DRIVER'S EFFICIENCY ANALYZER

A Design Project Report

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Design Project Report

Project Title: Driver's Efficiency Analyzer

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Abstract

Driver's Efficiency Analyzer provides drivers with intelligent feedback about their driving habits. This includes providing instantaneous vehicle speed and fuel consumption, while comparing these readings to ideal reference data for the specific vehicle. With the aid of the Driver's Efficiency Analyzer the drivers receive feedback on their performance and can subsequently correct their habits. The device is designed following the On-Board-Diagnostic (OBD) II standard. Serial communication is implemented between the standard OBD-II connection in the vehicle and the AVR microcontroller. The microcontroller is the core brain of the Driver's Efficiency Analyzer and its task is to request and process the information and then display it to the driver via five LEDs.

Executive Summary

In this project, an On-Board-Diagnostic (OBD) II aid to the driver that provides meaningful feedback on driving habits was designed, built, and tested. The project idea and the concept of inefficient driving habits were previously simulated in LabVIEW™. All design requirements specified prior to April 2012 were met, resulting in the Driver's Efficiency Analyzer (DEA) project being deemed as a success. Future improvements of the project will be decreasing the size of the device to an even more compact design and acquiring more precise data on a dynamometer for a range of vehicles.

The Driver's Efficiency Analyzer is composed of two microcontrollers: main and communication. The main 8-bit microcontroller, Atmega 644, acts as the brain of the system. It is designed to request, parse, and display data to the driver. It also processes and compares the instantaneous readings of fuel consumption and vehicle speed to an ideal reference data. This is the key concept behind the DEA. The communication IC, microOBD 200, is based on PIC24 architecture and is an off-the-shelf device widely used in the OBD-II readers industry. The focus of this project was to design a complete package that includes software and hardware that could be used on a daily basis without the need of any extra hardware such as a laptop or handheld device. Very important design constraint was offering minimum distraction to the driver.

The system begins operation once connected to the OBD-II port under the dashboard of the vehicle and the ignition key is in position three. The later gives power to the Engine Control Unit (ECU). The communication module runs a sequence of test signals to determine the communication protocol, which the driver cannot notice due to the speed of their execution. This version of the Driver's Efficiency Analyzer was designed for a 1997 BMW E36 M3. Once the vehicle is running, the DEA begins reading data instantaneously and the driver proceeds with normal operation.

The results from the Driver's Efficiency Analyzer proved to be very satisfying. If deployed as a commercial product for a wide range of OBD-II vehicle it will be an outstanding aid for novice or experienced drivers about their driving habits.

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1. Introduction

In today's fast-paced world, media constantly discusses fuel economy, greenhouse effects, and hybrid vehicles. All these terms frequently involve the automobile industry. However, fuel-efficiency and environment friendliness are not recent developments. In the dawn of car industry, around 1916, the Smith Flyer was the first attempt in automotive engineering to have a fuel-efficient vehicle. The vehicle weighed only 135 pounds and was an adaptation of a small gasoline engine originally designed to power a bicycle. In the beginning of the 21^{st} century, however, we expect more comfort; larger engines and storage space for our daily commutes. In most cases, people do not need a more efficient car to increase their fuel efficiency; a better option is to improve their driving effectiveness. For this objective, Driver's Efficiency Analyzer provides the drivers with feedback about their driving habits. The device monitors the instantaneous vehicle speed and fuel consumption, and compares these readings to ideal reference data. The reference data represent relationship between vehicle speed and fuel consumption. Drivers have the option to see their performance instantaneously.To display instantaneous driving performance, a colored system display was design to offer useful information with minimum distraction to the driver.The device utilizes the On-Board-Diagnostics (OBD) II standard that is implemented on all vehicles post-1996 production. Being an OBD-II complaint device makes it a highly marketable tool.With the aid of the Driver’s Efficiency Analyzer driver will be able to understand the concept of inefficient driving habits and can subsequently correct them.

The modern vehicle's on-board-diagnostics (OBD-II) provides a repair technician with access to information for various vehicle sub-systems. The amount of diagnostic information available via OBD-II has varied widely since its introduction in the mid 1990's. With the introduction of more economical and user friendly scanning devices, it is now practical for almost anyone to access OBD-II signals and use them for their own testing and repairs.

2. Background

Technical Aspects

In the beginning of the 1970’s, in order to comply with the Environmental Protection Agency (EPA) emission standards, manufacturers turned to electronically controlled fuel feed and ignition systems.

Sensors measured engine performance and adjusted the systems to provide minimum pollution. These sensors were also accessed to provide early diagnostic assistance. This was the dawn of on-board diagnostics (OBD). Through the years OBD systems have become more sophisticated and in 1996 the Society of Automotive Engineers (SAE) established a standard connector plug (Figure 1) and set of diagnostic test signals. This became known as OBD-II.

