM III, and the ADEM IV. These ECM types, for the most part, appeared in sequential order, and can be identified by the engine year and assigned Caterpillar engine prefix. An engine serial number beginning with “6NZ,” for example, indicates an ADEM 2000 C-15. Although the same in physical appearance, ADEM 2000 and ADEM III software tested differently, as is shown in this research. Examples of these Caterpillar ADEM ECMs are shown in [Figure 1](#).



Figure 1. ADEM II, ADEM 2000/III, and ADEM IV ECMs.

When most engine faults occur, a Diagnostic Record snapshot is created detailing vehicle and engine operation for 9.12 seconds before the fault and 3.36 seconds after, with data provided every 0.48 seconds. It must be noted that many of these faults require that the particular condition be observed by the ECM for a prescribed time duration before a fault code and snapshot are triggered. As an example, on a KCB C13 engine equipped with an ADEM III ECM, the code 102-4 (Boost Pressure Voltage Low) requires approximately two seconds from condition onset to snapshot generation, while code 108-4 (Barometric Air Pressure Voltage Low) requires approximately 30 seconds [8]. The Diagnostic Record is one of three different snapshot types documented by Caterpillar ECMs.

The second snapshot type is a Quick Stop file. This occurs when the wheel speed slows at a rate greater than that set in the ECM's configuration file. According to current Caterpillar literature, the Quick Stop rate, which is expressed in terms of miles per hour per second, is defaulted at zero mph/sec, thereby disabling this feature in many vehicles [9]. However, outside research has suggested that as of January 1, 2007, the default rate may be a non-zero number, thus actually enabling the feature [6]. In either case, when a Quick Stop is triggered, approximately 44 seconds before the event are written, followed by 15 seconds after, at a reported rate of 1.0 Hz. Like Diagnostic Records, these data include both engine and operational information.

The third type of snapshot that can be written is an External Trigger. This snapshot is initiated by the driver's intentional toggling of the truck's cruise control set/resume switch. An External Trigger can also be written through the Caterpillar Electronic Technician software, which is used to access snapshots and other ECM data. External Triggers are more closely related to Diagnostic Records as their recording time interval is 9.36 seconds before the event and 3.36 seconds

after the event at 0.48 second intervals. As was shown in this research, the different snapshot types are somewhat independent of each other in terms of how and when data are written. Throughout this paper, the general term "snapshots" refers to all three types unless otherwise specified.

Since the original Meyers and Ferrone publications, testing has been done to validate the data obtained from heavy truck ECMs. In particular, several authors found good correlation between the ECM reported speed and that obtained from independent sources, with some exceptions during wheel slip conditions [4,5,6,7, 16]. During such testing, Drew noted that while the data extracted from Caterpillar ECMs were accurate, the reported time interval between snapshot data points was doubled in some models. To correct the issue, the time intervals were reduced by half [6]. The research offered an expectation that this anomaly likely existed on Caterpillar ADEM III and early ADEM IV ECM models.

A second Caterpillar anomaly was observed by Messerschmidt, et al. In his 2010 study, the effects of power loss on Caterpillar, Cummins, Detroit Diesel, Mack, and Mercedes Benz ECMs were examined. While examining Caterpillar data, it was found that although the ECM clock was set properly, Quick Stop files were reported as having occurred on the following day [7]. Messerschmidt reported this to have occurred with the ADEM III ECM type.

The intent of this research was to examine all three Caterpillar snapshot categories from the different ECM types to confirm the anomalies identified by Drew, et al. and Messerschmidt, et al., to identify other issues of concern to collision reconstructionists, and to determine what modules and/or engines are susceptible to these errors. In doing so, 93 modules were tested, with ECM software dates ranging from 1993 to 2009. In some cases, ECM software was updated by the authors to the most current version available as of the test date. Test vehicles included those from seven different original equipment manufacturers (OEMs), and encompassed 27 Caterpillar engine models. In total, over 1100 controlled tests were performed.

