

Motor Vehicle Defect Petition to Recall All Tesla Vehicles Due to Sudden Unintended Acceleration

Sophie Schulman, Acting Administrator
National Highway Traffic Safety Administration
1200 New Jersey Avenue SE
Washington, DC 20590

14 April 2025

Dear Acting Administrator Shulman,

On May 12, 2023, I sent a letter to NHTSA requesting that investigation DP 20-001 be re-opened because of new information that NHTSA investigators erred in ascribing the cause of these incidents to pedal misapplication. The enclosed letter from NHTSA dated July 3, 2023, and enclosed ODI Resume Number DP 23-002 verify that NHTSA accepted this letter as a valid petition and stated that NHTSA would notify me upon completion of the investigation. As of 14 April 2025, this has not yet happened.

According to the rules for NHTSA petitions contained in the US Code of Federal Regulations, Title 49, Subtitle B, Chapter V, Part 552, NHTSA is required by law to:

- 1) conduct a technical review of the petition, and
- 2) notify the petitioner of the decision to grant or deny the petition within 120 days after its receipt of the petition.

It has now been almost two years since submitting my petition and this technical review has not still not happened. Therefore, I expect NHTSA to abide by this regulation and perform a technical review of my petition and notify me of the results. As acting administrator, it is your personal obligation to see that this is done.

During the forthcoming technical review of my petition, I ask that NHTSA include in its investigation the paper enclosed with this letter entitled "*LOG Data Confirms Tesla Unintended Acceleration*". This paper explains how the same LOG data that NHTSA included in its denial of petition DP 20-001 supports unintended acceleration instead of pedal misapplication. It does this by analyzing the missing data values in the vehicle LOG data supplied by Tesla to NHTSA and by proposing a simple cause of this missing data that leads to sudden unintended acceleration. NHTSA's pedal confusion hypothesis cannot explain these missing data values.

I urge that NHTSA also include in its technical review of ODI Resume Number DP 23-002 the evidence I provided in subsequent letters dated 19 May 2023, 5 June 2023, 1 August 2023, 4 August 2023, 23 August 2023, 20 July 2024, and 3 December 2024, as well as the enclosed paper entitled "*LOG Data Confirms Tesla Unintended Acceleration*".

Finally, it must be remembered that NHTSA investigations are meant to gather further information about an alleged defect that can aid a decision about a defect, and not merely to decide that there is insufficient information to justify an investigation, in which case the request for an investigation is denied. In this case, with all the information supplied to NHTSA that proposes a specific cause of sudden unintended acceleration in Tesla vehicles based on detailed information about the actual circuit design of Tesla's inverter electronics and on the analysis of specific vehicle LOG data

from two alleged sudden acceleration incidents, it is difficult to see how there is insufficient information on which to justify an investigation.

If you desire to contact me for any reason relevant to this letter, or wish to obtain a color copy of the enclosed paper, please use the email address given below.

Sincerely yours,

Ronald A. Belt

Ronald A. Belt

[REDACTED]

Email: [REDACTED]

Encl: Paper entitled "*LOG Data Confirms Tesla Unintended Acceleration*", 32 pages, dated 14 April 2025.

Petitions to NHTSA was submitted on 19 May 2023.

According to the rules for NHTSA petitions contained in the US Code of Federal Regulations, Title 49, Subtitle B, Chapter V, Part 552, NHTSA is required by law to:

- 3) conduct a technical review of the petition
- 4) notify the petitioner of the decision to grant or deny the petition within 120 days after its receipt of the petition.

Neither of these required actions has been done as of 20 July 2024.

§ 552.6 Technical review.

The appropriate Associate Administrator conducts a technical review of the petition. The technical review may consist of an analysis of the material submitted, together with information already in the possession of the agency. It may also include the collection of additional information, or a public meeting in accordance with § 552.7.

§ 552.8 Notification of agency action on the petition.

After considering the technical review conducted under § 552.6, and taking into account appropriate factors, which may include, among others, allocation of agency resources, agency priorities and the likelihood of success in litigation which might arise from the order, the Administrator will grant or deny the petition. NHTSA will notify the petitioner of the decision to grant or deny the petition within 120 days after its receipt of the petition.



U.S. Department
of Transportation
**National Highway
Traffic Safety
Administration**

1200 New Jersey Avenue SE.
Washington, DC 20590

July 3, 2023

Mr. Ronald A. Belt
[REDACTED]

NEF-104
DP23-002

Dear Mr. Belt,

This letter acknowledges receipt of your petition, received by the National Highway Traffic Safety Administration's Office of Defects Investigation (ODI) dated May 12, 2023, requesting "... investigation DP20-001 be reopened because of new information".

Your petition has been assigned a new identification number DP23-002. A copy of the opening resume formalizing the start of that review is attached for your information.

In accordance with Title 49 CFR Part 552, "Petitions for Rulemaking, Defects, and Noncompliance Orders," the National Highway Traffic Safety Administration will conduct a review of the petition and other pertinent information and will notify you further upon completion.

If you have or receive any additional information related to this investigation, we would appreciate receiving it. You will be notified of our findings at the conclusion of the investigation.

Sincerely,

[REDACTED]

Tanya Topka

Acting Director, Office of Defects Investigation

Enclosure: DP23-002 Opening Resume



U.S. Department
of Transportation

**National Highway
Traffic Safety
Administration**

ODI RESUME

OFFICE OF DEFECTS INVESTIGATION
NHTSA
Authentic US Government Information
National Highway Traffic Safety Administration
uses a digital certificate to ensure
the content has remained unchanged

Investigation: DP 23-002
Prompted by: DEFECT PETITION
Date Opened: 06/29/2023
Investigator: Tariq Bond
Approver: Tanya Topka
Subject: Sudden Unintended Acceleration
Reviewer: Gregory Magno

MANUFACTURER & PRODUCT INFORMATION

Manufacturer: Tesla, Inc.
Products: MY 2013 - 2023 Tesla Model 3, Model Y, Model S, Model X
Population: 1,800,000 (Estimated)
Problem Description: The petition alleges a theory that the subject vehicles contain a defect that can cause sudden unintended acceleration, which may result in crash and injury.

FAILURE REPORT SUMMARY

	ODI	Manufacturer	Total
Complaints:	0	TBD	TBD
Crashes/Fires:	0	TBD	TBD
Injury Incidents:	0	TBD	TBD
Number of Injuries:	0	TBD	TBD
Fatality Incidents:	0	TBD	TBD
Number of Fatalities:	0	TBD	TBD
Other*:	1	TBD	TBD

*Description of Other: Petitioner's submission

ACTION / SUMMARY INFORMATION

Action: Open this Petition for a grant or deny decision.

Summary:

The Office of Defects Investigation (ODI) received a petition requesting that ODI reevaluate its decision to deny DP20-001 on the basis that intermittent high electrical current demands on the vehicles' 12VDC systems may have caused some or all of the incidents examined by ODI in DP20-001.

The petitioner bases this information on a review of open-source research and the DP20-001 denial. The petition and related materials can be reviewed at [NHTSA.gov](https://www.nhtsa.gov) under the following ODI number: 11528471.

LOG Data Confirms Tesla Unintended Acceleration

by

Ronald Belt

USA

8 April 2025

Abstract: EDR and LOG data from two alleged Tesla Model 3 sudden acceleration incidents are discussed. Gaps in the vehicle LOG accelerator pedal data produced in one incident are consistent with a fault in the drive motor control module. The unique one-second-long duration of the zero values in the OTA LOG accelerator pedal data in the second incident allows further localization of the fault to the power management integrated circuit (PMIC) device that provides the +5V supplies to the accelerator pedal position (APP) sensors and the CAN bus transmitter. The fault is caused by the PMIC device going into reset when the device exceeds its maximum temperature specification of 85°C. This causes the +5V supply to go to ground (0V) for exactly one second, during which the the APP sensors lose their supply voltage. If the ADC senses the +5V supply voltage while it is at 0V during reset, and then uses this lower voltage as a ratiometric correction to the APP sensor outputs when the +5V supply is restored, then the incorrect supply voltage of 0V will cause the digital outputs of the two APP sensors to increase up to 4V or more while the analog outputs of the sensors remain at 0.4V and 0.2V. This will cause the digital accelerator pedal % value to increase up to 100% even though the driver is not pressing on the accelerator pedal. Since this same PMIC device is used in all Tesla vehicles, this same thermally-induced reset in the PMIC device will occur in all Tesla vehicles, producing sudden acceleration from a low speed. Unintended acceleration starting at higher speeds can also be caused by the loss of the accelerator pedal signal when the PMIC device goes into reset because the RAM location that provides the input to the pedal map cannot be updated with new pedal % values. Therefore, the drive motor continues operation using the current pedal % value in the RAM location, which cannot be changed by the driver while the PMIC is in reset. No diagnostic test code (DTC) is produced in either case.

I. Introduction

This work began when the author found an article on the Internet written by Mr. Fuyu Yang in China^[1] that analyzed the EDR and vehicle LOG data discussed in an NHTSA report^[2] that denied a petition by Brian Sparks to investigate Tesla Sudden acceleration. The EDR data in NHTSA's report was supplied by the author, while the LOG data in the report was provided by Tesla at NHTSA's request. The NHTSA report concluded that this incident, and all other alleged Tesla sudden acceleration incidents, were caused by pedal faults instead of vehicle faults. Mr. Yang noticed that the vehicle LOG data in the NHTSA report contained several irregularities in the form of missing data and inconsistent data that raised doubt about NHTSA's conclusion. He concluded that the missing accelerator pedal values in the vehicle LOG data would upset the drive motor control loop to cause sudden acceleration. The author believes that Mr. Yang's conclusion that missing accelerator pedal position values in the vehicle LOG data can upset the drive motor control loop is incorrect, but that Mr. Yang's observation of missing accelerator pedal vehicle values in the vehicle LOG data is an important clue that must be investigated further. When the author added the accelerator pedal OTA

LOG data from a second alleged sudden acceleration incident that he had analyzed in an earlier paper^[3], he was finally able to deduce how sudden acceleration could be created by the fault that caused the missing vehicle LOG data in the NHTSA report. We will now discuss the data from these two alleged sudden acceleration incidents, starting with the data found in NHTSA's report.

II. Discussion and Analysis of NHTSA Data

Figure 1 shows the data from the first alleged sudden acceleration incident in the NHTSA report.

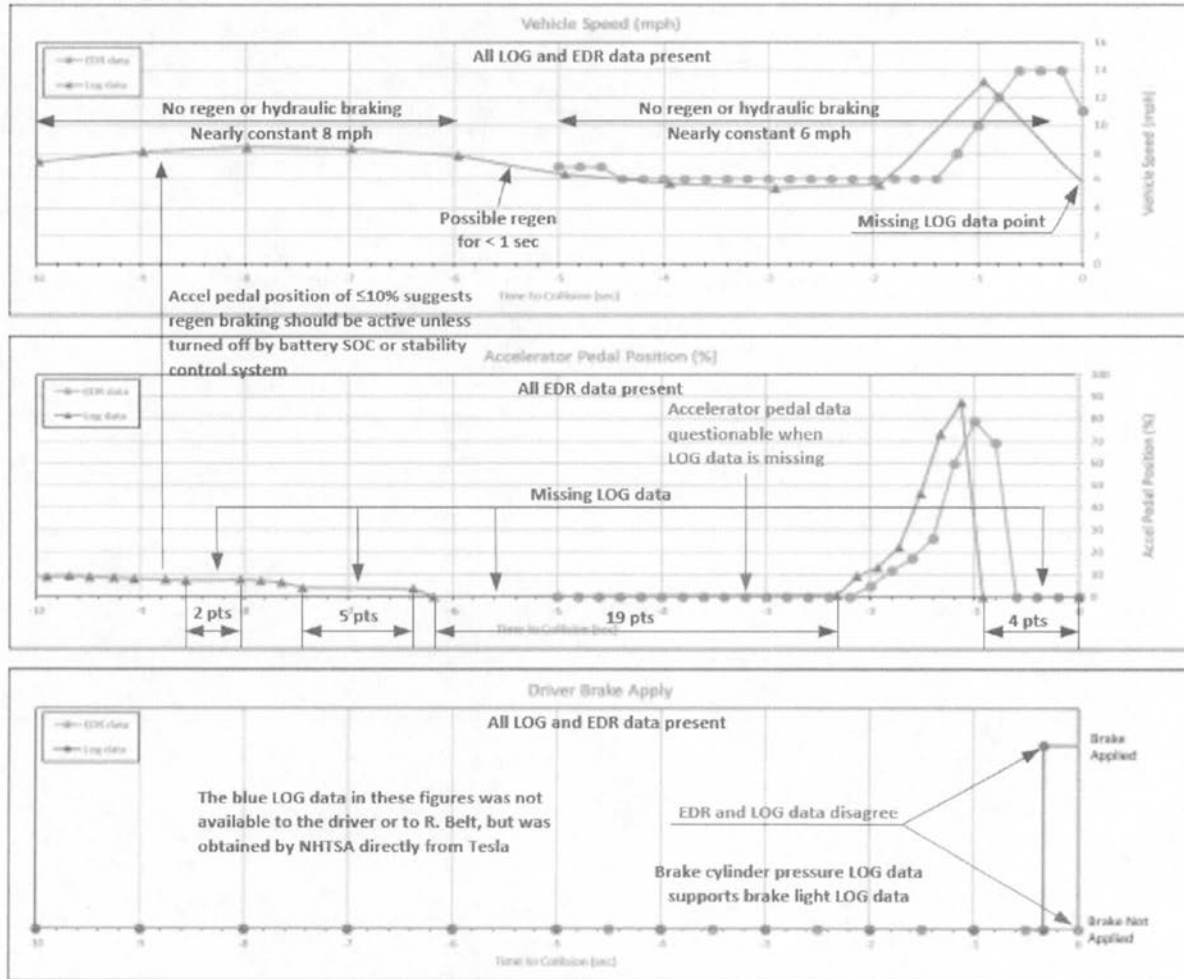


Figure 1. Data from NHTSA's denial of Brian Spark's petition of Jan 8, 2021, page 9.^[2]

EDR data included in the petition was supplied by the author.