Figure 1. OBD-II J1962 connector

Diagnostics have found value in vehicle servicing and repairs. Diverse diagnostic techniques are used in production line vehicles. There are currently five signaling protocols in use with the OBD-II interface. Every vehicle has one of these protocols. It is often possible to determine the specific protocol by merely examining the pin-out of the J1962 connector or by knowing the vehicle's manufacturer. For more detailed information on these signal protocols, see Appendix A. Driver's Efficiency Analyzer is targeted to be a multi-protocol system.

In order to communicate over OBD-II, all devices use Parameter IDs (PID) requests to retrieve the needed information. PID codes are part of SAE standard J1979, which was implemented in all cars sold in North America since 1996. There are ten modes of operation in the latest OBD-II standard. For more detailed information on PID codes and modes, see Appendix B.

Competitors

Thanks to the introduction of more cost efficient electronics, it has recently become easy for the home mechanic to afford a cost-effective diagnostic system, driver supplementary vehicle instrumentation or hand-held scanner. The market has a vast variety of OBD-II based devices.

One interesting product on the market is ScanGauge II (Figure 2). It is an integrated trip computer that provides feedback to the driver. The digital gauges give real time data for the vehicle and the built-in scan tool allows the user to read trouble codes. However, the interpretation of numbers such as MPG can be an incomplete reflection on driving efficiency. It lacks a reference basis for comparison. At a price of $169.95, ScanGauge II is tool that reads PIDs from the Engine Control Unit (ECU) via OBD-II but displays them without giving meaningful feedback.

Figure 2. ScanGauge II

Smartphones and other pocket-size devices have very powerful operational platforms providing the user with broad range of applications including OBD-II scanners and diagnostics. Rev (Figure.3) is an application for iPhone which takes advantage of all the built-in technology of the platform to provide interesting metrics. The beauty of this iPhone application is that it communicates with an OBD-II reader wirelessly, such that the user does not have to deal with cables. Rev provides data-logging capabilities, GPS tracking, lateral and forward acceleration. It also has the classic engine code retrieve and reset. However, this product lacks the fundamentals of providing the driver with comparative feedback to reference data. A complete package with Wireless OBD-II reader and the iPhone application is currently priced around $150.

Figure 3. Rev iPhone Application

In the past year, a well-known Automotive Insurance company, Progressive has started offering their customers a device that monitors Driving Habits. The Snapshot is also an OBD-II compliant device. It records information automatically but the user has no access to it. Progressive claims that the device looks for facts like gentle braking and driving fewer miles than the average driver in the customer's state. Based on that data they provide you with discount on Insurance. The device also looks at how much you drive during off peak hours between midnight and 4am. According to Progressive there is no way the device can harm one's current policy. It takes about 30 days of data acquisition to get any improved rates. There is not much available information about the circuitry inside of the Snapshot.

Figure 4. Progressive Snapshot

3. Approach

There are three major parts in the design of the Driver's Efficiency Analyzer project that needed to be addressed. The first module is the OBD-II vehicle, followed by an OBD-II compliant reading chip. Lastly, analyzing and displaying of the information to driver is implemented using an Atmel AVR ATmega 644 microcontroller and a specially designed LED color system.

Vehicle

As Driver's Efficiency Analyzer requires the OBD-II standard, it applies to vehicles manufactured after 1996. Although five different signal protocols exist all cars since 2008 in North America use the ISO 15765 CAN bus signal protocol, minimizing the likelihood of encountering the other four protocols. At the time of this project access to an actual vehicle was limited. As a compromise to that issue for development purposes an ECU simulator board was introduced (Figure 5).

Figure 5. ECUSim 2000 OBD-II CAN Simulator

The ECUSim 2000 OBD-II Simulator from OBDSolutions is a valuable tool for the development and testing of OBD-II diagnostic programs and hardware. The Diagnostic Trouble Codes (DTC) button can be used to generate trouble codes and illuminate the Malfunction Indicator Light (MIL). The trouble codes can be cleared using a Clean Service request or by simply cycling the power to the simulator. Physical connection is made through a standard SAE J1962 connector (OBD-II). More importantly, this ECU Simulator has 5 adjustable PID (potentiometers) for simulating Coolant Temperature (ECT), RPM, Speed (VSS), O2 voltage and Mass Air Flow (MAF).

At a later stage of the development, the Driver's Efficiency Analyzer was designed to work with a 1997 BMW E36 M3. The protocol utilized by all European manufacturers is ISO-9141-2.

Communication IC

There are various off-the-shelf OBD-II communication integrated circuits. The DEA is utilizing microOBD 200 (PIC24 microcontroller) which is designed around the STN1120. MicroOBD 200 is a quick and easy way to add OBD support to any project. The STN11xx chip itself is an enhanced version of the popular ELM327 chip. It is the world's smallest, lowest cost multiprotocol OBD to UART interpreter IC. It provides an easy means of accessing hundreds of real-time parameters. The STN1120 outperforms the original ELM327 IC in every category: stability, performance, and features.