During the testing, the following engine models were tested:

1. ADEM II (1994 to 1998 Engines)
 - a. 5EK 3406E
 - b. 6TS 3406E
 - c. 9CK 3176B
 - d. 9NS C-12
 - e. 2PN C-10
2. ADEM 2000 (1999 to 2001 Engines)
 - a. 2WS 3406E

- b. 6NZ C-15
- c. 2KS C-12
- d. 3CS C-10
- 3. ADEM 2000 HEUI Series (1998 - 2001 Engines)
 - a. 7AS 3126B
 - b. 8YL 3126B
 - c. CKM 3126E
- 4. ADEM III (2002 "Bridge" Engines)
 - a. MBN C-15
 - b. MBL C-12
 - c. MBJ C-10
- 5. ADEM III HEUI Series (2002 "Bridge" Engines)
 - a. HEP 3126E
- 6. ADEM III (2003 to 2006 Engines)
 - a. BXS C15
 - b. KCB C13
 - c. KCA C11
- 7. ADEM III HEUI Series (2003 to 2006 Engines)
 - a. 9DG C9
 - b. KAL C7
 - c. SAP C7
 - d. WAX C7
- 8. ADEMIV (2005 Engines)
 - a. MXS C15
 - b. NXS C15
- 9. ADEM IV (2007 and Newer Engines)
 - a. SDP C15
 - b. LEE C13

In addition to studying identified issues with snapshot data, the authors also attempted to determine the amount of time needed between individual diagnostic events in order for multiple files to be written. In other words, the authors sought to determine whether multiple snapshots stemming from a single crash incident could be recorded.

METHODOLOGY

In testing the various ADEM ECM types, engines were identified by their serial number prefixes as test candidates

from around Wisconsin. To examine the engines, the authors traveled to various locations throughout the state to perform one or more test batteries as was possible given truck availability. In some situations, driving tests were not performed due to ECM password protection preventing the programming of a Quick Stop rate. All of the testing took place between May 2010 and December 2010.

The bulk of the tests were performed at Fox Valley Technical College in Appleton, Wisconsin, the Door County, Wisconsin, Highway Department, the City of Appleton, Wisconsin, Department of Public Works, and the Winnebago County, Wisconsin, Highway Department. These were semi-closed facilities, thereby allowing files to be generated safely in a controlled environment. For moving tests, vehicle speeds were measured using a Vericom VC4000DAQ accelerometer. This unit samples acceleration on the X, Y, and Z axes at 100 Hz, and also allows for a Global Positioning System (GPS) receiver to sample at 5 Hz. Similar instruments have been recognized in past research for accuracy [7, 10-11].

In all moving test runs, a brake application was initiated during the testing in order to compare ECM data with speed readings obtained from the VC4000DAQ. When creating graphs for comparison, the data were synchronized using the point where speed was initially reduced from this brake application. This procedure allows for the interval anomaly initially discussed by Drew to be easily observed where applicable [6]. The synchronization using the point of speed reduction applies to all graphs shown throughout this study.

In some situations, training ECMs used at Fox Valley Technical College for educational purposes were examined. For these modules, engine sensors were connected to the ECM through stock wiring harnesses for Diagnostic Record testing. In addition, a vehicle speed sensor was also connected to the ECM, thereby allowing for testing of the Quick Stop feature. To verify snapshot data, including reporting time intervals, visual observations of a stopwatch were recorded. Also, the software used for accessing Caterpillar ECMs, Electronic Technician (ET), has a data logging feature. Past research has shown the program's Data Log entries to correlate well with external speed measuring devices [6]. Therefore, this feature was used to assist in examining some snapshot indicated time intervals.

For all ECMs, Diagnostic Records were examined with a protocol that used iterative techniques for triggering up to three diagnostic faults. To accomplish this, separate on-engine sensors were linked to switched potentiometers that could trigger a fault by adjusting the voltage returned to the ECM from that particular sensor. The effect simulated the onset of a diagnostic condition that would ultimately trigger a snapshot. By varying and recording the time between fault onsets, it was possible to determine the amount of time needed between faults in order for both to be recorded

through snapshots. [Figure 2](#) details how a sample sensor was accessed, while [Figure 3](#) shows the switched potentiometers connected to an LEE C13 ADEM IV EPA07 test engine provided by the Door County, Wisconsin, Highway Department.



Figure 2. Interface with Intake Manifold Air Temperature Sensor.



Figure 3. LEE C13 Test Vehicle with Potentiometers Hooked to Three Engine Sensors.