The vehicle LOG data was supplied by Tesla at the request of NHTSA.

Figure 2 shows how a single CAN bus transfers the data in Figure 1 from the drive control unit, the iBooster unit, and the ESP hev unit to the EDR and the vehicle LOG. Figure 3 shows how the CAN bus messages are sent in an interleaved fashion from CAN transmitters in the drive control unit, the iBooster unit, and the ESP hev unit to CAN receivers in the EDR and vehicle LOG units.

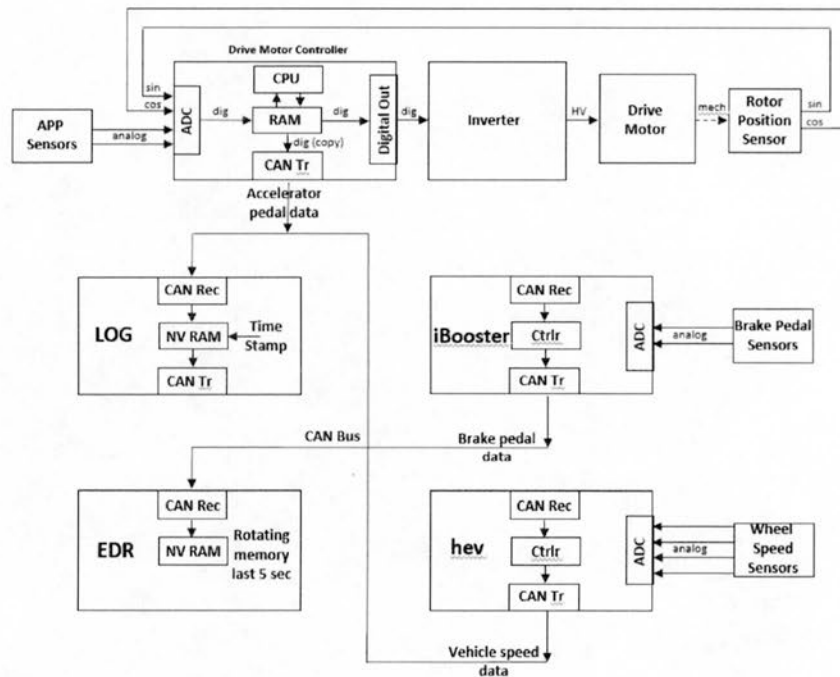


Figure 2. Data is transferred to the vehicle LOG and EDR via a single CAN bus.

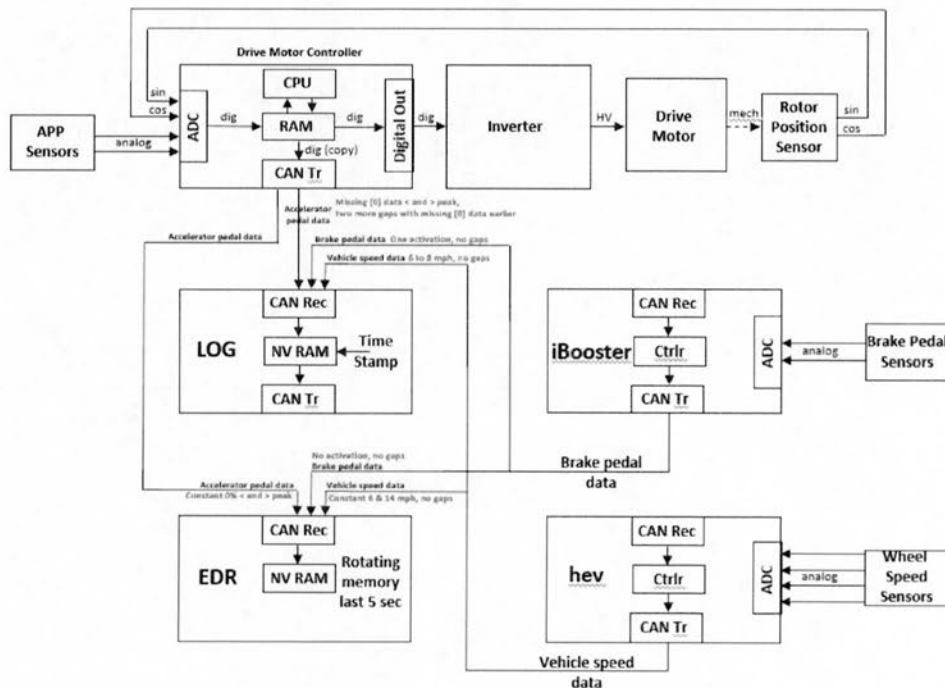


Figure 3. CAN bus messages interleave data between three data sources and the vehicle LOG or EDR.

From Figures 1, 2, and 3 we can draw the following conclusions:

- 1) The data in the vehicle LOG and the EDR comes from three different sources:
 - a. Accelerator pedal data comes from the drive motor control module.
 - b. Vehicle speed data comes from the ESP hydraulic valve (hev) brake module.
 - c. Brake application data comes from the iBooster module.
- 2) All data is transferred to the vehicle LOG and to the EDR via CAN bus messages.
 - a. The three data sources transmit the data via CAN transmitter functions.
 - b. The vehicle LOG and the EDR receive the data via CAN receiver functions.
 - c. The messages from the three sources are interleaved as they are received by the vehicle LOG and the EDR at each point in time.
- 3) Examination of the data shows that there is no missing data either in the vehicle speed data, the driver brake apply data, or the accelerator pedal EDR data. However, there is missing data in the accelerator pedal vehicle LOG data.
 - a. The lack of any missing data in either the vehicle speed LOG data or the vehicle speed EDR data suggest that the CAN bus is working normally [Footnote 1] at all times for all CAN messages from the hev brake module to either the vehicle LOG module or the EDR module. (The differences between the vehicle speeds in the vehicle LOG and EDR data; namely, the magnitudes and timing differences, are assumed to be slight and are thus ignored). Therefore, the CAN transmitter in the hev brake module and the CAN receivers in the vehicle LOG module and the EDR module must be operating normally at all times.[Footnote 2]
 - b. The lack of any missing data in the accelerator pedal EDR data suggest that the CAN bus is working normally during the last five seconds before the crash for all CAN messages from the drive control module to the EDR module. Therefore, the CAN transmitter in the drive control module and the CAN receiver in the EDR module must be operating normally during the last five seconds before the crash.
 - c. The lack of missing data in either the driver brake apply vehicle LOG data or the driver brake apply EDR data or the vehicle speed EDR data suggest that the CAN bus is working normally at all times for all CAN messages from the iBooster module to either the vehicle LOG module or the EDR module. Therefore, the CAN transmitter in the iBooster module and the

¹ Working “normally” here means that the data is being transferred faithfully as designed or intended. It does not mean that the data values themselves are correct as obtained from a sensor or from a calculation, but only that they are within the allowed range of expected data values.

² If data is being transferred “normally” over a data path, we can infer that all the CAN hardware and software used to transfer the data faithfully as designed is also operating “normally” because all the individual components involved in the data transfer must be operating as designed. However, if an error occurs during data transfer, we cannot infer that the source of the error is in a component within the data path. This is because CAN bus errors in one node can be created by errors in one or more other nodes, as may happen with a fault induced in one node by a bus BUSY signal created erroneously in another node.

CAN receivers in the LOG module and the EDR module must be operating normally at all times.

- d. The vehicle speed data in the vehicle LOG and the EDR show that the vehicle speed changes very little until 2.4 seconds before the crash, which implies that neither regen braking nor mechanical braking are operable before the crash. However, if the accelerator pedal data in the vehicle LOG and the EDR are correct, being between 0% and 10% at the same time, then the vehicle drive motor could be in regen mode until 2.4 seconds before the crash if the high voltage battery is able to accept the regen charge. Therefore, there is conflicting evidence for whether regen braking or mechanical braking are operable before the crash, and we cannot know for certain what the state of the drive motor was before the the crash.

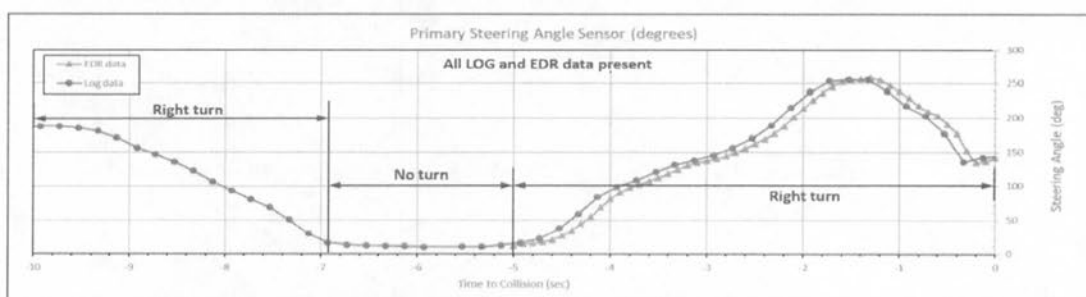


Figure 4. Steering angle for the first incident shows that two turns were made with a short path of no turn in between the two turns.

- a. The presence of missing accelerator pedal data in the vehicle LOG suggest that faults are occurring somewhere in the vehicle before the accelerator pedal % values start to increase at 2.4 seconds before the crash. The missing vehicle LOG data occurring between 5 seconds before the crash and 2.4 seconds before the crash appear to be at odds with the EDR data, indicating that either the EDR data is incorrect or the vehicle LOG data is incorrect. But we cannot localize the source of these faults to specific nodes or CAN bus modules because CAN bus faults can be created not only by the specific CAN nodes sending and receiving this accelerator pedal data, but also by other faulty nodes on the CAN bus. Therefore, we are unable to determine the cause of this missing accelerator pedal LOG data. This is unfortunate, because missing accelerator pedal vehicle LOG data is a sign that something is not operating normally. But to find the cause of these faults requires further evidence from another source.

III. Discussion and Analysis of Data from the Second Incident

Let us now take a look at the accelerator pedal LOG data from another alleged sudden acceleration incident.

Back in 2018, the author wrote a paper entitled ["Tesla's Sudden Acceleration Log Data – What it Shows – 5/1/18"](#). In that paper he showed a figure containing accelerator pedal OTA LOG data from a vehicle that had suffered a sudden acceleration incident. That figure is shown in Figure 5.