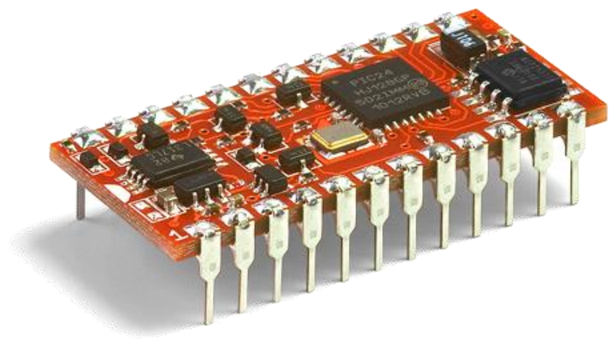


Figure 6. microOBD 200 OBD-II interpreter IC

Reference Data and Analysis

The final, and most essential, feature of the project is the actual processing and display of the received information. A set of PID requests are sent to the ECU to receive the desired data. The microOBD 200 handles the serial communication between the ECU of the vehicle and the ATmega 644 microcontroller. The first stage of the display and analysis has been previously implemented via simulations in LabVIEW. This provided the evidence that the concept of inefficient driving habits does in fact exists.

Two specific values that the Driver's Efficiency Analyzer utilizes are the vehicle speed and the fuel consumption. In the North American automotive industry, the units for these are Miles per Hour (MPH) and Miles per Gallon (MPG), respectively. For the first, the ECU responds in Kilometers per Hour, which is easily converted to MPH (Equation 1).

$$MPH = VSS \times 0.621371$$

Equation 1

Estimating MPG is more involved. Efficient fuel consumption in an internal combustion engine requires a carefully adjusted amount of air. For gasoline fuel, the stoichiometric air-fuel mixture is approximately 14.7:1. This number also depends on the fuel used. Mixture less than a 14.7:1 ratio is considered to be a “rich” mixture, above that ratio is a “lean” mixture. The ECU spends almost 100% of its time maintaining that ratio at 14.7, which it can do quite accurately using a closed loop feedback system involving the O2 sensors. Based on these facts it is obvious that product is not going to look for the amount of fuel, but for the amount of air that is going through the intake system of the vehicle. Hence, the formula for fuel consumption (Equation 2) involves the Mass Air Flow (MAF) sensor reading and the MPGs are calculated as:

$$MPG = \frac{14.7 \times 6.17 \times 454 \times VSS \times 0.621371}{3600 \times MAF}$$

Equation 2

Stoichiometric air-fuel ratio - 14.7 grams of air to 1 gram of gasoline

Density of gasoline - 6.17 pounds per gallon

Vehicle speed in kilometers per hour - VSS

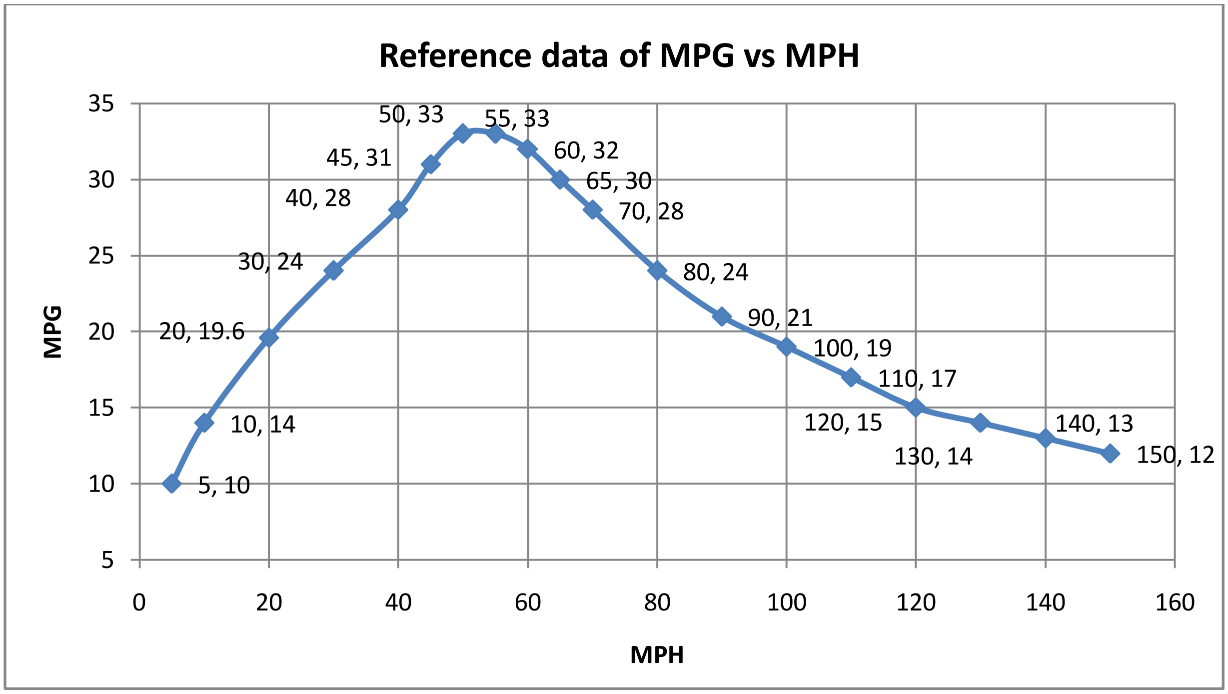
Mass air flow rate in grams per second - MAF