In connecting to various sensors, attempts were made to trigger faults requiring different onset times. In addition, some sensors are the responsibility of the OEM, while the majority of those directly monitoring engine performance are installed by Caterpillar. These sensors are wired to different harnesses on the ECM. Referred to as the “engine harness” and the “vehicle harness,” it is the sensors on the vehicle harness that are the responsibility of the OEM. [Figure 4](#) shows the harness locations on an ADEM 2000/III ECM while [Table 1](#) lists the specific sensors for a 2KS C-12.



Figure 4. ADEM 2000 Engine and Vehicle Harness Locations

Table 1. ADEM 2000 2KS C-12 Sample Sensor Locations

Sensor	Harness
Atmospheric Pressure Sensor	Engine Harness
Boost Pressure Sensor	Engine Harness
Oil Pressure Sensor	Engine Harness
Primary Engine Speed Sensor	Engine Harness
Secondary Engine Speed Sensor	Engine Harness
Coolant Temperature Sensor	Engine Harness
Fuel Temperature Sensor	Engine Harness
Intake Manifold Temp. Sensor	Engine Harness
Coolant Level Sensor	Vehicle Harness
Throttle Position Sensor	Vehicle Harness
Vehicle Speed Sensor	Vehicle Harness

When testing Diagnostic Records, the authors also triggered what are considered to be “Critical Events” to determine if there was a hierarchy in overwriting existing files. As will be discussed in this research, some ECM models were found to be prone to an anomaly where only one Diagnostic Record could be stored in the module at any given time. In particular, this anomaly affected ADEM 2000 Hydraulic Electronic Unit Injector (HEUI) ECMs, ADEM III “Bridge” ECMs (including HEUI), and ADEM III HEUI ECMs. With these modules, existing Diagnostic Records could not be overwritten, and had to be manually cleared through the ET software program in order for a new snapshot to be written.

To ensure that the overwrite anomaly was not dependant on the type of fault generated, the authors attempted to create Diagnostic Records using sensors from both the engine and vehicle harness, including “Critical Events.” Critical Events are diagnostic occurrences that are potentially harmful to the engine itself. Generally, when these events occur, the ECM causes the engine to either derate or shutdown. For ECMs

that have this feature, such occurrences are subsequently logged in the “Critical Event Log.” It is noted that a Quick Stop is actually considered to be a Critical Event, although the occurrence does not prompt an engine to shutdown or derate.

Given that certain diagnostic occurrences are considered to be “critical,” the authors also triggered these events using the switched potentiometers described previously. This allowed for conclusions to be drawn that considered snapshots stemming from OEM sensors, those that stem from sensors that are considered the responsibility of Caterpillar, and Diagnostic Records that are the result of Critical Events. As an example of faults that are considered to be critical, the following is a listing of Critical Events for a KCA C11 [8]:

- Vehicle Overspeed Warning
- Quick Stop Occurrence
- Low Fuel Pressure
- Very Low Oil Pressure
- Very High Coolant Temperature
- Very Low Coolant Level
- Engine Overspeed Warning

As an additional part of this testing, ECM clocks were changed to simulate events occurring on different days of the week or month. This allowed for the studying of anomalies occurring only on specified days. As will be presented, some ECMs were found to be prone to anomalies when events occurred on the 31st day of an applicable month.

In accessing the Caterpillar ECMs, two versions of the Electronic Technician software were used. These were 2009A and 2010A. No significant differences were noted between the two programs, and the software versions did not appear to have an effect on the data retrieved. In addition, in communicating with the ECM, an RP1210A compliant device is needed. For this testing, a Nexiq USB Link, as well as Caterpillar Communications Adapters II and III, were used at various points during the research. Again, no significant differences were observed as related to the imaged data.

TEST RESULTS

The findings of this testing are ordered by ECM type, then by the engine prefixes tested. A table outlining the test outcomes has also been included in the [Appendix](#). A summary of the testing results is as follows.

ADEM II (1994 - 1998 ENGINES)

5EK 3406E; 6TS 3406E; 9CK 3176B; 9NS C-12; 2PN C-10

In testing ADEM II ECMs, a total of nine modules were examined, spanning the five engine models listed above. These ECMs were installed in trucks manufactured by Ford, Freightliner, International, Kenworth, and Peterbilt, and had software dates ranging from December 1993 to December 1999, which was the newest software version for the 3406E truck at the time of testing. As a test vehicle example, Door County Waste and Recycling of Sturgeon Bay, Wisconsin, provided the 1995 Ford shown in [Figure 5](#).