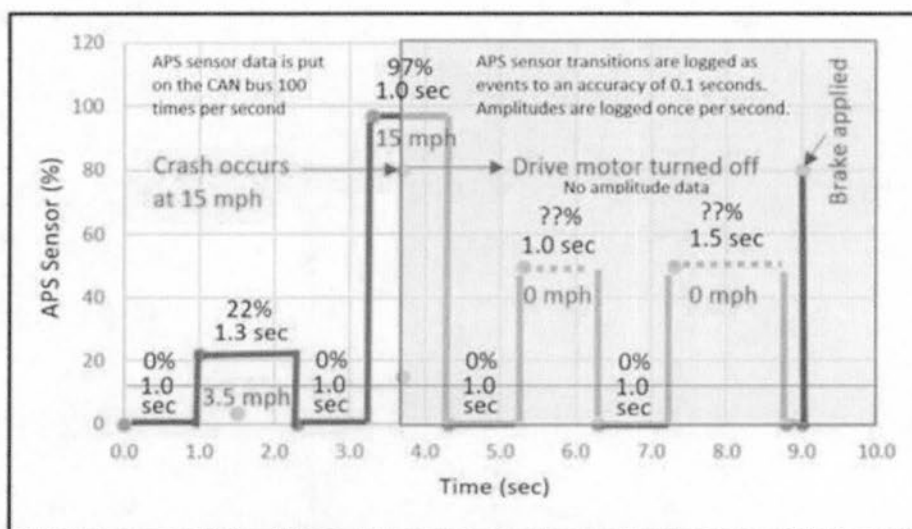


Figure 5. OTA LOG accelerator pedal % data for a sudden unintended acceleration incident as summarized in NHTSA's denial of Brian Sparks' petition. NHTSA states on p16 that "Dr. Belt's reconstruction imagines the APPS log data as a square wave ..." and on p17 that "ODI does not believe that Dr. Belt's reconstruction of the log data is accurate. The data log is not capable of recording a square wave with 1 Hz sampling rate of the APPS data." These statements by NHTSA falsely describe the data in Figure 5 above, which NHTSA could have found out by asking Dr. Belt for an explanation of this OTA LOG data, just as they asked Tesla to supply the LOG data for their report in Figure 1. Figure 6 below provides the explanation that would have been given to NHTSA had they asked.

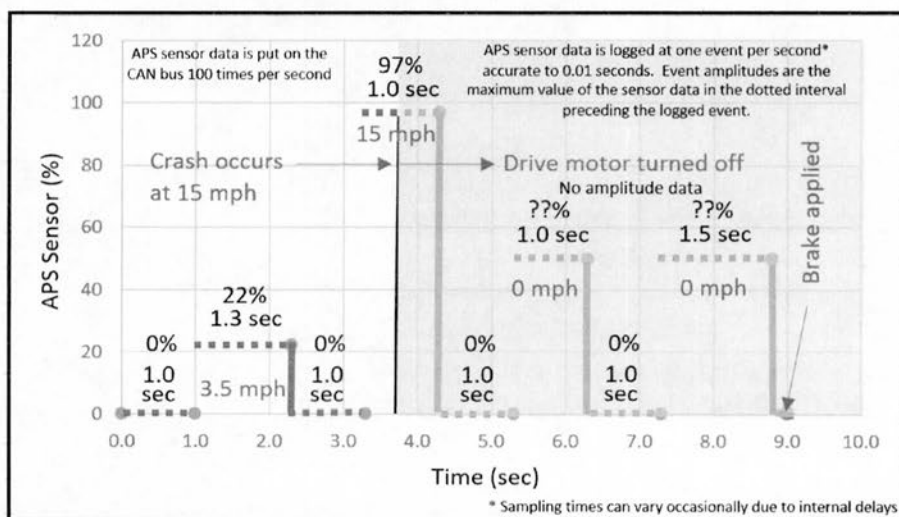


Figure 6. This figure shows the same OTA LOG data as in Figure 5, but with the graphics modified to clarify what the data represents. The APPS data in the OTA LOG is stored at one sample per second as shown by the blue dots in Figure 6. The timing of these dotted events is accurate to less than 0.1 second. Some intervals are longer than one second because the sampling times can vary due to internal delays. The amplitude for each dotted event is the maximum value of the sensor data in the interval before the

dotted event. This amplitude is represented by only one vertical line in Figure 6 instead of two vertical lines in Figure 5, to clarify that the maximum amplitude is associated with a single dotted event. The horizontal dashed lines preceding each dotted event indicate the interval from which the maximum value was obtained. They are included as an aid to the reader to show the length of each interval and the upper limit of all the sensor amplitudes within that interval. The dashed lines do not imply that all the sensor outputs within that interval have the same value, or that the sensor data is a square wave. Note that the horizontal dashed lines for two intervals after the crash are shown in red instead of blue. This is because their amplitudes could not be determined by Tesla. However, the start and end times of these two intervals could be determined from the time stamps associated with the zero-valued intervals on either side of the intervals with missing data.

Now, this OTA LOG data was obtained directly from Tesla during a telephone conversation in which a Tesla engineer described to a driver the OTA LOG data that was obtained after a sudden acceleration incident.^[Footnote 3] (NOTE: This is OTA LOG data, and not EDR data, as can be seen from the fact that the data continues for over 5 seconds after the crash, while EDR data would stop after the crash. Also, it is not vehicle LOG data taken from the removable SD card found in the gateway ECU on the vehicle, which has a higher data rate for accelerator pedal % data). The OTA LOG data is obtained from the vehicle LOG data, but undergoes an additional OTA transfer from the vehicle to the Tesla server. Each data value in Figure 6 represents the maximum value of the accelerator pedal % pedal values during the preceding time interval.

Notice that in Figure 6 there are four intervals of 0% data with a duration of exactly one second. Since 0% is the maximum for each interval, this means that all the data values during this interval have the value 0%. And since each accelerator pedal % value in the vehicle LOG from which the OTA LOG data is obtained is given a time stamp as it arrives from the CAN bus at 100 values per second, the time of each vehicle LOG and OTA LOG value is known to an accuracy of 0.01 seconds. The Tesla engineer tried to explain at the time that these four intervals were created by the driver alternately pressing and releasing the accelerator pedal. However, the author argued in his paper that there is no way that a human driver can produce four time periods of exactly one second duration accurate to less than 0.1 second by alternately pressing and releasing the accelerator pedal. Therefore, he began to look for an alternative way to explain these periods of zero amplitude in the OTA LOG data by some malfunction of the electronic circuitry. One suspicion he had at the time was that the four time periods of zero amplitude are caused by some integrated circuit component going into reset.

At the time the author wrote his paper in 2018, he had no idea of how Tesla's electronic circuitry was designed. Therefore, he made some gross assumptions of how the circuitry was designed and came up with an explanation of how the 0% values could be produced by a device going into reset that he later concluded to be wrong. So, the rest of the 2018 paper is wrong. But the OTA LOG data itself remains valid.

Here are some other interesting things that can be seen in the OTA LOG accelerator pedal % data:

³ See Appendix A for how this data was obtained and what it means.

- 1) There are four intervals of data containing all-zero accelerator % pedal values that last exactly 1.0 second ± 0.1 second. These intervals could correspond to times when some unknown device goes into reset and remains there for 1.0 seconds. These all-zero pedal % values are difficult to explain if they truly indicate a zero accelerator pedal % value reading, because such a reading would seem to imply that the accelerator pedal circuitry remains operational.
- 2) There are four intervals of varying time durations between 1.0 to 1.5 seconds that alternate with the intervals containing all-zero pedal % values. These intervals contain non-zero pedal % values or unknown values and could correspond to the time it takes for some unknown device to heat back up again after coming out of reset until it becomes too hot to remain operational and goes back into reset.
- 3) The maximum accelerator pedal % value goes to 97% just before the crash. This contradicts the driver's testimony that she did not press on the accelerator pedal.
- 4) The alternating values of 0% pedal and non-zero % pedal continue for four seconds after the crash while the vehicle is presumed to be stationary and the drive motor was turned off. It is possible to have accelerator pedal readings after the crash because the accelerator pedal can be pressed at any time regardless of whether or not the drive motor is operating.
- 5) There are two intervals of data after the crash for which the maximum values could not be determined by the Tesla engineer. It is believed that the Tesla engineer couldn't give the accelerator % pedal values for these two intervals in the OTA LOG data because the intervals contained no data values instead of just showing "0" values. This could happen if the data packets containing the % pedal values for these two intervals failed to get from the vehicle to the centrally located Tesla server that stores the OTA LOG data. This is explained in more detail in Appendices A and B.
- 6) Finally, the OTA LOG data shows the brake pedal was applied almost 5 seconds after the crash, but not at any other times. The Tesla engineer tried to explain that the brake pedal was not applied before the crash because the driver had her foot on the accelerator pedal at the time instead of the brake pedal.

Three years later, in 2021, the author found that the Tesla Model 3 uses an Infineon TLF35584QVVS2 PMIC device as the voltage source for all the 5V, 3.3V, and 1.2V supplies on the Model 3 inverter electronics board. The author also found one more interesting fact about this PMIC device at this time; namely, that if it gets too hot ($>85^{\circ}\text{C}$) it will go into reset for exactly 1.0 seconds.^[Footnote 4] And during this reset timeout, the 5V and 3.3V supplies will cease to operate (i.e., go to ground voltage = 0V) while the 1.2V supply will continue working.

Finally, the author had found a possible reason for why the OTA LOG data in Figure 5 had four intervals of 0% data that were exactly 1.0 seconds long. It was because the

⁴ See TLF35584QVVS2 PMIC datasheet at https://www.infineon.com/dgdl/Infineon-TLF35584QKVS1-DataSheet-v02_10-EN.pdf?fileId=8ac78c8c92bcf0b001932f56a8c31703. On page 109 is says "In case of a thermal shutdown the minimum FAILSAFE time $t_{\text{FAILSAFE,min}}$ is 1s."

TLF35584QVVS2 PMIC device got too hot that caused the 5.0V supplies to the APP sensors and the CAN bus to go to 0V for exactly one second. Then, after exactly one second, when the PMIC device came out of reset, these voltage supplies would start to operate again. Then the PMIC device would continue to operate for a second or more until it overheated again, when it would go back into reset for exactly one second.

While the PMIC resetting can explain the existence of four intervals that are exactly one second long, there is still a problem that requires explanation. The problem is that the value of all zeroes in the OTA data during these intervals seems to imply that the accelerator pedal circuitry is operating normally, with the values of 0% indicating that accelerator pedal is released during these intervals. But when the PMIC device goes into reset, causing the +5V supply voltage to the APP sensors and the CAN bus transmitter in the control unit to go to ground, then the CAN bus transmitter operation should also be inoperable during these intervals, and there should be no accelerator pedal % values sent to the OTA LOG storage during these intervals. Therefore, the accelerator pedal % values for these intervals should be absent in the OTA LOG data, just like it was for the two intervals with no data after the crash. So why are the pedal % values in these four intervals equal to 0%?

The answer to this problem is that the OTA LOG data can have two types of missing data, as explained in Appendix B. One type of missing OTA LOG data is caused by the loss of data packets between the vehicle and the Tesla server. This type of missing OTA LOG data can explain the two intervals after the crash for which the Tesla engineer was unable to determine any maximum value. The other type of missing OTA LOG data is caused by data missing in the vehicle LOG, from which the data in the OTA LOG is obtained. When there is missing data while entering values into the vehicle LOG, then the values stored in the vehicle LOG remain the preset values that all the memory locations on the SD card are set to when the memory is installed. These preset values can be either all zeroes or the maximum values of all binary ones. Therefore, if the all-zero values in the four one-second long intervals are interpreted to be the preset values of the SD card memory sites, then the all-zero values in the OTA LOG data become explainable by the CAN bus transmitter in the motor controller being inoperable during the PMIC reset time. At the same time, the APP sensors would also be inoperable because their supply voltage is zero, allowing no calculation of a pedal % value. But the drive motor would still remain operational because there would be no pedal % values calculated to update the RAM memory that provides an input to the pedal map. So when the input to the RAM memory is absent, the RAM memory output stays the same. Therefore, the RAM output to the pedal map remains the same and the output of the pedal map provides the previous torque command to the drive motor.

In summary, the "0%" values in the four one-second long intervals of the OTA LOG data in Figures 5 and 6 are not caused by the accelerator pedal being released by the driver. Instead, they are caused by the preset memory values of zero on the SD card when pedal % values are missing in the data stream as it is being read into the SD card of the vehicle LOG, from which the OTA LOG data is obtained.

Because the zero values in the one-second long intervals of the OTA data are created by the off-time of the CAN bus transmitter, which is determined by the reset time of the PMIC device, this is why the durations of the four all-zero intervals are exactly one

second long ± 0.1 second, which is the reset time of the PMIC device. If these zero values were instead 0% values, then the durations of the all-0% intervals would be determined by the driver, which would require that the driver be able to release the accelerator pedal four times for exactly one second ± 0.1 second each time. This is clearly a human impossibility.

