EMBRY-RIDDLE
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McNair Scholars Research Journal

Volume 2

Article 3

2015

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Andre Napier
Embry Riddle Aeronautical University, napier@my.erau.edu

Christopher Rowe
Embry Riddle Aeronautical University, christopher.rowe1@my.erau.edu

Recommended Citation

Napier, Andre and Rowe, Christopher (2015) "Control Area Network Limitations in EcoCAR," *McNair Scholars Research Journal*: Vol. 2 , Article 3.
Available at: https://commons.erau.edu/mcnair/vol2/iss1/3

Control Area Network Limitations in EcoCAR

Andre Napier & Christopher Rowe
Advisor: Ilteris Demirkiran
McNair Scholar Program
Embry Riddle Aeronautical University
Daytona Beach, Florida, USA

Abstract

This research was conducted to produce a Communication Area Network (CAN) system that can effectively send messages using an Arduino with a CAN shield and to determine characteristic robustness. CAN systems are the most prominent form of communication between microcontrollers and devices primarily within vehicles. The CAN system itself was analyzed to determine the system's robustness and weaknesses, along with proving that a twisted-paired wire is much more effective than a non-twisted pair. A relay was used to control the CAN messages to determine CAN practical usability. An Electro-magnetic Field radiation meter was used to determine the ambient electromagnetic field intensity at which the signal of both the twisted paired wire and the non-twisted paired wire distorted.

Keywords: CAN Bus, distortion, EMI, limitations.

I. Introduction

This research was inspired by the EcoCAR team at Embry Riddle Aeronautical University (ERAU). EcoCAR is a university program sponsored by General Motors automotive company and the U.S Department of Energy. The program consists of 15 different universities that work on GM donated vehicles to reduce fuel emission, increase fuel economy while maintaining consumer acceptability.

ERAU decided to retrofit the GM-donated vehicle into a plug-in hybrid electric vehicle. The fuel selected to power the vehicle was bio diesel because of its on campus accessibility and the low greenhouse gas emission in comparison to gasoline. A series hybrid was the selected architecture and is shown below in figure 1 and its energy flow in figure 2. A series hybrid is a vehicle architecture that has a generator directly coupled to the engine, with a traction motor to propel the vehicle. With this setup, both the engine and the generator can run at peak efficiency by tuning the coupler's ratio.