Figure 5. 5EK 3406E Test Vehicle Provided by Door County Waste and Recycling in Sturgeon Bay, Wisconsin.

According to Caterpillar literature, the ability to record Quick Stop snapshots was introduced with a November 1995 ECM software date [12]. Therefore, only those ECMs initially having this software date, or having later been “flushed,” or updated, to this revision, are capable of recording Quick Stop events. However, as will be discussed, the authors were unable to successfully image a Quick Stop file from ADEM II ECMs with a serial number ending in “CA.” Although a file was created, it was not able to be retrieved.

For all of the ADEM II ECMs that were tested, a maximum of 11 snapshots were observed. These were broken down by six Diagnostic Records, four External Triggers, and, for post-November 1995 software revisions, one Quick Stop event. In testing Diagnostic Records, approximately 14 to 15 seconds was needed between two events for both to have snapshots recorded. As was stated earlier, fault occurrences require that a condition be met for different specified time durations. This testing suggested that regardless of the necessary condition time, once the code itself is triggered, 14 to 15 seconds must pass before a second code occurs in order for both to be

documented through separate Diagnostic Records. If the two faults occur prior to that timeframe, only the first is recorded.

When Diagnostic Records were tested in conjunction with Quick Stop files, the needed time duration was dependent on which event occurred first. If a Diagnostic Record was written first, approximately ten seconds was required before a Quick Stop could be recorded. Conversely, when a Quick Stop was documented first, approximately four seconds were needed before a diagnostic fault in order for both to be written. In both scenarios, the Diagnostic Record was always written, but the Quick Stop file was not documented as a snapshot when the given time requirements were not met. The Quick Stop event was, however, shown in the Critical Event Log.

For all of the Quick Stop files created during this testing, Snapshot time differed from the Critical Event Log by 14 to 15 seconds. Testing indicated that the actual time was consistent with that recorded in the Critical Event Log. [Figure 6](#) shows the available snapshot for a Quick Stop file, while [Figure 7](#) shows the Critical Event Log timed 15 seconds prior.

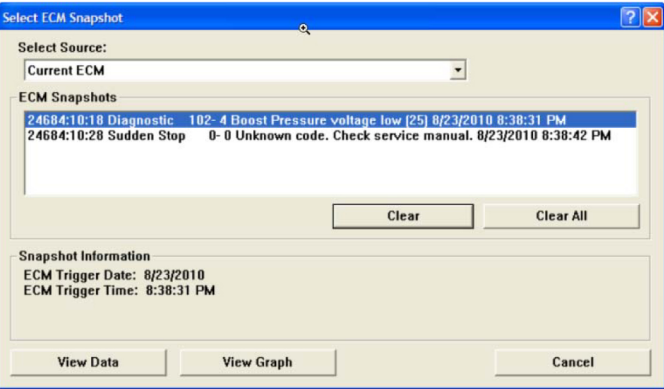


Figure 6. Sudden Stop (Quick Stop Occurrence) Shown at 8:38:42 PM.

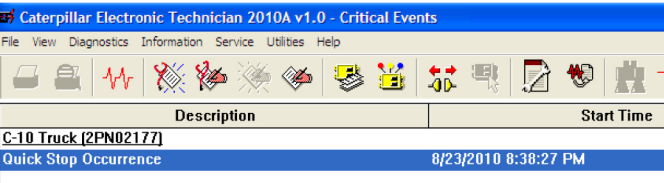


Figure 7. Critical Event Log Showing Quick Stop Occurrence at 8:38:27 PM.

Testing completed with ADEM II ECMs showed that the reported time intervals were correct, and therefore the issue identified by Drew, et al. was not applicable to ECMs of this type [6]. [Figure 8](#) shows the wheel speed data recorded during a Boost Pressure Voltage Low Diagnostic Record in

comparison with VC4000DAQ GPS speed readings. As was stated previously, for all graphs shown herein, the data were synchronized at the point of speed reduction. An examination of these data shows a good correlation between the reported time intervals.