With this explanation for the data Figures 5 and 6, let us now go back to Figure 1 and see how we can explain the missing data in Figure 1 by using the results from Figures 5 and 6.

IV. Further Discussion of Data from the First Incident

In Figure 1, notice that the blue vehicle LOG data for the vehicle speed and brake pedal data have no missing data values. Only the blue vehicle LOG data for the accelerator pedal % data has missing data values. Recall that we said earlier that we are unable to determine the cause of these missing accelerator pedal values because we cannot localize the source of these faults to specific nodes or CAN bus modules. However, we can localize the source of these faults if we bring in other valid data.

So let's assume that the cause of this missing accelerator pedal data in Figure 1 is the same as for Figures 5 and 6. Then, the cause of these missing accelerator pedal values is that the PMIC device in the motor controller is going into reset at these times. This assumption is supported by the durations of two of the intervals with missing data in Figure 1; namely one interval with five missing data points making it exactly one second long, and the other with nineteen missing data points making it very close to twenty seconds long or four one-second intervals. This explains the missing accelerator pedal data in Figure 1 because when the PMIC device goes into reset, the CAN transmitter in the motor controller loses its supply voltage, causing it to become inoperable. It also explains why the blue vehicle LOG data for the vehicle speed and brake pedal data have no missing data values, because these two types of data originate in a separate brake control module that has its own CAN transmitter and PMIC device that differ from the CAN transmitter and PMIC device in the motor controller module and that remain ON at all times.

One may ask why the missing accelerator pedal % values in the vehicle LOG shown in Figure 1 are completely missing while the missing accelerator pedal % values in the OTA LOG data of Figures 5 and 6 are not completely missing, but have zero values. This may be the result of the vehicle LOG data in Figure 1 being stored on an SD card whose preset values are the maximum values of all binary ones, while the vehicle LOG data in Figures 5 and 6 are stored on an SD card whose preset values are all zeros. In this case, it is easy to conclude that data in Figure 1 is missing if one sees a maximum value in the vehicle LOG because maximum 100% values are rarely attained, while it is not so easy to conclude that data is missing if one sees a zero value in the vehicle LOG because zero % values are often attained.

Observe also in Figure 1 that a note says that the brown accelerator pedal EDR data is questionable when vehicle LOG data is missing. This note is included because the same CAN bus transmitter in the drive control module is used for the vehicle LOG data as for the EDR data. So when the PMIC device goes into reset to cause this CAN bus transmitter to become inoperable, it creates missing data to both the vehicle LOG and

the EDR. In the EDR, however, missing data in the incoming data stream does not cause missing data in the EDR. If an incoming EDR value is missing, then the current EDR value remains unchanged while writing into the EDR. This means that when a value P_{ti} is missing in the incoming data stream, the value stored in the EDR becomes $P_{ti} = P_{ti-N}$ where N = the number of memory locations needed to store five seconds worth of P_{ti} data. Therefore, the EDR data will never have any missing data points. But some data points may be incorrect because they may repeat data that occurred five seconds earlier. In Figure 1, this means that the points in the EDR accelerator pedal % data between 5.0 seconds and 3.2 seconds, which correspond to missing points data in the vehicle LOG data caused by an inoperable CAN bus transmitter, likely occurred five seconds earlier (or more), placing them out of the figure.

We will now discuss how the accelerator pedal % values can suddenly increase to above 80% in Figure 1 and to 97% in Figures 5 and 6 to cause sudden acceleration.

V. How the Pedal % Values Can Suddenly Increase to Cause SUA

Notice that the accelerator pedal % values in both incidents start to increase immediately after an interval with missing data. This corresponds to the time when the PMIC device comes out of reset. When the PMIC device comes out of reset, it is designed to first activate the 1.2V core DSP supply, then the 3.3V supply, and finally the 5V supply. This means that the analog-to-digital converter (ADC), which operates with a 3.3V supply, can become operational while the 5V supply is still at zero volts.

Therefore, if the ADC samples the reference voltage as the first signal to be digitized [Footnote 5], it will see a reference voltage of zero analog volts because the reference voltage for a ratiometric APP sensor [Footnote 6] must be the APP sensor supply voltage, which is currently at zero volts. It then digitizes this reference voltage to get zero digital volts. A short while later, when the 5V supply finally gets powered up, and the ADC samples the APP sensor signal for the first time, it sees an analog sensor output voltage of 0.4V or 0.2V if the accelerator pedal is not pressed, which the ADC digitizes to 0.4V or 0.2V digital volts. The final digital values of the APP sensor signals are obtained by dividing the digitized sensor signals by the digitized reference voltage, which gives digital values of 0.4V/0V and 0.2V/0V, which are much larger digital values than 0.4V and 0.2V. Therefore, even though the accelerator pedal is released, because the driver is not stepping on the accelerator pedal at the time, the digital accelerator pedal signals are large while the analog accelerator pedal signals remain at their normal values. When these larger digital accelerator pedal signals are used to calculate the accelerator pedal % values, the result is that the accelerator pedal % values will suddenly increase to over 80% in Figure 1 and to 97% in Figures 5 and 6 to cause sudden unintended acceleration,

⁵ It makes sense that the ADC reference voltage is the first signal to be digitized after a reset or vehicle start because this voltage is used to divide all ratiometric sensor signal voltages to obtain a digitized sensor voltage free of variations in the supply voltage. Many of the sensors used in the Tesla inverter are ratiometric sensors with the same 5V supply voltage.

⁶ A ratiometric sensor is a sensor whose output increases (or decreases) by the same percentage as its supply voltage increases (or decreases). Therefore, if one divides the digitized sensor output by the digitized supply voltage, a larger (or smaller) supply voltage in the denominator will cancel a larger (or smaller) supply voltage in the numerator, and a sensor output free of variations in the supply voltage can be obtained.

even though the driver is not pressing on the accelerator pedal. And no diagnostic trouble code (DTC) will be produced by this mechanism because the digitized APP sensor signals fall within the range of allowed values.

The mechanism responsible for causing sudden unintended acceleration in this case is discussed in the author's paper entitled "*A Cause of SUA Common to All Vehicles with Electronic Throttles*".^[4] The only difference between the mechanism discussed in this paper and the mechanism discussed in the author's previous paper is that in the mechanism discussed in the present paper the voltage dip causing the sudden acceleration has a longer duration of one second instead of a just a few hundred milliseconds. This is a result of being caused by the reset of a PMIC device instead of by a transient inrush current from an electric motor turning on. In both cases, ratiometric APP sensors are used, and the ADC reference voltage is the +5V sensor supply voltage.

Normally, when the sensor supply voltage varies by 10% or less, then the ratiometric sensor output voltage varies by this same amount. So, if one divides the ratiometric sensor output voltage by a reference voltage equal to the sensor supply voltage, one gets a digitized sensor voltage that is free of the voltage variations of 10%. This operation is used by all manufacturers in their vehicles with electronic throttles. However, this operation assumes that the sensor output voltage and the ADC reference voltage see the same voltage variations. If they are not the same, and if the reference voltage digitized by the ADC is smaller than the normal supply voltage, then the digitized ratiometric sensor voltage will be larger than the analog sensor voltage. This mechanism with a PMIC device going into reset exists in addition to the mechanism with shorter inrush currents caused by electric motors turning on as discussed in previous papers for all vehicles with electronic throttles, and helps to explain the seven times higher incident rate for sudden acceleration in Tesla vehicles than for other vehicles with electronic throttles.

While this mechanism for causing sudden acceleration may seem difficult to understand by those who lack electronic design experience, it is based on the actual circuit design of the Tesla inverter as found by the author^[5] and on the industry-wide design practice of how ratiometric sensors are used in vehicles with electronic throttle throttles.^[6] And the conclusion it leads to regarding sudden unintended acceleration is supported by the human testimony of the two drivers involved in the two incidents discussed.

We will now discuss how the PMIC device can overheat to cause a reset that leads to sudden acceleration.

VI. How the PMIC Device Can Overheat to Cause Reset

It is easy to see how the PMIC device can overheat to cause reset. Figure 7 shows the Tesla Model 3 inverter with the PMIC device circled in red near the upper left-hand corner of a rectangular-shaped resistor bank in the center of the inverter. This resistor bank can carry a heavy current at times which causes it to heat up to a high temperature. The heat can be so intense that Tesla engineers have covered the resistors with a compressible silicone heat spreader as shown in Figure 8 that provides a better heat-conductive path to the water-cooled aluminum chassis than the air path used for all other devices on the inverter. Clearly, Tesla engineers would not do this unless this resistor heating was a problem. And one problem is that the PMIC device has a short

conductive heat path to the resistor bank so that its temperature can exceed 85°C, causing it to reset.

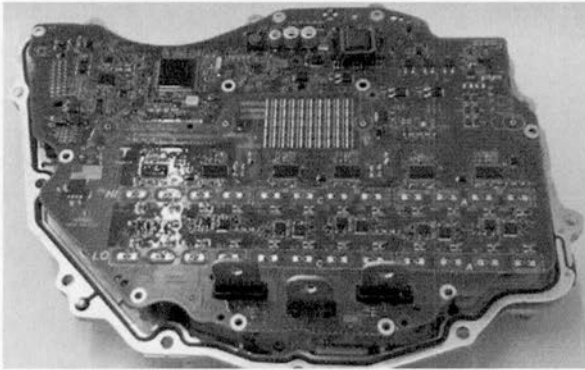


Figure 7. Tesla Model 3 inverter showing resistor bank close to PMIC device circled in red.

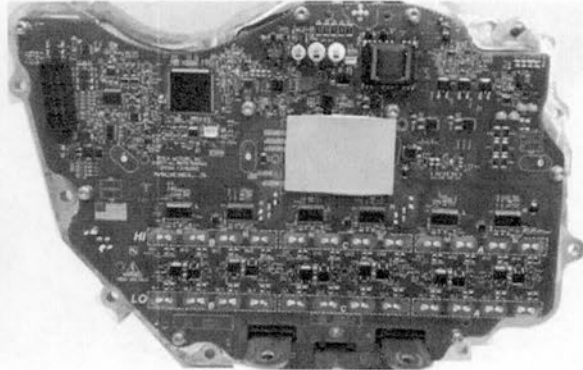


Figure 8. Resistor bank requires a silicone pad to improve heat conduction to the water-cooled chassis.

A question that may arise is why does this heating of the PMIC device to its reset temperature cause sudden acceleration to occur from a vehicle stop instead of randomly at any vehicle speed? The answer is that the sudden acceleration is correlated with the PMIC device coming out of reset, and not with the PMIC device going into reset. The heating of the device causing it to go into reset is a necessary condition, but this heating can occur during some period of time while the vehicle is operating normally before the sudden acceleration incident. During this time the PMIC chip can go into reset and remain in reset, causing the loss of accelerator pedal input to the pedal map. The current input to the pedal map remains unchanged in this case, allowing the drive motor to continue operation with the last pedal input that was received before the PMIC device went into reset.^[Footnote 7] During this time the accelerator pedal remains ineffective for changing the drive motor torque, so the motor torque remains the same during PMIC reset. If this happens during regen braking, then regen braking will continue until the vehicle speed is less than five miles per hour, when regen braking stops because the regen current gets too small.^[Footnote 8] In this case, heating of the PMIC device by the resistor bank stops and the PMIC device begins to cool, lowering its temperature until it gets below 85°C, causing it to come out of reset. Sudden acceleration then follows when the PMIC chip comes out of reset as described in Section IV. Therefore, sudden acceleration occurs from a low vehicle speed because the PMIC device comes out of reset at this time as a result of the device cooling down after regen braking stops when the vehicle speed is less than five miles per hour. But it does not occur from a vehicle stop just after the vehicle is started, because regen braking has not yet occurred that causes the PMIC device to go into reset.

⁷ The time that this mode of operation can last can be from one reset time of one second up to several reset times for a minute or more.

⁸ If the PMIC device goes into reset while the driver is positioning the accelerator pedal to request a positive torque, then the current positive torque will continue without the driver being able to change the torque. This may be the cause of some high-speed sudden acceleration incidents that have occurred in Paris, Norway, and China as well as in the USA.

Appendix C contains further discussion of the braking resistor and how it is used during regen braking to give the reader some background on how and when it gets heated.