Conversion - 454 grams per pound

Conversion - 0.621371 miles per hour/kilometers per hour

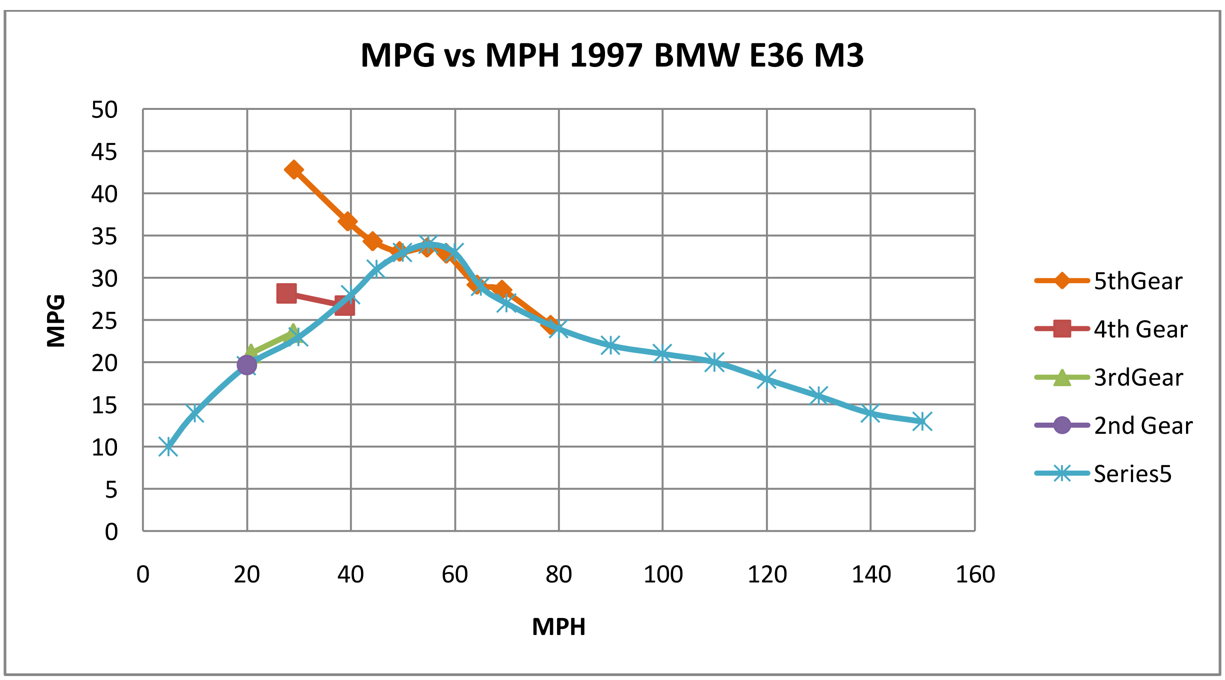
Conversion - 3600 seconds per hour

Having the two instantaneous readings the software interface is able to give the drivers feedback on their driving habits. The feedback in the Driver's Efficiency Analyzer is based on reference data already stored in the Atmel microcontroller via simple data approximation equations. Ideally the manufacturer for each specific vehicle would provide reference data. However this is not normally provided to the general public. Initially a reference ideal graph of MPG versus MPH was generated after studying the behavior of a standard vehicle and reviewing multiple car performance periodicals. More accurate data points can also be determined using a dynamometer while operating the specific vehicle model. Unfortunately, access to a full scale dynamometer was not possible during the development of the project. Instead, the test vehicle, BMW M3, was run through multiple tests on flat roads at steady speeds. The resulting reference data between MPG and MPH is shown on Graph 1. All the speeds above the speed limits are generated as data estimation.



Graph 1. BMW E36 M3 Reference Data (Fuel Consumption vs. Speed)

The first iteration of tests was done in 5th gear varying between 30MPH to 65MPH. The purpose of this test was to acquire the top possible MPG value at peak vehicle speeds of 50-55MPH.



Graph 2. Raw data generated over multiple road tests

As it can be noticed on Graph 2, the values for MPG in 5th gear continue to go higher at lower speeds of 30MPH and below. However, those data points prove to be unrealistic for the purposes of the DEA comparison algorithm since in order to achieve such high fuel consumption numbers at such low speeds it will require first reaching speeds of about 55MPH passing through a lower gear like 4th and only then being able to coast the vehicle down in 5th gear. Inherently speeds like that also drop the engine speed down below 2000 RPMs where the torque peak power is much less so a down shift is mandatory.