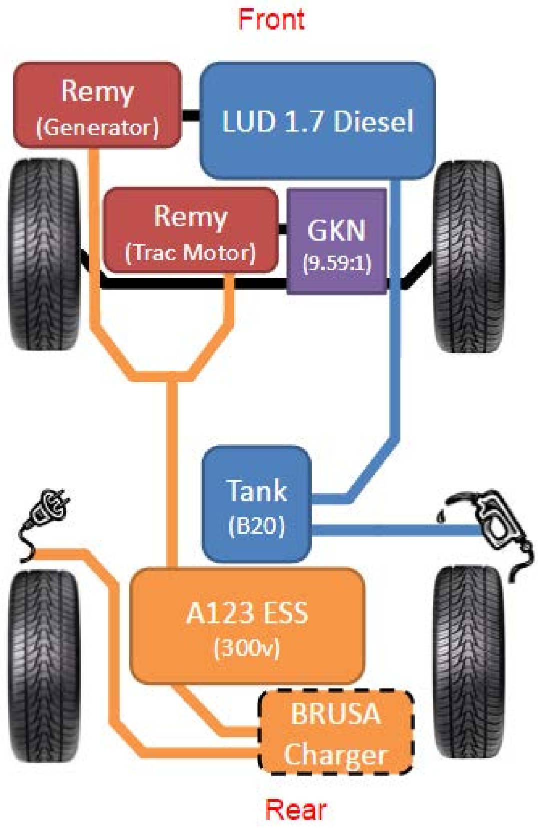

Figure 1: Vehicle Architecture

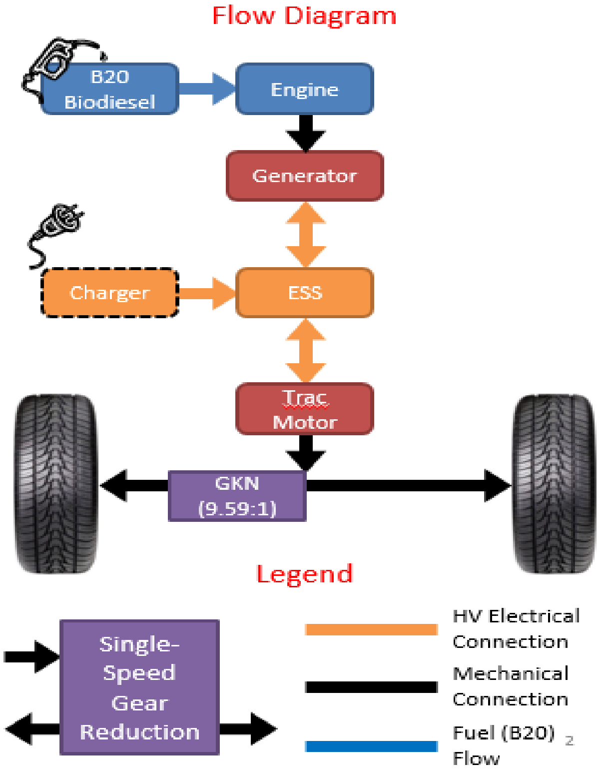

Figure 2: Energy Flow

II. Problems in EcoCAR

Throughout working with the EcoCAR program, there arose several problems. The vehicle's relay box was unable to actuate systems properly and the Supervisory Control Unit had issues communicating over the Control Area Network (CAN). The traction motor could not spin the wheels of the vehicle, because of the inverter. The Brusa was unable to charge the energy storage system. A diagram of the vehicle's electrical components is shown in figure 3. The relay box issue was corrected by thoroughly going through the vehicle's wire harness. The traction motors, the inverters, and the Brusa were all high voltage related problems, but they all utilized the CAN bus. There were problems with the wire harness and the Control Area Network (CAN) bus within the vehicle. These problems brought forth many issues within EcoCAR. One of which occurred when the vehicle reached high speeds. The vehicle shuttered and relayed error messages to the vehicle's main microcontroller. After an analysis was done on the CAN bus it was assumed that there was an impedance mismatch due to the length of stubs and the bus itself. To address the problem further investigation and research was required.

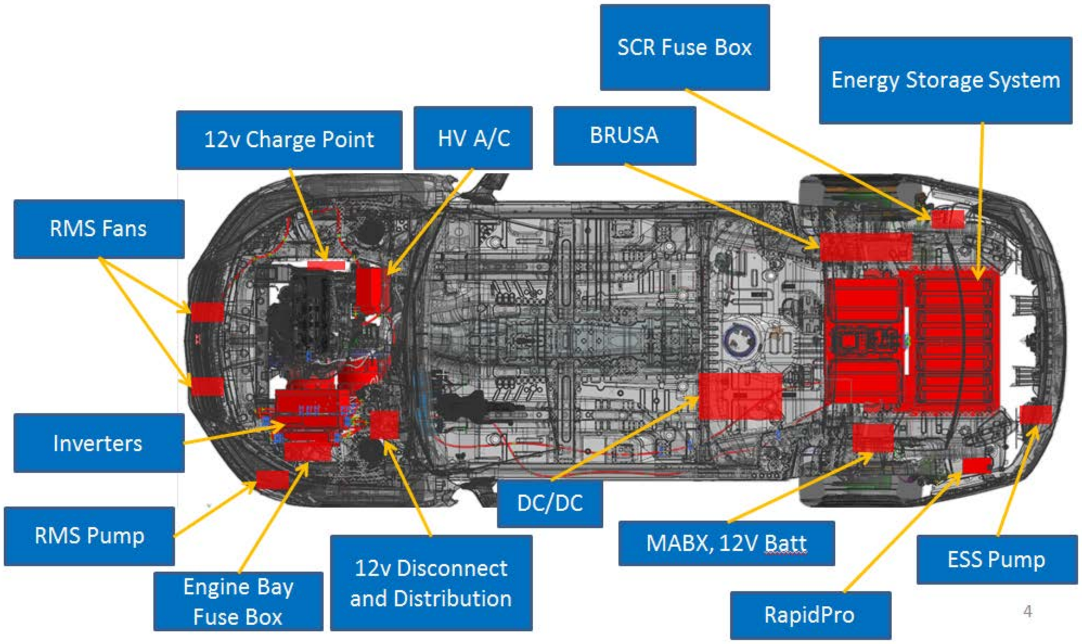

Figure 3: EcoCar Vehicle

III. What is CAN Bus?

CAN bus is a serial communication system that uses a two-wire topology to communicate between 8-16 bit microcontrollers. The protocol was created by the engineering company Robert Bosch GmbH in the mid 1980’s, to be used in vehicles. During the early 1990’s it was made a standard by the International Organization for Standardization. There is low- and high-speed CAN communication, where high-speed CAN communication is done at 40Kbits/sec -1Mbits/s, and the wires are terminated with 120 at both ends of the bus and low speed CAN utilizes 40Kbits/sec-125Kbit/sec with terminations at each device.