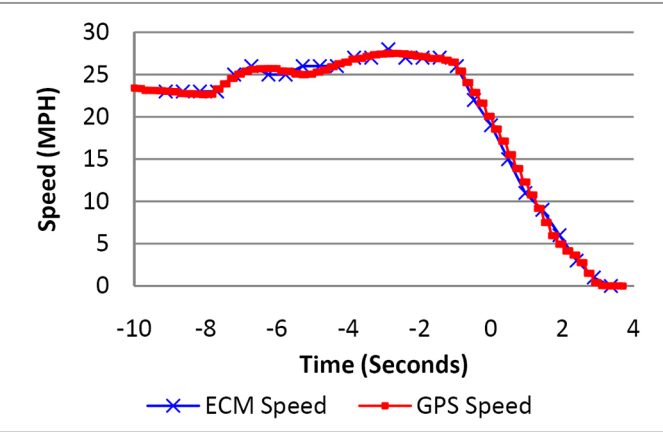


Figure 8. 9NS C-12 Diagnostic Record Indicated Speed in Comparison with VC4000DAQ GPS Indicated Speed

Information obtained from Caterpillar indicates that only ADEM II ECMs with serial numbers ending in “CG” or “CJ” have the ability to time stamp snapshots and diagnostic event logs, while those ending in “CA” do not [13]. This was confirmed with testing performed on models ending in both “CA” and “CJ.” As suggested by the Caterpillar literature, the “CA” ECMs did not have a traditional date and time clock, while the “CJ” models did. For those ECMs that were able to record the date and time, no errors were observed in terms of reporting the date properly.

As part of this testing, two 5EK 3406E “CA” ECMs which were incapable of recording time and date information were examined. For snapshots written by the authors, a date and time was shown in conjunction with the saved records. However, for each occurrence, the snapshot was shown as having occurred on January 1, 1985 at 12:00:00 a.m. This is shown in [Figure 9](#). It should be noted that while the dates and times are shown as being the same for three snapshots, diagnostic clock intervals confirm that they occurred at different times.

The “CA” ECMs are visually recognizable in that these models have a removable personality module cover on the front side of the module. While newer ECMs require only a software “flash” to upgrade the module, it is necessary to physically remove the personality module itself from these ECMs and replace it with one having updated software. During this testing, the authors did perform this task on a 5EK 3406E “CA” ECM, thereby upgrading the software from December 1993 to December 1999. This software was the most current available at the time of testing. In addition, a

second “CA” ECM was tested that had previously been updated to a December 1998 version. [Figure 10](#) shows an example “CA” ECM with the personality cover having been removed.