The next set of tests performed was done in lower gears where the behavior in 4th gear was almost similar but it was sufficient to provide the down peak value from 55 MPH. Naturally 2nd and 3rd gear provided the rest of the needed information.

Instantaneous Display System

To display instantaneous driving performance, a colored system was created to offer useful information with minimum distraction to the driver. The display system is very simple. It consists of five LEDs as shown on Figure 7.

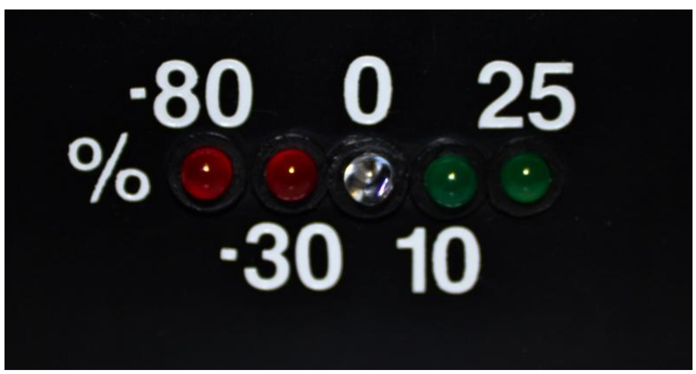


Figure 7. DEA LED system display

If the driver matches the reference data the blue light at 0% will be lit up. Depending on the manners of driving, the lights on the left or the right of the blue one will light up. As it can be seen in Figure 7, the weights of the red and the green lights are not equal. That is because it is easy to fall below the reference data. It should be pointed out whenever the blue light is on it still means that this is a fuel efficient drive. The weights were chosen experimentally using common sense and driving experience.

The driver sees the readings of vehicle speed and fuel consumption instantaneously in a form of lights. The instantaneous reading raises a question that needs to be answered – how is the device going to compensate for going uphill, where it is inevitable that the fuel consumption will go down, and vice versa for downhill? The answer is simple. On a round trip, if the driver went uphill somewhere, he is definitely going to go downhill and compensate for that and there will be a balance. There are numerous factors that could change the fuel consumption of the car from the temperature outside and the wind resistance, to the type of tires and the amount of air they have in them. All these conditions will be neglected for the purposes of this project.The Driver's Efficiency Analyzer will not provide feedback when the vehicle is idling because there is no easy way to provide reference for that process. In addition, the Driver's Efficiency Analyzer operates only at speeds higher than 5MPH.

One benefit of the Driver's Efficiency Analyzer is that a persistent inability to match the reference data may be an indicator that the vehicle needs a tune-up, or a certain component is entering a failure mode.