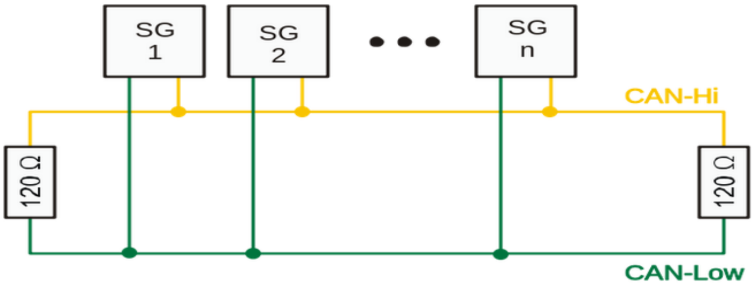

Figure 4: CAN Bus Topology

IV. Purpose of Research Paper

The purpose of this research paper is to address the aforementioned problems and to understand the limitations of the CAN bus systems and limiting factors for future implementation. For testing purposes, it was required to create an operable CAN bus to control a relay using a microcontroller, and a Vector CANcase. The goal of this research effort was to bring forth a better understanding of a CAN bus, and to determine universal limiting factors and efficiency.

Issues with the CAN bus was widespread, and how to solve the problem was uncertain. Research was done to build a CAN bus test bench system to simplify testing. This made it easier to build a robust and reliable system outside of the vehicle. The findings from the experiment were compared to the malfunctioning set up within the vehicle. Based on the finding it was determined that the problem was in the length of the CAN bus stubs. Further research was carried out on the CAN bus system to implement more reliable communication schemes and to avoid problems.

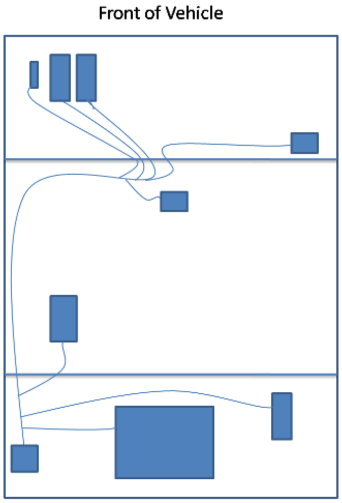

Figure 5: Initial Vehicle CAN bus design

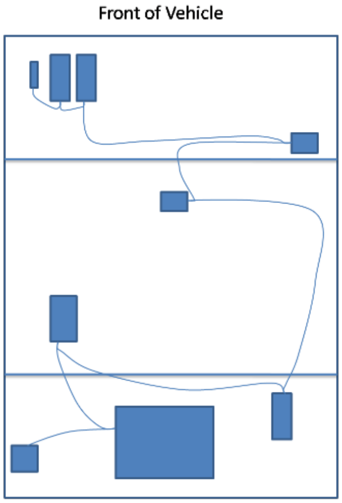

Figure 6: Modified Vehicle CAN bus design

The first task was to create a CAN bus system and control that network using a relay and determine its functionalities. More CAN bus systems were created with different lengths, characteristics, such as insulation shielding, wire shielding or drain and factory twisted pair cables versus non-twisted pair cables. Examples are shown in Figures 5 and 6.

V. Six Inch CAN Bus

Initially, a number of CAN bus systems were created to conduct tests. The first CAN bus was created 6 inches in length, not shielded, with a CAN drain connected, which was a non-twisted pair of cables. Each connection was soldered to a DB-9 connector with no further nodes or stubs in between. A basic communication code was created to transmit messages across the bus using an Arduino microcontroller board. The messages sent were basic numbers from 0-7, 8 numbers in total. A vector CAN case was used as the receiving device and also to view the messages being sent across the bus. A layout of the connection is shown below in figure 7.