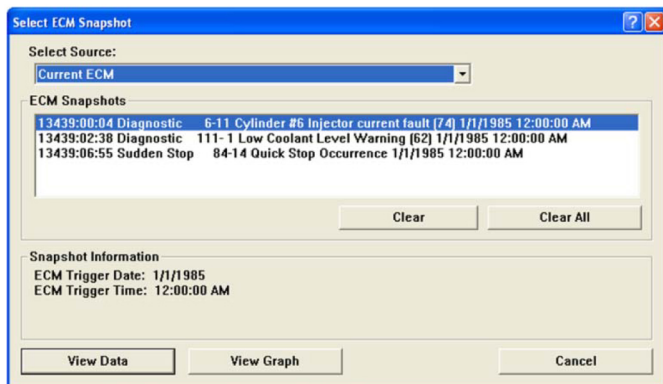


Figure 9. Date and Time Stamp for 5EK 3406E “CA” ECM without Clock Ability

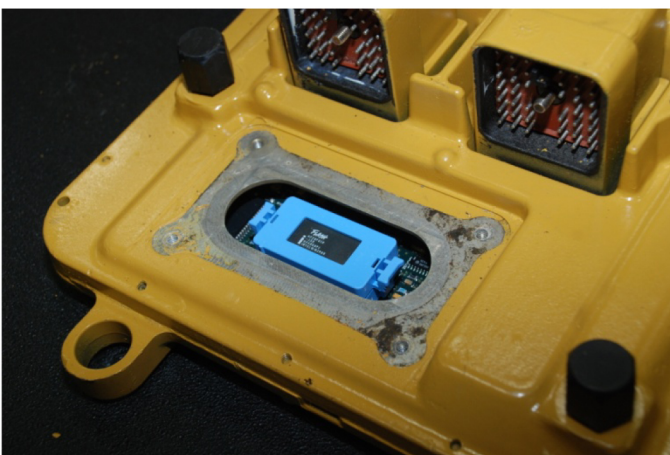


Figure 10. ADEM II “CA” ECM with Personality Module Cover Removed

In addition to not having a traditional date and time clock, Caterpillar literature also indicates that the “CA” ECMs do not have an internal battery [13]. Therefore, if power is lost to these modules, some stored data will be lost. With the “CA” models tested by the authors, upon removing the system from its 12-Volt battery source, all Diagnostic, External Trigger, and Quick Stop snapshots were erased. In addition, with a loss of power, all Driver and Fleet trip data stored in the ECM was subsequently cleared.

With a loss of power to the “CA” ECMs, the time and mileage records in the cumulative totals were also altered. Here, the Cumulative Trip values were returned to those observed prior to the start of testing. Literature reviewed by the authors indicates that the “CA” ECMs store snapshots and active trip data in memory that is dependent on the battery

connection. After two hours, 50 miles, or 40 gallons of fuel being used, trip data is transferred from this volatile memory to permanent memory [13]. While these values were not tested by the authors, the fact that the time and mileage values returned to their earlier entries confirms the need to maintain power to these ECMs following a collision event.

In 2010, Messerschmidt, et al. found that when data were successfully imaged following a power loss situation, the information was found to be accurate. However, this previous research did not specifically look at the “CA” ADEM II ECMs that do not have an internal battery [7]. Rather, the original authors focused on a later “CJ” ECM when looking at ADEM II controllers. Therefore, an iterative testing methodology similar to that of the Messerschmidt study was employed to determine if the erasure of data is immediate upon the ECM's removal from its power source. Here, power was removed from the ECMs for increasing time durations in order to determine when data were lost.

In removing power from the “CA” ECMs for specified amounts of time, a set critical timeframe could not be conclusively determined. In some tests, data were lost in as little as 21 seconds without power, while other tests showed that data were preserved for as much as one minute twenty-one seconds. Therefore, the only conclusion that can be drawn is the confirmation that data were lost in the “CA” ECMs following their removal from a power source. This also states the importance of preserving power to these module types following a collision event and the danger of cutting or disconnecting the truck's battery cables.

In some tests, when power was reapplied to the ECMs, an initial control snapshot triggered by the authors was shown along with several other new snapshots labeled as being “0-0 Unknown Code.” These additional Snapshots were shown as having occurred at diagnostic time “00:00:00.” Furthermore, the diagnostic time for the snapshot was shown to have occurred at diagnostic time “15998:12:29.” However, the fault was actually set at “13438.12.29.” An example of this observation is shown in [Figure 11](#).

When viewing the files imaged after the power loss in comparison with the control (pre-power loss) snapshots, data were found to be anomalous. For example, what should have been displayed as relatively constant entries were instead records with sharp spikes and/or changes in the data. [Figure 12](#) shows the snapshot data prior to initiating the power loss, while [Figure 13](#) shows the file after it was displayed with an improper diagnostic time and in combination with “0-0 Unknown Code” entries.

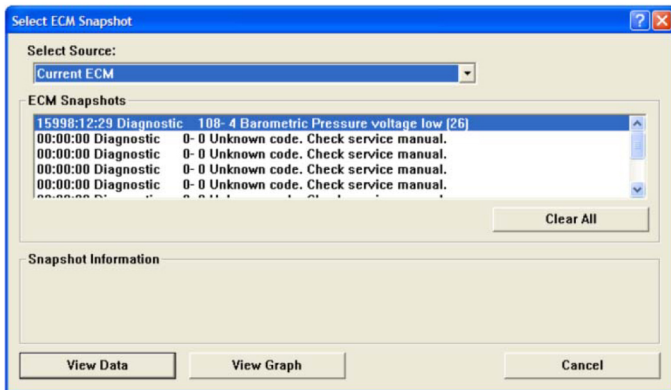


Figure 11. Available Snapshots Following Loss of Power to 5EK 3406E “CA” ECM.