4. Block Diagram

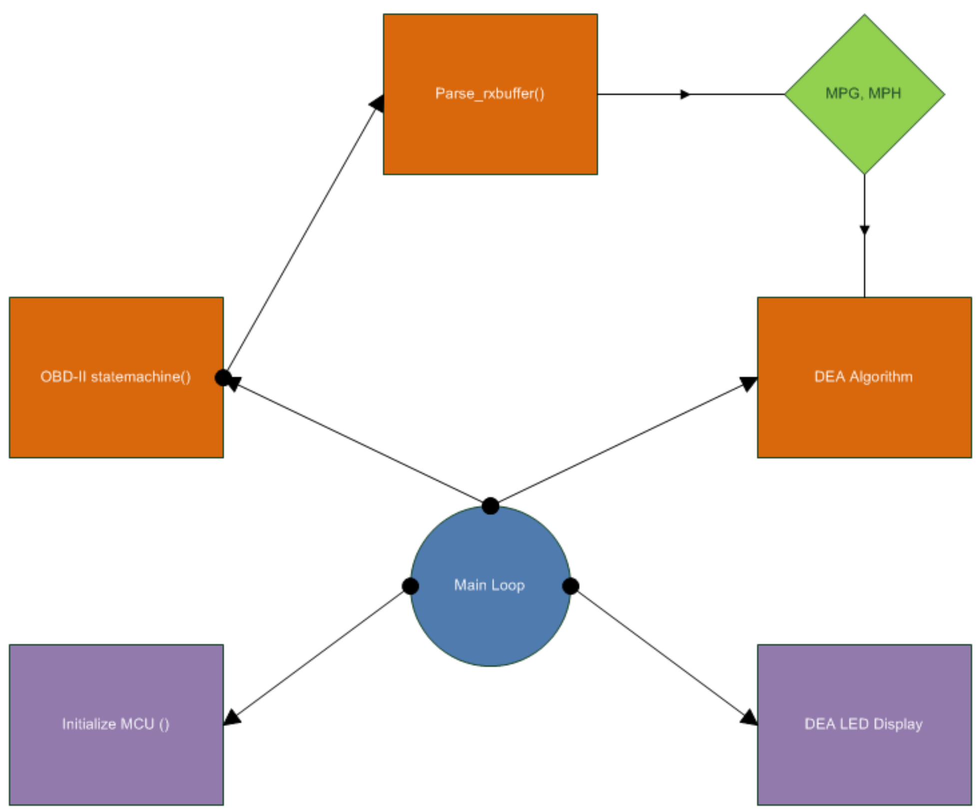


Figure 8. DEA Block Diagram

The block diagram above describes the algorithm flow of the Driver's Efficiency Analyzer. The code was written in C using AVR Studio 4. On power-up the microOBD 200 runs a sequence of tests to determine the ECU signal protocol if different from the one saved in its memory. The main loop of the ATmega 644 is already running and waiting for a response from the microOBD. The ready signal from the microOBD is a prompt response of 0x3E in HEX or the equivalent of ">". After that the ATmega 644 immediately begins requesting values for speed in KPH and mass air flow in g/s. Once the response from the ECU is received the data is being parsed, converted into North American units of MPH for speed and MPG is being calculated using Equation 2. The two values are passed along to the DEA algorithm which determines the percentage difference from the reference data equations described in Appendix C. The later results are being displayed to the driver instantaneously using an exponential average that takes 0.9 of the previous input and 0.1 of the current input. This is done for a smooth transition of the readouts. The OBD-II state machine including the parser of the received response run at the full clock speed of the ATmega's crystal which is 16Mhz. The DEA algorithm and the LED display are updated every 100 milliseconds. The communication between the two microcontrollers is at 9600 baud. Reference to Appendix E for the complete source code written for the ATmega 644 in C.

5. Schematics, PCB and Enclosure

The Driver's Efficiency Analyzer utilizes the protoboard design Version 11 produced by Pr. Bruce Land for ECE 4760 students. Its compact measurements and the capabilities of using Atmel 644 with serial communication for debugging were vital for the success of the DEA project. In addition, a custom printed circuit was designed using ExpressPCB services.

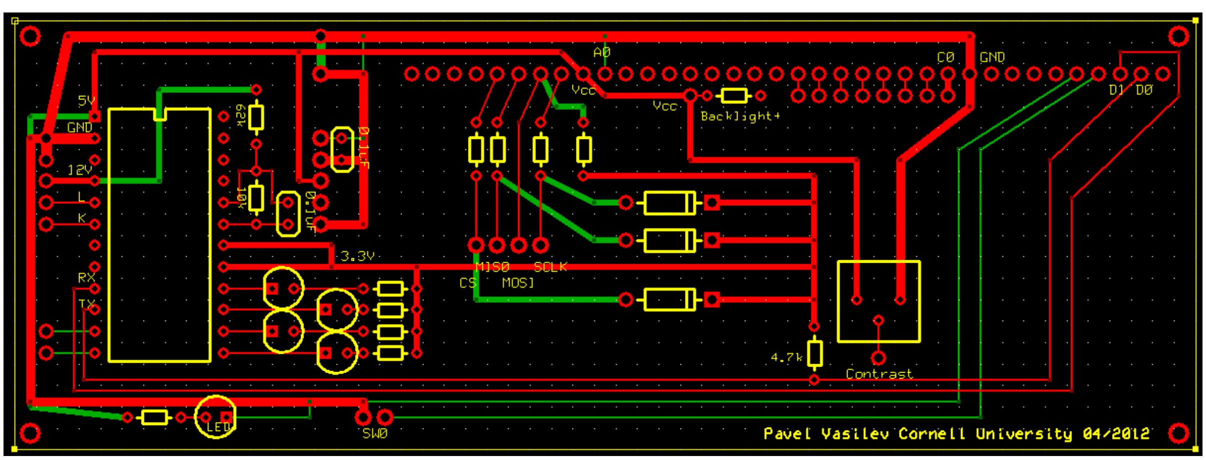


Figure 9. PCB design

The PCB design was shared between two individual OBD-II projects. The SD card connections for SPI mode, the ADC connection to channel 0 and the LCD pins on PORT C were not utilized. A complete schematic for the Driver's Efficiency Analyzer is shown on Figure 10, below.