VII. Summary and Conclusion

There are three types of LOG data for a Tesla vehicle: 1) vehicle LOG data obtained from a micro SD card in the gateway ECU, 2) OTA LOG data obtained from a Tesla server, and 3) EDR data obtained from EDR module in the restraint control module. Each of these three types of LOG data behaves differently to missing data in the incoming data stream. A single RAM storage address that serves as the input to the pedal map also behaves differently to missing data in the incoming data stream. Missing data can be created by a PMIC device going into reset, which causes the supply voltage to the two accelerator pedal position (APP) sensors and the CAN bus transmitter in the drive motor control module to go to zero volts or ground voltage, making them inoperable.

When values are missing in the incoming data stream, one must understand the changes that take place in the RAM, vehicle LOG, OTA LOG, and EDR, in order to interpret the data correctly. These changes are as follows:

RAM Input to Pedal Map. A single RAM storage address serves as the input to the pedal map. If an accelerator pedal % value is missing because the 5V supply to the APP sensors is non-functional, then when a WRITE operation occurs to this RAM address, the current value of the RAM will remain unchanged. Therefore, the torque command to the drive motor will remain unchanged and the motor will continue to operate without being responsive to the driver's attempts to change the accelerator pedal. If the current accelerator pedal % value is a request for regen braking, then the driver may not realize that the accelerator pedal is unresponsive, and the vehicle will continue to slow down until it is nearly stopped. If the current accelerator pedal % value is a request for positive torque, then the vehicle will continue to run at the designated speed while the driver will be unable to change the vehicle speed because the accelerator pedal is unresponsive.

EDR Data. The accelerator pedal % data stored in the EDR consists of values P_{ti} where $P_{ti} = 0\%$ to 100% , with no time stamp. When a value P_{ti} is missing in the incoming data stream, the value stored in the EDR becomes $P_{ti} = P_{ti-N}$ where N = the number of memory locations needed to store five seconds worth of P_{ti} data. Therefore, EDR data will never have any missing data points. But some data points may be incorrect because they may repeat data that occurred N time periods t_i earlier.

Vehicle LOG Data. The accelerator pedal % data stored in the vehicle LOG consists of values P_{ti} where $P_{ti} = 0\%$ to 100% , along with a time stamp for each value accurate to 0.01 seconds. When a value P_{ti} is missing in the incoming data stream, the value stored in the vehicle LOG along with the time stamp is the preset memory value of either $P_{ti} = 0$ or the maximum memory value (binary value of all ones, 111...11). If it is 0, then it is impossible to tell whether the data value P_{ti} is valid 0% pedal data or merely the preset memory value of zero. If it is the maximum value of 100%, then one can sometimes tell if P_{ti} is valid 100% pedal data or if there was a missing incoming data value (ie, SNA value, where SNA means Signal Not Available). The time stamps stored with the P_{ti} values are not affected by the missing incoming data values.

OTA LOG Data. The accelerator pedal % data stored in the OTA LOG consists of values P_{ti} where $P_{ti} = 0\%$ to 100% , along with a time stamp for each value accurate to 0.01 seconds. Missing data to the OTA LOG can be caused by two different mechanisms:

- 1) missing incoming data to the vehicle LOG from which the OTA LOG data are obtained, in which case the effects on the stored OTA LOG values are the same as those described for the vehicle LOG values, and
- 2) one or more missing cellular telephone data packets between the vehicle and the centrally located Tesla server, in which case multiple contiguous OTA LOG data values P_{ti} in each data packet may be lost as well as their time stamps.

By using this knowledge of what happens when missing values are present in the incoming data stream, the following facts were obtained from the OTA LOG data of Figures 5 and 6:

- 1) The accelerator pedal % values for the last two “non-zero” intervals are completely missing because the cellular telephone data packets were not received by Tesla. This is why it was impossible for the Tesla engineer to give the maximum values for these intervals.
- 2) The “0” values for the four one-second long intervals are caused by the preset memory values of zero in the vehicle LOG when the pedal values are missing in the incoming data stream. They do not represent actual 0% pedal values. This helps to understand why the duration of these intervals is exactly 1 second 0.1 seconds, which is caused by the PMIC device being in reset. When the PMIC device is in reset, there can be no % pedal values in the incoming data stream because the CAN bus transmitter in the drive motor control module is inoperable. In this case, the values stored in the SD card of the vehicle LOG are the preset memory values of zero. If they are wrongly considered to be 0% values caused by the driver releasing the accelerator pedal, then the driver would have to release the accelerator pedal four times for exactly one second ± 0.1 second each time while pressing the accelerator pedal in between each of these intervals for over a second to cause non-zero pedal readings. This is clearly a human impossibility. Therefore, NHTSA is in error to say that this data shows that the driver was pressing on the accelerator pedal instead of the brake pedal to cause the sudden acceleration.
- 3) The large value of 97% for the accelerator pedal % data occurs after the PMIC device comes out of reset, when the APP sensors, ADC, and CAN bus transmitter in the motor control module begin to operate normally again. When this happens, the ADC can resume operation before the supply voltage of the two APP sensors can turn on. If the ADC then digitizes the reference voltage as the first voltage to be digitized, it will see the ratiometric sensor supply voltage of zero volts instead of the normal supply voltage of 5V. Then, after the APP sensors turn on, the ADC will use this incorrect zero-volt value as the reference voltage during APP sensor signal digitization instead of the normal 5V. The result is that the analog sensor values of 0.4V and 0.2V for a released accelerator pedal get divided by the ADC reference voltage value of zero volts instead of the normal 5V to produce final digitized values of the sensor voltages of $0.4/0$ and $0.2/0$. These final digitized values of the APP sensor voltages can be 4.0V and 2.0V or greater, which correspond to

accelerator pedal % values of 100% or more. This causes the sudden jump in accelerator pedal % values resulting in sudden unintended acceleration. And it happens while the driver's foot remains off the accelerator pedal.

By using this knowledge of what happens when missing values are present in the incoming data stream, the following facts were obtained from the vehicle LOG data of Figure 1:

- 1) Gaps with missing data are found in the accelerator pedal % data. One gap with 5 missing points has a duration of exactly one second. Another gap with 19 missing points has a duration of 3.8 seconds. This is only one point shy of being four one-second intervals. These time durations suggest that the gaps are caused by a device in the motor control module going into reset for exactly one second. Based on the conclusion drawn from Figures 5 and 6, this device is the PMIC device, which has a reset duration of exactly one second. This can explain the missing accelerator pedal % vehicle LOG data because when the PMIC goes into reset, the CAN bus transmitter in the motor control module cannot send any accelerator pedal % values to the vehicle LOG. When the vehicle LOG tries to write this absent data, the result is a time stamp with the absent data value being the preset value of the SD card memory location. This preset value can be either 0 or the maximum value of all binary ones. In this case, the preset value is the maximum memory value of all binary ones, which allowed Tesla to know that the accelerator pedal % data values were missing.
- 2) The accelerator pedal % values begin to rise from zero toward a peak value of about 89% near the end of the interval containing 19 missing points. This is the time when the PMIC device comes out of reset, allowing the APP sensors, ADC, and CAN bus transmitter in the motor control module to begin operating normally again. When this happens, the pedal % value can rise to a large value as described in conclusion 3 for the OTA data above. This causes the sudden jump in accelerator pedal % values to 89%, while the driver's foot remains off the accelerator pedal. The result is sudden unintended acceleration.
- 3) No missing data is seen in the vehicle speed data or the brake apply data. This is because the CAN bus transmitters for these two types of data are different from the CAN bus transmitter for the accelerator pedal % data. And they remain operable because their supply voltages are provided by a different PMIC device.

By using this knowledge of what happens when missing values are present in the incoming data stream, the following facts were obtained from the EDR of Figure 1:

- 1) The accelerator pedal % values of 0% between -5.0 seconds and -2.4 seconds in the EDR data occur while the corresponding accelerator pedal % values in the vehicle LOG data are missing. However, the EDR and the vehicle LOG both obtain their data from the same CAN bus transmitter. Therefore, if data is missing in the vehicle LOG data, this same data should also be missing at from the EDR data at the same time. The reason why missing data does not occur in the EDR is that the EDR can never have any missing data if data is missing in the incoming data stream. Instead, the data in the EDR locations corresponding to the missing incoming data remain the EDR values that

occurred five seconds earlier. Therefore, it is impossible to know from the EDR accelerator pedal % values between -5.0 seconds and -2.4 seconds what the state of the true accelerator pedal % values truly were at the time before the % values start to increase. **So, if one has only EDR data without any corresponding vehicle LOG data, then one can never know if the EDR data for some interval is the true data for that interval or merely some data that occurred 5 seconds earlier. This is why it is essential to have vehicle LOG data whenever EDR data is used to interpret what happened during an alleged sudden unintended acceleration incident. EDR data by itself is unreliable.**

- 2) The EDR accelerator pedal % values begin to rise from zero toward a peak value of about 89% near the end of the interval in the vehicle LOG data containing 19 missing points. This is the time when the PMIC device comes out of reset, allowing the APP sensors, ADC, and CAN bus transmitter in the motor control module to begin operating normally again. When this happens, the pedal % value can rise to a large value as described in conclusion 3 for the OTA data above. This causes the sudden jump in EDR accelerator pedal % values to 80%, while the driver's foot remains off the accelerator pedal. The result is sudden unintended acceleration.

All of these facts are consistent with the driver's testimony in these two incidents.

Based on these facts, the following conclusions were obtained. Gaps in the vehicle LOG accelerator pedal data produced in one incident are consistent with a fault in the drive motor control module. The unique one-second-long duration of the zero values in the OTA LOG accelerator pedal data in the second incident allows further localization of the fault to the power management integrated circuit (PMIC) device that provides the +5V supplies to the accelerator pedal position (APP) sensors and the CAN bus transmitter. The fault is caused by the PMIC device going into reset when the device exceeds its maximum temperature specification of 85°C. This causes the +5V supply to go to ground (0V) for exactly one second, during which the the APP sensors lose their supply voltage. If the ADC senses the +5V supply voltage while it is at 0V during reset, and then uses this lower voltage as a ratiometric correction to the APP sensor outputs when the +5V supply is restored, then the incorrect supply voltage of 0V will cause the digital outputs of the two APP sensors to increase up to 4V or more while the analog outputs of the sensors remain at 0.4V and 0.2V. This will cause the digital accelerator pedal % value to increase up to 100% even though the driver is not pressing on the accelerator pedal. Since this same PMIC device is used in all Tesla vehicles, this same thermally-induced reset in the PMIC device will occur in all Tesla vehicles, producing sudden acceleration from a low speed. Unintended acceleration starting at higher speeds can also be caused by the loss of the accelerator pedal signal when the PMIC device goes into reset because the RAM location that provides the input to the pedal map cannot be updated with new pedal % values. Therefore, the drive motor continues operation using the current pedal % value in the RAM location, which cannot be changed by the driver while the PMIC is in reset. No diagnostic test code (DTC) is produced in either case.

NHTSA's conclusion that the drivers in these two incidents caused the incidents by stepping on the accelerator pedal instead of the brake pedal requires the following:

- 1) Either NHTSA must explain why four intervals of accelerator pedal % values in the OTA LOG data of Figures 5 and 6 have a duration of exactly one second accurate to ± 0.1 seconds if the driver is alternately pressing and releasing the accelerator pedal, or NHTSA must ignore this fact.
- 2) Either NHTSA must explain why this one-second duration matches exactly the reset time of the PMIC device in the Tesla inverter, or NHTSA must ignore this fact.
- 3) Either NHTSA must explain why there are missing accelerator pedal % values in the vehicle LOG data of Figure 1, or NHTSA must ignore this fact.
- 4) Either NHTSA must explain why two intervals of missing accelerator pedal % values in the vehicle LOG data of Figure 1 have durations of exactly one second and approximately four seconds, which are one and four times the reset duration of the PMIC device in the Tesla inverter, or NHTSA must ignore this fact.
- 5) Either NHTSA must explain how two different drivers in two different incidents can produce multiple intervals of released pedal values of exactly the same duration of one second accurate to ± 0.1 seconds, or NHTSA must ignore this fact.
- 6) Either NHTSA must explain why missing data in the vehicle LOG occurs only in the accelerator pedal % data and not the vehicle speed data or the brake apply data, or NHTSA must ignore this fact.
- 7) Either NHTSA must explain why the accelerator pedal % values of 0% between -5.0 seconds and -2.4 seconds in the EDR data can be present while they must pass through the same CAN bus transmitter as the accelerator pedal % values in the vehicle LOG when the corresponding values in the vehicle LOG are missing, or NHTSA must ignore this fact.
- 8) Finally, NHTSA's conclusion requires that the driver's testimony in these two incidents must be rejected.