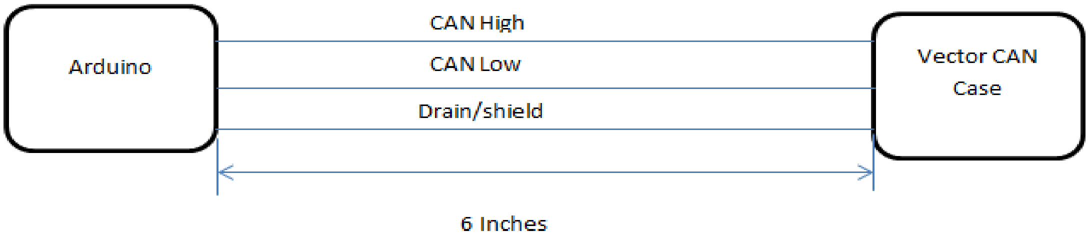

Figure 7: 6-inch CAN bus

Relay

The relay controlled CAN bus was controlled using another Arduino board. Supply power came from a 12V d/c source to the relay which was controlled by a transistor whose base was connected to the second Arduino's digital output. With this setup, a CAN bus can be controlled using a relay under certain conditions. One of the reasons could be due to time/periodicity or relevance. The information being processed might be periodic over a large time frame which may draw unnecessary power or cause a strain on the primary CAN bus. Another relay controlled CAN bus was designed using one Arduino board in which the relay's coil was controlled by a digital pin using a transistor. The CAN high bus being connected to the normally closed lead relays.

CAN Bus Dynamics

After creating a relay-controlled CAN Bus, the relay was removed and the dynamics of the CAN bus was tested. It was determined that the CAN bus operated in two distinct states, namely recessive and dominant, recessive being the state of zero differential voltage and the dominant being the state with a differential voltage of 2V. In the dominant state the current flowing through the high bus fluctuated at 30mA ±1mA with 3.5V phase to ground. The low bus had a current and a voltage of 12 mA ±0.5 mA and 1.5V respectively. Whereas in the recessive state the current and voltage was measured to be approximately 20 mA ± 1 mA and 2.5V respectively on both busses. These measurements yield

$$R= \frac{V}{I} = \frac{3.5V}{0.03A} = \frac{1.5V}{0.012A} = \frac{2.5V}{0.02A} = 120\Omega$$

This result agrees with the 120 resistor terminations at the end of each bus. Nonetheless, these measurements changed under certain conditions. When a variable resistor was placed on the bus centered between the 120 resistors the voltage dropped on the bus and so did the current. The system self-maintained a voltage difference of roughly 1.5 V continuously until the high impedance dropped the CAN-high bus voltage below 1.5V, which caused a differential of less than 1.5V between the 2 busses. Distortion of the signal occurred when the CAN-high bus dropped to 1.8V and became inoperable at about 0.8V.

Testing Against EMI

The primary limitation tested was the electromagnetic interference (EMI) immunity of the CAN bus system. Initially, the 6-inch, unshielded, CAN bus from figure 2 was tested by placing it next to a circuit distributing roughly 36 watts of power, the voltage being 12V direct current (d/c), and the current being 3A. This experiment had no effect on the CAN bus whatsoever. For greater EMI, a solenoid was constructed around the CAN bus with a length of roughly 3.5 inches and a half-inch diameter. The solenoid is roughly 0.5833% of the CAN bus length. When allowing 3A to flow throughout the solenoid the CAN signal appeared undisturbed. To increase the EMI from the solenoid, a relay was used to control the current flowing through it. The relay was opened and closed manually and with this method the signals were still not distorted. Using an EMI/ghost meter the solenoid produced an electromagnetic field (EMF) radiation between 2~30m Gauss. Transformers were then used to create larger EMI from the solenoid by opening and closing a switch manually. The EMF rose to over 100m Gauss, but the CAN bus was still unaffected. These tests were also performed on 3 feet and 7 feet, shielded and twisted paired CAN buses and there were not any signs of distortion.

Unable to determine the CAN bus distortion environment, the drain was removed to reduce immunity and test the drain's integrity. Using the relay and manually toggling the switch, the CAN signal distorted at approximately 9.3m Gauss. Increasing the EMF to over 100m Gauss could not completely distort the signals; nonetheless, the drain's integrity was tested. A CAN bus 3 feet long, twisted paired, with shielding and no drain connected was then placed in a solenoid with a length of 21 inches. This length being 0.5833% of the 3 feet CAN bus length. With this solenoid, the CAN bus was distorted at 5.7m Gauss. Again this CAN bus could not be completely distorted with EMI’s over 100m Gauss.

Conclusion

Based on the results, CAN networks appear to loose robustness based on length, the impedance of the line, and the wire drain, with the drain not being a required feature, but a beneficial factor. The excess stub lengths of the CAN bus within the vehicle increased the lines impedance and thus increased the line's reflections. As a result the CAN bus produced errors when the vehicle produced higher EMF. The results show that the drain itself increases the EMF immunity by more than a factor of 10.

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