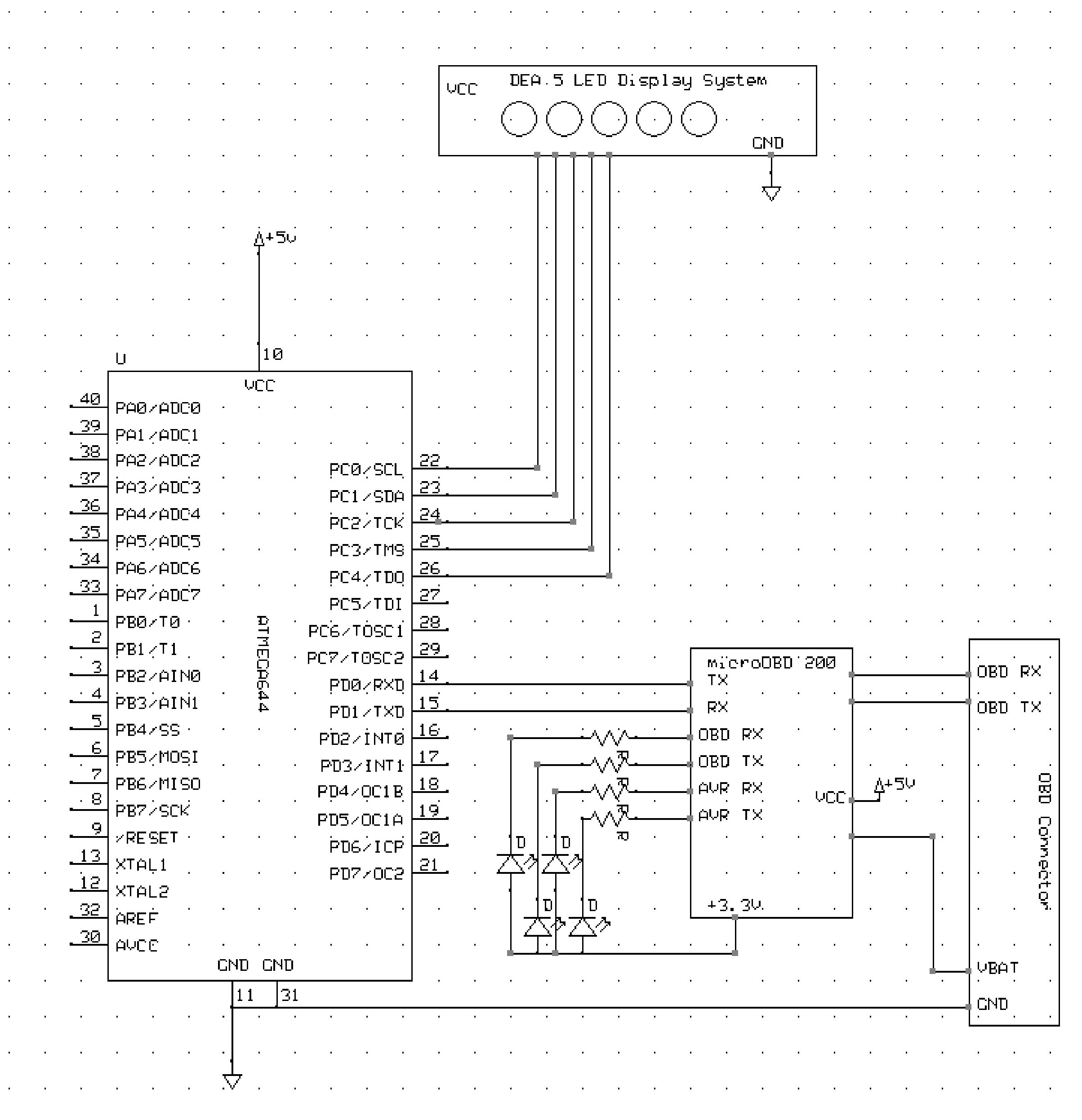


Figure 10. DEA Schemactics

A successful project is only finished once packaged appropriately. The following figures show the end result.