Appendix A.

Description of LOG Data for the Second Incident

- A. The driver describes the incident as follows: As she was slowly entering a perpendicular parking space on level ground in front of a building, the vehicle's motor was at idle and her foot was hovering over the brake pedal but not in contact with it. She then heard the motor rev up by itself, but the vehicle did not accelerate immediately. Then, about a second later, the motor noise revved up to maximum amount by itself and the vehicle accelerated over a concrete curb and crashed into the building wall. The brakes were not applied by the driver. The crash caused the air bags to deploy, but there was only minor property damage done to the building. There was substantial front end damage to the car and damage to one of rear wheels. No personal injuries were caused by the accident.
- B. Tesla obtained the following information from the OTA LOG data that was transmitted from the vehicle to Tesla immediately after the incident. This data was not obtained from the electronic data recorder (EDR) in the airbag management system. Nor was this data obtained from the vehicle LOG. The Tesla engineer was looking at this OTA LOG data as he provided the following summary to the driver during a telephone call. This accelerator pedal OTA LOG data is stored at a rate of 1 sample per second. The Tesla engineer could obtain the durations of the intervals by looking at the time stamps of the data before and after each interval. And he could determine the amplitude of each event by looking at the OTA LOG amplitude for that event.. The summary below is almost a word-for-word transcript of what the Tesla engineer said during the telephone call:
1. There were four separate applications of the accelerator pedal with intervals of about one second between each application.
 2. The first application lasted 1.3 seconds and resulted in the pedal being pressed to about 22% of its maximum. The amount of pedal depression comes from the two accelerator pedal sensors, which read 22% and 21.6%, respectively.
 3. Between the first and second application, there was a one second interval when the accelerator pedal was not pressed.
 4. The second application lasted about 1.0 seconds and resulted in the pedal being pressed to about 97% of its maximum.
 5. Between the second and third application, there was a one second interval when the accelerator pedal was not pressed.
 6. The third application lasted about 1.0 seconds. The maximum value for any of the 10 data points in this application could not be determined.
 7. Between the third and fourth application, there was a one second interval when the accelerator pedal was not pressed.
 8. The fourth application lasted about 1.5 seconds. The maximum value for any of the 15 data points in this application could not be determined.
 9. The brake pedal was pressed only after the last (fourth) application of the accelerator pedal.
 10. The crash occurred during the second application of the accelerator pedal.
 11. At the time of the crash the vehicle speed was 15 MPH. Before the crash the vehicle speed was 3.5 MPH.

12. The air bags deployed at the time of the crash.
 13. After the crash, the motor torque was reduced to zero because the engine control system cuts the motor torque whenever a crash occurs.
 14. Tesla interprets this data to imply that the driver caused the accident by pressing on the accelerator pedal instead of the brake.
- C. Conclusions made by this author from the LOG data:
1. The Tesla engineer refers to four applications of the accelerator pedal interleaved with four intervals in which the accelerator pedal was not pressed.
 2. The one-second duration stated for each of four intervals that were not pressed were obtained by subtracting the time stamp for the previous interval from the time stamp for the current interval. The accuracy of these time stamps is ± 0.01 seconds, so the length of the one-second intervals is accurate to less than ± 0.1 seconds.
 3. The four one-second intervals between the non-zero applications of the accelerator pedal were interpreted by the Tesla engineer to be intervals in which the accelerator pedal was not pressed. The words “where the accelerator pedal was not pressed” was assumed to mean 0% pedal application.
 4. The 1.3 second duration of the first non-zero application of the accelerator pedal (item 2 above) was obtained by subtracting the time stamp for the previous non-zero interval from the time stamp for the current interval. The accuracy of these time stamps is ± 0.01 seconds, so the length of the 1.3 second interval is accurate to less than ± 0.1 seconds.
 5. From items 10, 6, and 8 it can be determined that last two non-zero applications of the accelerator pedal occurred after the crash. It is possible to have non-zero values of the accelerator pedal application because the accelerator pedal sensors as well as the ADC electronics continue to operate after the drive motor is shut down. It is also clear that the vehicle speed at all times after the crash was 0 mph.
 6. The Tesla engineer could not give a reason for why the maximum values in the last two accelerator pedal applications could not be determined. If the data points had been normal values between 0% and 100% inclusive, then he could have easily stated so. But he didn't. If they had been abnormal values of greater than 100% or less than 0%, then he could have easily stated so. But he didn't. The only reason why he couldn't give the maximum value of the data points for these two regions is that all the data points in these two regions were missing. He could easily determine the duration of these two regions of pedal application by subtracting the time stamp for the last value in the preceding one-second interval from the first value in the following one-second interval. The accuracy of these time stamps is ± 0.01 seconds, so the length of these two regions with unknown accelerator pedal % values is 1.0 seconds and 1.5 seconds accurate to less than ± 0.1 seconds.
 7. The Tesla engineer interpreted this data to imply that the driver caused the accident by pressing on the accelerator pedal instead of the brake. But no human driver can press the accelerator pedal with durations of 1.3, 1.0, 1.0, and 1.5 seconds interleaved with four intervals of exactly 1.0 seconds accurate to less than ± 0.1 second during which the accelerator pedal was not pressed.

This can only be explained by some electrical or mechanical phenomenon having a time constant of exactly 1.0 seconds ± 0.1 second.

Appendix B

Tesla LOG Types and Missing Data

There are three types of log data for a Tesla vehicle; namely, EDR data, vehicle LOG data, and OTA LOG data, where OTA stands for Over-The-Air. The EDR data and the LOG data are stored on the vehicle while the OTA LOG data is stored on a centrally located Tesla server. Each of these data logs contains its own unique data types and data rates, as shown in Table B1.

RAM Input to Pedal Map

The origin of the accelerator pedal % data sent to these three logs is a single RAM address in the accelerator pedal sensor (APP) signal chain shown Figure B1. The contents of this RAM address, along with the vehicle speed, point to a location in the pedal map that provides a torque command to the drive motor as requested by the driver. If an error is found in the APP sensor output during subsequent validity tests, then a DTC is posted and the % pedal value is not calculated. But if an APP sensor output is missing because the sensor supply voltage is not present, then no DTC is posted because there is nothing to test, and the % pedal value is not calculated. In either case, a missing accelerator % pedal value occurs at the RAM input while a RAM WRITE operation occurs, which results in the current value of the RAM memory location remaining unchanged. This allows the torque command to the drive motor to remain unchanged by a temporary sensor error. The following sections describe what happens when an error occurs in the transmission of the % pedal data from the RAM location to the three destination logs as a result of the CAN transmitter being non-functional.

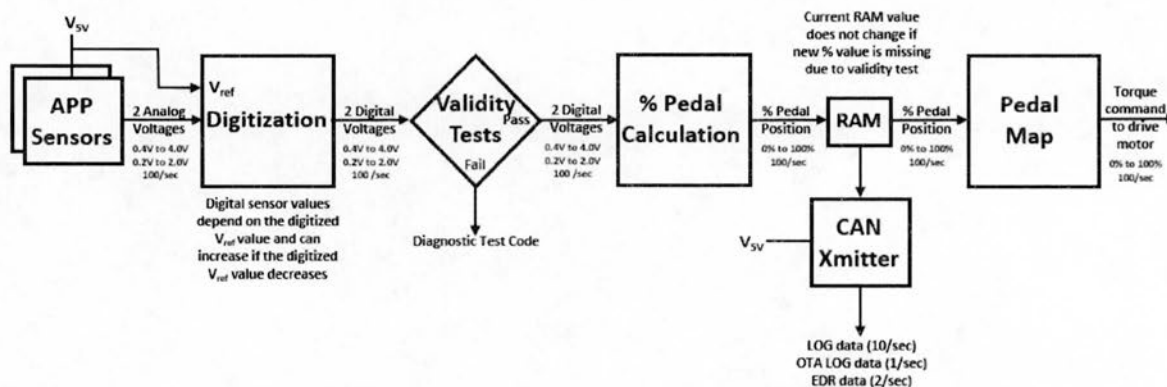


Figure B1. Signal chain for accelerator pedal data showing that the pedal data appearing in the EDR and vehicle LOG originates from a RAM location that serves as the input to the pedal map. If an error is detected in the sensor output, then a DTC is posted and the % pedal value is not calculated. But if an APP sensor output is missing because the sensor supply voltage is not present, then no DTC is posted because there is nothing to test, and the % pedal value is not calculated. This causes a missing % pedal value at the RAM input, which results in the current value of the RAM memory location remaining unchanged. This causes the torque command to the drive motor to remain unchanged by the missing sensor value. The RAM value at any time serves as the origin of the % pedal data sent to the EDR, the vehicle LOG and the OTA LOG via the CAN bus. Before

the CAN data is transmitted, the DSP down-selects the samples from the RAM operating at 100 samples/second to create the lower data rates required for the three data destinations shown in Table B1. However, if the CAN transmitter is non-functional because its 5V supply is not present, then missing % pedal values will be included in the data stream to the vehicle LOG, the OTA LOG, and the EDR.

A single RAM storage address serves as the input to the pedal map. If an accelerator pedal % value is missing because the 5V supply to the APP sensors is non-functional, then when a WRITE operation occurs to this RAM address, the current value of the RAM at that address will remain unchanged. Therefore, the torque command to the drive motor will remain unchanged and the motor will continue to operate without being responsive to the driver's attempts to change the accelerator pedal control. If the current accelerator pedal % value is a request for regen braking, then the driver may not realize that the accelerator pedal is unresponsive, and the vehicle will continue to slow down until it is nearly stopped. If the current accelerator pedal % value is a request for positive torque, then the vehicle will continue to run at the designated speed while the driver will be unable to change the vehicle speed because the accelerator pedal is unresponsive.

EDR Data

The EDR consists of a memory that records five seconds worth of accelerator pedal data that occurs just before a crash. This is done by writing the incoming data values into successive memory locations whose addresses change in a rotating fashion as shown in figure B2.

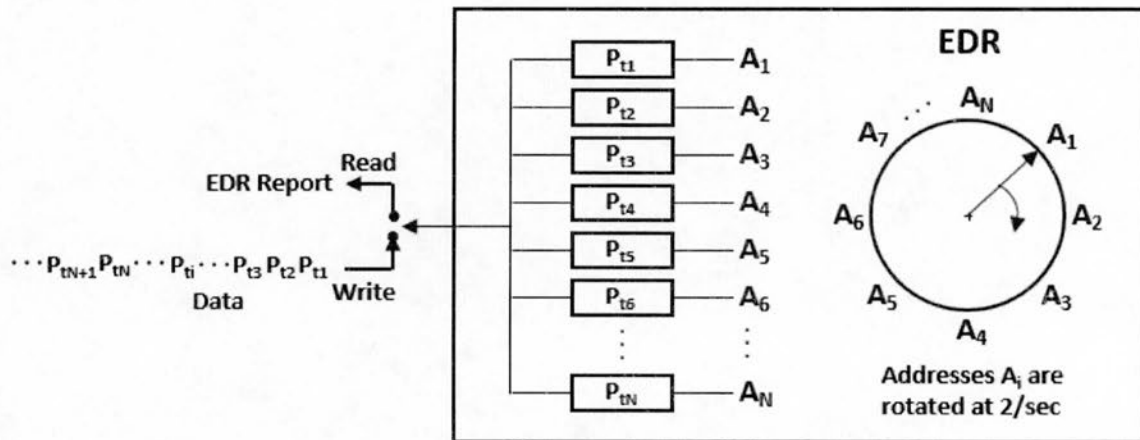


Figure B2. The EDR operates by writing the incoming accelerator pedal % values into successive memory locations whose addresses change in a rotating fashion. If a point P_{ti} is missing in the incoming data stream, the value stored in the EDR remains the current value $P_{ti} = P_{ti-N}$.

The memory capacity of the EDR is very small compared to the amount of data in the incoming data stream. This means that data coming into the EDR must continually overwrite the data already in the EDR. If a new data value P_{ti} is missing in the incoming data stream, then the value at address A_i in the nonvolatile RAM remains at its current

value P_{ti-N} . Therefore, EDR data will never have any missing data points. But some data points may be incorrect because they may repeat data that occurred N time periods t_i earlier. For current EDR's, $N = 5 \text{ sec} \times 2 / \text{sec} = 10$, for 10 data points or 5 seconds earlier. One cannot tell if a data point at any given time is valid data or a repeat of data that occurred N time periods earlier unless one has additional valid data showing that there are no missing data points at the given time. So, when a point P_{ti} is missing in the incoming data stream, the value stored in the EDR becomes $P_{ti} = P_{ti-N}$.