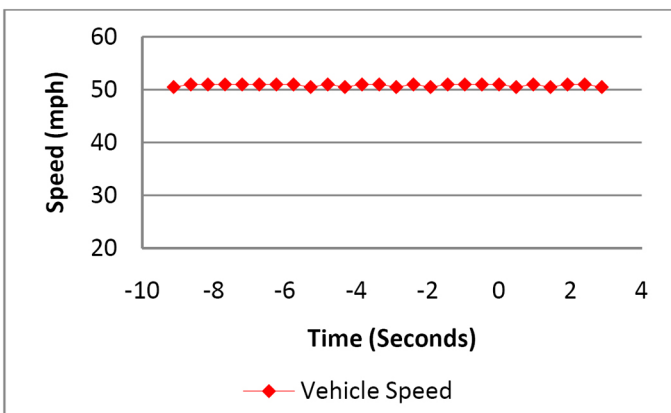


Figure 12. 108-4 Barometric Pressure Voltage Low Control Snapshot As Imaged Prior to Power Loss.

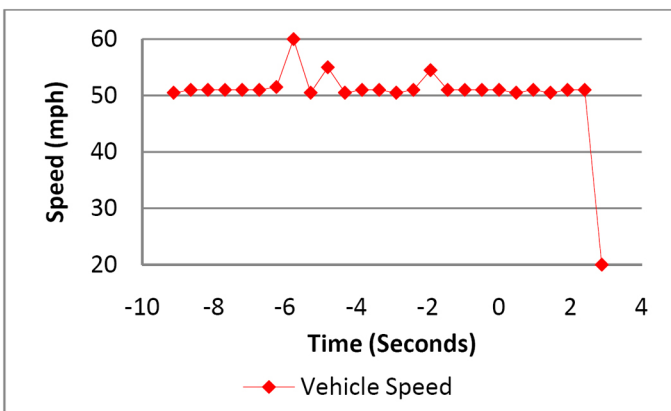


Figure 13. 108-4 Barometric Pressure Voltage Low Control Snapshot As Imaged After Power Loss.

As was stated previously, although a Quick Stop file was created, the authors were not able to retrieve the data from either “CA” ECM that was tested. In spite of the Quick Stop event having been logged and a snapshot being shown as available, an error message was received when attempting to

image the snapshot. This occurred in both the December 1998 and December 1999 software upgrades. Again, this later date represented the most current available software at the time of testing. The available snapshots and the error message received on each attempt to image the snapshot are shown in Figures 14 and 15.

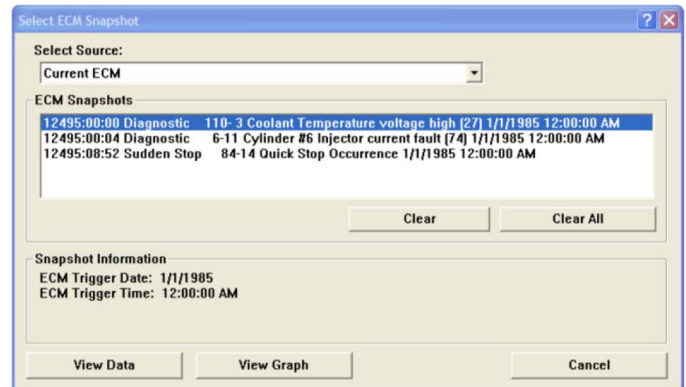


Figure 14. 5EK 3406E “CA” ECM Showing an Available Quick Stop Snapshot.



Figure 15. Caterpillar Electronic Technician Error Message Displayed When Attempting to Image Quick Stop Snapshot Data from 5EK 3406E “CA” ECMs.

ADEM II Test Results Summary:

1. Approximately 14 to 15 seconds were needed between diagnostic faults in order for both to be documented through snapshots. If two faults occur prior to this timeframe, only the first was recorded in a snapshot.
2. Approximately 10 seconds were needed between a diagnostic fault and a Quick Stop occurrence. If the timeframe was shorter, only the Diagnostic Record was written.
3. Approximately 4 seconds were needed between a Quick Stop occurrence and a diagnostic fault. If the timeframe was shorter, only the Diagnostic Record was written.
4. The Snapshot time indicated for Quick Stop files was shown as being approximately 15 seconds after that recorded in the Critical Event Log.
5. If power was lost to a “CA” ECM, Driver and Fleet Trip Data, Diagnostic Records, External Triggers, and Quick Stop files were cleared.