The accelerator pedal % data stored in the EDR consists of values P_{ti} where $P_{ti} = 0\%$ to 100% , with no time stamp. When a value P_{ti} is missing in the incoming data stream, the value stored in the EDR becomes $P_{ti} = P_{ti-N}$ where $N =$ the number of memory locations needed to store five seconds worth of P_{ti} data. Therefore, EDR data will never have any missing data points. But some data points may be incorrect because they may repeat data that occurred N time periods t_i earlier.

Vehicle LOG data

The memory capacity of the vehicle LOG is very large compared to the amount of data in the incoming data stream. The Model S vehicle LOG has a memory capacity of 4 GB and the Model 3 vehicle LOG has a memory capacity of 8 GB. This means that incoming data points never overwrite valid data already stored in the vehicle LOG memory. If a new data value P_{ti} is missing in the incoming data stream, then the value stored at memory location A_i in the vehicle LOG remains at its current value. This current value is the value that all vehicle LOG memory locations are set to when the memory is first installed. This value should be a value that is not present in the incoming data stream, like the maximum possible value of all ones, or binary 111...11. But sometimes software engineers get sloppy and either set the initial memory values to all zeroes, or else don't prepare the memory with any initial value at all, which allows the value set by the manufacturer to remain the initial value, which is often zero. In this case, if a new data value P_{ti} is missing in the incoming data stream, then the value at memory location A_i remains at its current value $P_{ti} = 0$. Therefore, when a value zero appears in the LOG data, it is impossible to tell whether the data point is valid data or merely the preset value of zero that all memory locations were set to initially and which remains stored when a missing data point occurs. So, when a point P_{ti} is missing in the incoming data stream, the value stored in the vehicle LOG becomes either $P_{ti} = 0$ or the maximum value of all ones, or binary 111...11. If it is 0, then it is impossible to tell whether the data point is valid data or merely the preset background value of zero. If it is the maximum value, then one can sometimes tell it is a missing data value. NOTE: Whatever the value, it is stored in the vehicle LOG with a time stamp accurate to 0.01 seconds.

The accelerator pedal % data stored in the vehicle LOG consists of values P_{ti} where $P_{ti} = 0\%$ to 100% , along with a time stamp for each value accurate to 0.01 seconds. When a value P_{ti} is missing in the incoming data stream, the value stored in the LOG along with the time stamp is the preset memory value of either $P_{ti} = 0$ or the maximum memory value (binary value of all ones, 111...11). If it is 0, then it is impossible to tell whether the data value P_{ti} is valid 0% pedal data or merely the preset memory value of zero. If it is the maximum value of 100%, then one can sometimes tell if P_{ti} is valid 100% pedal data or if there was a missing incoming data

value (ie, SNA value, where SNA means Signal Not Available). The time stamps stored with the P_{ti} values are not affected by the missing incoming data values.

OTA LOG data

OTA LOG data is generated by sending a subset of the vehicle LOG data to a centrally located Tesla server at a lower data rate. Therefore, it is similar to vehicle LOG data with the following exceptions:

- 1) The OTA LOG data rate can be slower than the vehicle LOG data rate. The OTA LOG data rate for accelerator pedal % data is one data point per second while the LOG data rate is ten data points per second. Also, each OTA LOG data value is the maximum value that occurred in the vehicle LOG data during the previous one second interval.
- 2) If the original vehicle LOG data had missing incoming data, then the stored OTA LOG data will be affected in the same way as the stored vehicle LOG data. The effects of this missing incoming data are discussed above in the section entitled vehicle LOG data.
- 3) There is a second mechanism that can create missing OTA LOG data. This is because the OTA data is sent to a centrally located Tesla server in packets of contiguous data points over a cellular telephone link, and sometimes one or more of the data packets can be missing. In this case, if an interval of contiguous points P_{ti} are missing in the incoming data stream, then no values will be stored in the OTA LOG file for these contiguous P_t data values and their time stamps.

The accelerator pedal % data stored in the OTA LOG consists of values P_{ti} where $P_{ti} = 0\%$ to 100% , along with a time stamp for each value accurate to 0.01 seconds.

Missing data to the OTA LOG can be caused by two different mechanisms:

- 1) missing incoming data to the vehicle LOG, in which case the effects on the stored OTA LOG values are the same as those described above for the vehicle LOG values, and
- 2) one or more missing cellular telephone data packets to the centrally located Tesla server, in which case the multiple contiguous OTA LOG data values P_{ti} in each data packet are lost as well as their time stamps.

Table B1. There are three types of Tesla LOG data, each with different data and data rates.

Tesla CAN Data From vehicle CAN bus	Tesla Vehicle LOG data From vehicle gateway ECU	Tesla OTA LOG data From Tesla OTA server	Tesla EDR data From vehicle RCM module
CAN bus rate = 100/sec No time stamps	Rates vary with data Every nth sample of CAN data Time-stamped to accuracy of 10 milliseconds	Rates are all 1/sec Every nth sample of LOG data Time-stamped to accuracy of 10 milliseconds	Rates vary with data Every nth sample of CAN data No time stamps
Continuous sensor data: APP sensor (100/sec) Vehicle speed (100/sec) Brake pedal (upon change)	Sensor data for >15 sec before and after crash: APP sensor (5/sec) Vehicle speed (1/sec) Brake pedal (upon change)	Sensor data for >15 sec before and after crash: APP sensor (1/sec) Vehicle speed (1/sec) Brake pedal (upon change)	Sensor data for 5 sec before crash: APP sensor (5/sec)* Vehicle speed (5/sec)* Brake pedal (upon change)
Continuous sensor data: Front motor torque (100/sec) Rear motor torque (100/sec) ABS (ON/OFF upon change) Steering angle (100/sec)	Sensor data for >15 sec before and after crash: Front motor torque (1/sec) Rear motor torque (1/sec) ABS (ON/OFF upon change) Steering angle (5/sec)	Sensor data for >15 sec before and after crash: Front motor torque (1/sec) Rear motor torque (1/sec) ABS (ON/OFF upon change) Steering angle (1/sec)	Sensor data for 5 sec before crash: Rear motor speed (2/sec)* ABS (ON/OFF 5/sec)* Steering angle (10/sec)* ESC (ON/OFF 5/sec)*
Continuous sensor data: Brake light (upon change) Brake pressure (100/sec) Cruise Set speed (100/sec) Cruise state (upon change) AP state (upon change) AP lead distance (100/sec) L & R turn indicator	Sensor data for >15 sec before and after crash: Brake light (upon change) Brake pressure (5/sec) Cruise Set speed (1/sec) Cruise state (upon change) AP state (upon change) AP lead distance (1/sec) L & R turn indicator	Sensor data for >15 sec before and after crash: Brake light (upon change) Brake pressure (1/sec) Cruise Set speed (1/sec) Cruise state (upon change) AP state (upon change) AP lead distance (1/sec) L & R turn indicator	
If P_{ti} is missing in the incoming data stream to the pedal map, then the current input to the pedal map remains unchanged. Therefore, the motor torque is	If P_{ti} is missing in the incoming data stream, the value stored in the LOG becomes either $P_{ti} = 0$ or the maximum value.	If P_{ti} is missing in the incoming data stream, the value stored in the OTA LOG becomes either $P_{ti} = 0$ or the maximum value. AND If points P_{ti} are missing in the cellular telephone data	If P_{ti} is missing in the incoming data stream, the value stored in the EDR becomes $P_{ti} = P_{ti-N}$

not changed by a temporary error in the sensor output.		packet between the vehicle and the Tesla server, no values will be stored in the OTA LOG file at the time points P_{ti} are written.	
		Pre-crash accelerometer data Lateral accel (10/sec) Long accel (10/sec) Roll rate (10/sec) Yaw rate (10/sec)	
		Post-crash accelerometer data Long accel (100/sec) Lateral accel (100/sec) Normal accel (100/sec) Longitudinal ΔV (100/sec) Lateral ΔV (100/sec)	

* Will increase to 10/sec after 2027.

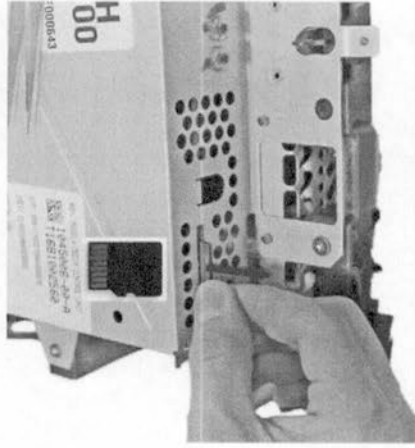


Figure B3. Tesla Model S vehicle LOG data on 15x11 mm 4 GB Micro SD card in gateway ECU chassis

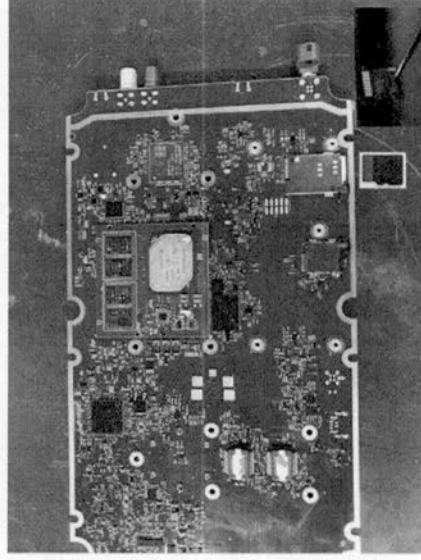


Figure B4. Tesla Model 3 vehicle LOG data on 15x11 mm 8 GB Micro SD card on gateway ECU board

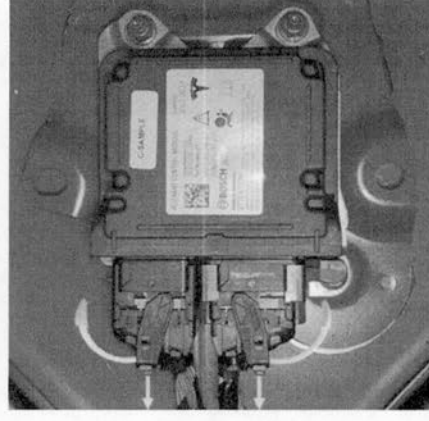


Figure B5. Tesla EDR module in restraint control module between driver and front passenger

Appendix C

Regen Braking and Regen Braking Resistor

Regen braking is controlled by the pedal map, which translates the accelerator pedal position values into torque requests to the motor controller as a function of the vehicle velocity. A typical pedal map is shown in Figure C1. Positive torques in red result in acceleration while negative torques in blue result in regen braking.

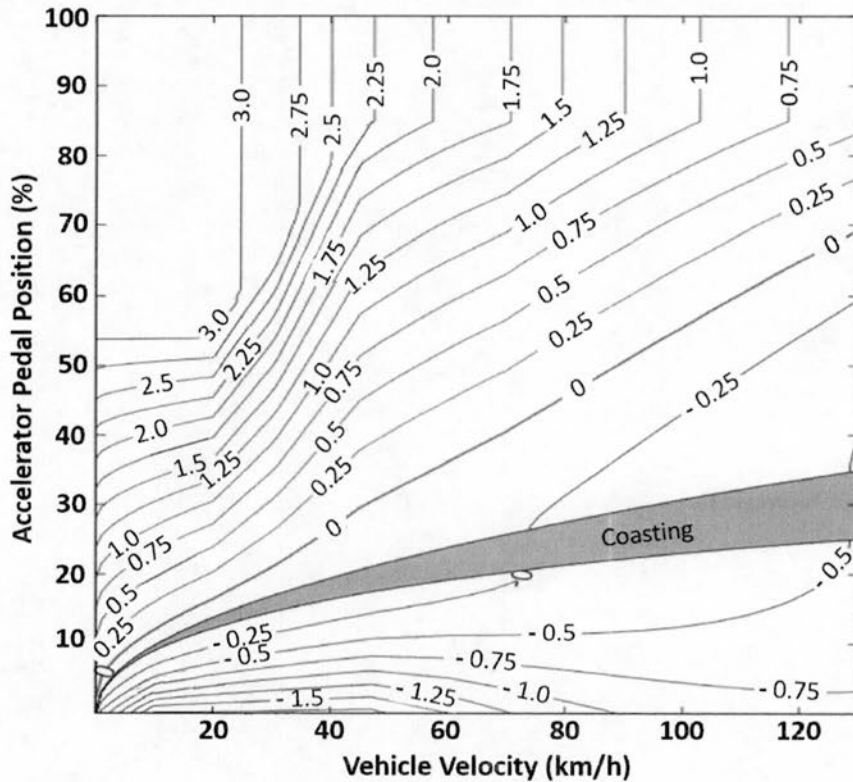


Figure C1. A pedal map translates accelerator pedal position values into torque requests. This typical map from a non-Tesla vehicle shows deceleration values in tenths of g's produced by the requested torques when acting on a constant vehicle inertia. Positive torques in red provide acceleration while negative torques in blue provide regen braking. Zero torque (also called neutral torque) corresponds to the torque value that allows the vehicle to move at a constant speed with no acceleration or regen braking. It increases approximately linearly with vehicle velocity. Coasting torque is the minimum regen braking torque that gives the driver the feeling of slowing down. It increases more slowly with vehicle velocity than the zero or neutral torque. Negative torque requests are set to zero by the motor controller when regen braking is turned off.

Regen braking can be turned off by other vehicle systems as shown in Table C1.

Table C1. Regen braking can be turned off when it causes issues for other vehicle systems

	Condition When Regen Braking is Turned Off	Source of Regen OFF Command
1	Battery SOC too high (>95%) after recharging	Battery management system
2	Battery SOC too high (>95%) during regen	Battery management system
3	Battery temperature too high for charging	Battery management system
4	Battery temperature too cold for charging	Battery management system
5	Vehicle speed too low (<5 mph)	Braking system wheel speeds
6	ABS activated due to stopping too hard	Braking system ABS function
7	Bumps in the road cause wheel slip	Braking system ABS function
8	Gravel roads cause wheel slip	Braking system ESP function
9	Icy roads cause wheel slip	Braking system ESP function
10	During turns when wheel speeds vary	Braking system ESP function
11	Going up or down hills	Braking system ESP function
12	Wrong size tires or winter tires	Braking system ESP function
13	During traction control operation	Traction control system

Commands for positive and negative torque issued by the pedal map are carried out by the inverter circuitry shown in Figure C2.

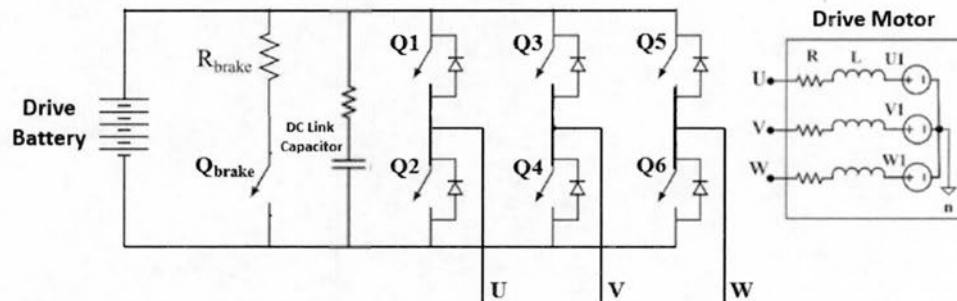


Figure C2. An inverter uses six high voltage transistors to control drive motor operation. Motor torque can either be positive during the acceleration mode or negative during the regen braking mode. Negative motor torque means that the motor is slowing down. It does not mean that the motor is operating with a positive torque in the reverse direction.

Commands for positive torque are carried out by operating the six inverter transistors as shown in Figure C3.

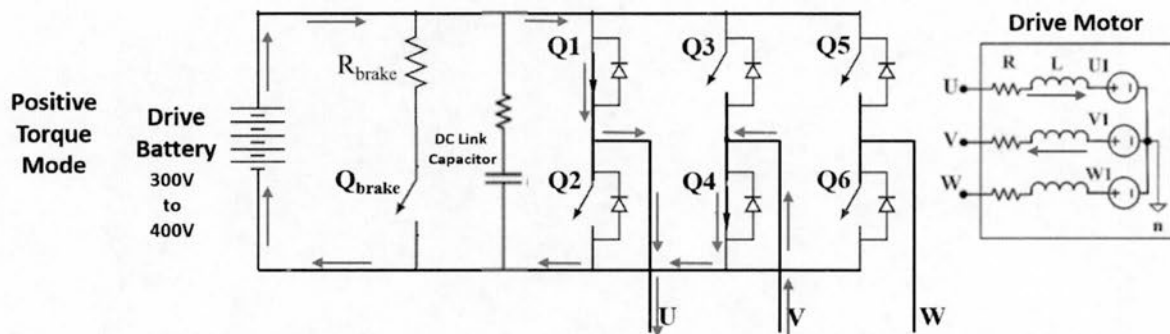


Figure C3. In the positive torque mode, one upper transistor and one lower transistor are turned ON at the same time where the lower ON transistor provides a path through the motor windings and not a direct path to ground. Forward motion is obtained by rotating the transistor settings to the right at the motor speed while reverse motion is obtained by rotating the transistor settings to the left. Torque is controlled by modulating the conduction of the two active transistors. The brake resistor is not used in the positive torque mode.

Commands for negative torque that cause regen braking are carried out by operating the six transistors as shown in Figure C4.

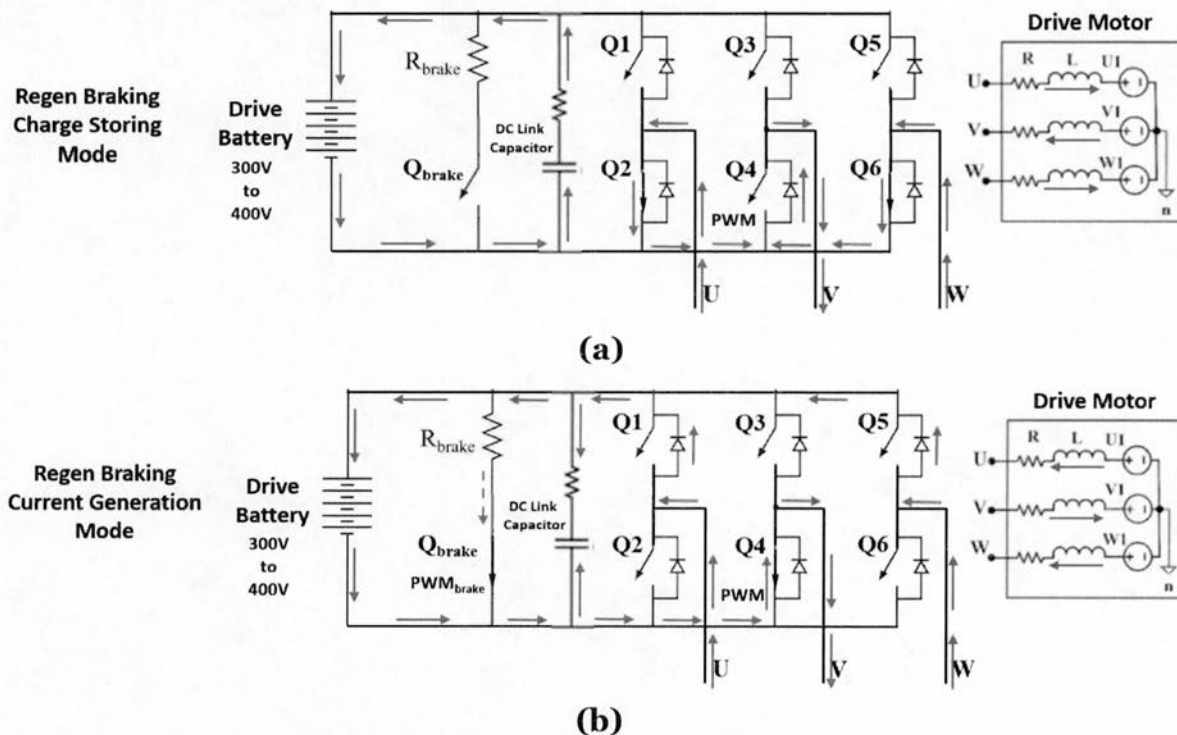


Figure C4. Regen braking involves two modes of operation, a charge-storing mode as shown in (a) and a current generation mode as shown in (b). In both regen braking modes, all upper transistors are turned OFF and regen braking magnitude is regulated by varying the duty cycle of the lower PWM transistor. PWM is short for “pulse width modulation” and it implies that the transistor is alternately turned fully ON or fully OFF, with the duty cycle being the ratio of the ON time to the sum of the ON time plus the

OFF time. Thus, 0% duty cycle implies the transistor is always OFF while 100% duty cycle implies it is always ON.

During the regen charge-storing mode (a), when the PWM transistor Q4 is turned OFF while the other two lower transistors are turned ON, energy from the back EMFs U is stored in the inductances L of each stator winding while the isolated DC link capacitor discharges slightly to the drive battery. Forward motion is maintained by rotating the transistor settings to the right at the decreasing motor speed. The braking resistor is not used in the charge storing mode.

During the regen current generation mode (b), when the PWM transistor Q4 is turned ON while the other two lower transistors are turned OFF, current is transferred from the inductances L of the drive motor to the DC link capacitor and the drive battery. In this case, when the regen voltage exceeds the battery voltage, regen current passes through the isolation diodes of the upper transistors. Forward motion is maintained by rotating the transistor settings to the right at the decreasing motor speed. The braking resistor is PWM'd with PWM_{brake} when necessary to keep the battery current and voltage within battery limits. The excess current passed through the braking resistor heats up the braking resistor at a rate proportional to I^2R . Deceleration remains unchanged when excess current is shunted through the braking resistor to ground, because both the battery and the braking resistor are loads that behave in the same way to regen current and voltage.

One might ask how regen current can be passed into the battery when the back EMF voltage U is less than the battery voltage. This occurs when the motor operates at a speed in the base region of motor operation. The answer is that the inverter circuitry and the motor circuitry combine to form a natural boost voltage converter as shown in Figure C5.

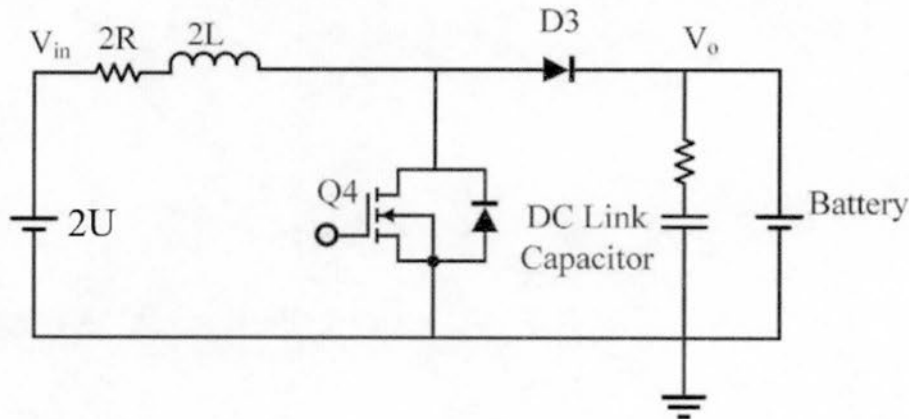


Figure C5. The equivalent circuit for Figures C4 forms a voltage boost converter with the motor inductance L the playing the role of the inductor in the boost converter. The input voltage of the boost converter is $V_{in} = 2U$, where U is the back EMF of the motor. The output voltage is $V_o = V_{bat}$, where V_{bat} is the battery voltage. R and L are the resistance and inductance of one phase of the motor, respectively.

Assuming that the boost converter shown in Figure C5 operates in a continuous conduction mode (CCM), the following relation can be derived if the resistance $2R$ is neglected:

$$D = 1 - \frac{2U}{V_{bat}}. \quad (\text{Eq C1})$$

Since the motor EMF U increases linearly with motor speed ω , we can substitute $E = K\omega$, and this becomes:

$$D = 1 - \frac{2K\omega}{V_{bat}}. \quad (\text{Eq C2})$$

Therefore, the PWM duty cycle D needed to boost the EMF voltage U up to the battery voltage V_{bat} can be computed by sensing the motor speed ω and using Eq C2.

In summary:

Regen braking is switched ON and OFF by changing the activation pattern of the inverter transistors. The level of regen braking is determined by changing the duty cycle of the lower PWM transistors. The braking resistor is used only during regen to keep the battery current and voltage within battery limits. It does not increase or decrease the level of regen braking.

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