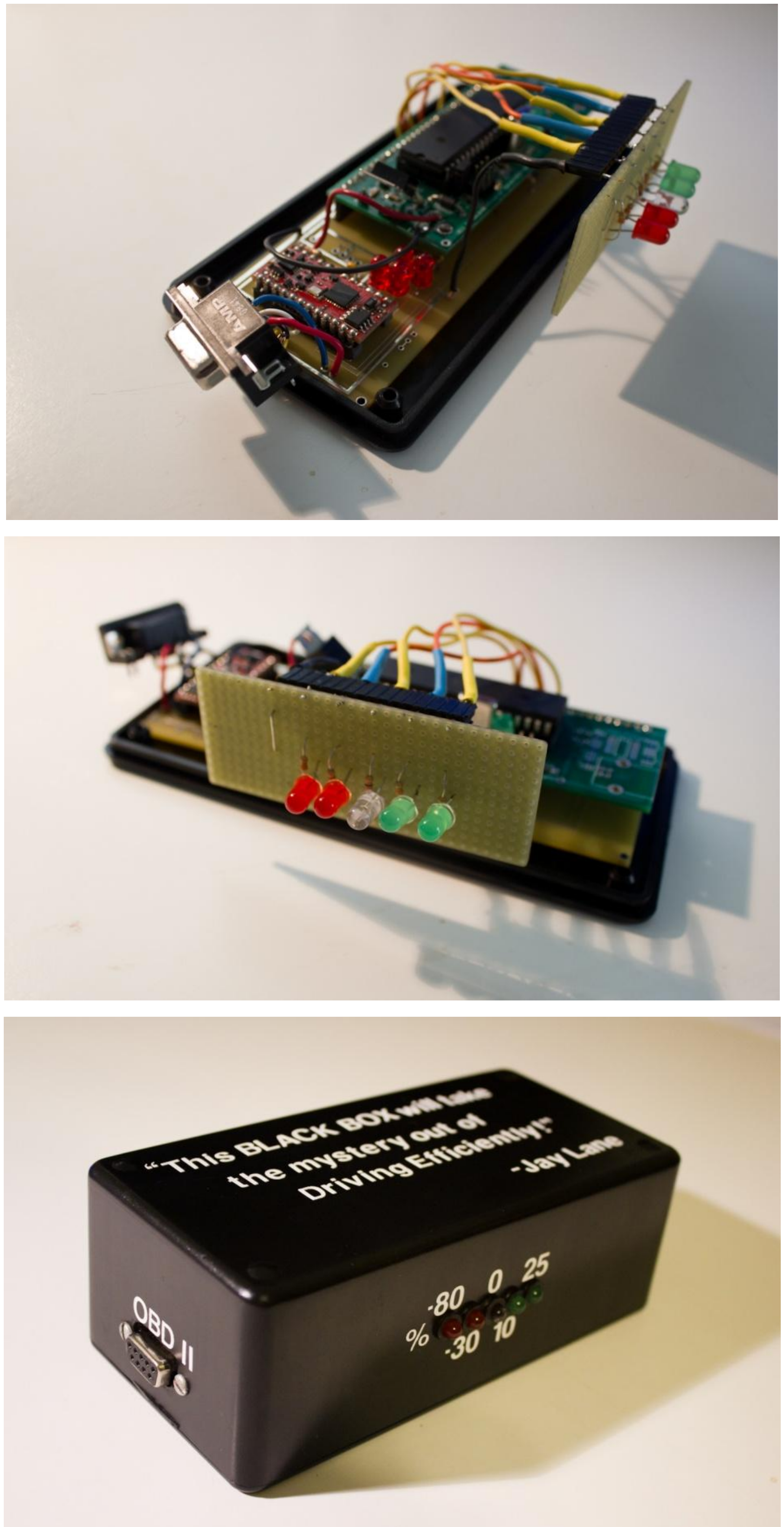


Figure 11-13. DEA Enclosure

6. Milestones

- August 2011 – pick advisor and propose project;
- October 2011 – decide on components and locate test vehicle;
- December 2011 – complete 60% of project write-up for ECE 6930, and evaluate project expenses;
- January 2012 – order all components and begin testing microOBD 200 IC and ATmega644 for reading simple PID parameters;
- February 2012 – generate reference data for an actual vehicle either on a dynamometer or by road testing, which will be less effective. Implement data approximation algorithm on the AVR microcontroller; Test the color display system.
- March 2012 –test and finalize work on Driver's Efficiency Analyzer;
- April 2012 – finalize writing project documentation;
- May 9th 2012 – present DEA on ECE Day at Cornell University

7. Evaluation of Inefficient Driving Habits

Four tests were selected to prove the effectiveness of the Driver's Efficiency Analyzer and the indication of inefficient driving habits. With the use of the Software Speed Simulator (Appendix C) the project was tested on a simulated 2 mile-flat road with no stops (Figure 14) with maximum vehicle acceleration of 6 ft/s^2. A similar test was next run on the 2 mile-flat road with a stop at 1 mile (Figure 15). For a third test the number of stops was increased to two at approximately 0.7 miles and 1.4 miles while the acceleration was kept at its maximum (Figure 16). A last test used the 2 miles of road with no stops but with 2 ft/s^2 initial acceleration.

Figure 14. Two Miles with No Stops

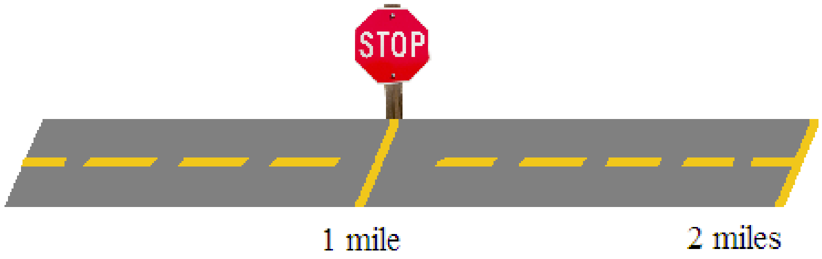


Figure 15. Two Miles with 1 Stop

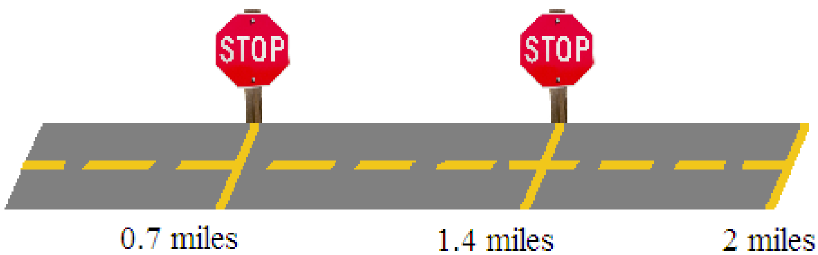
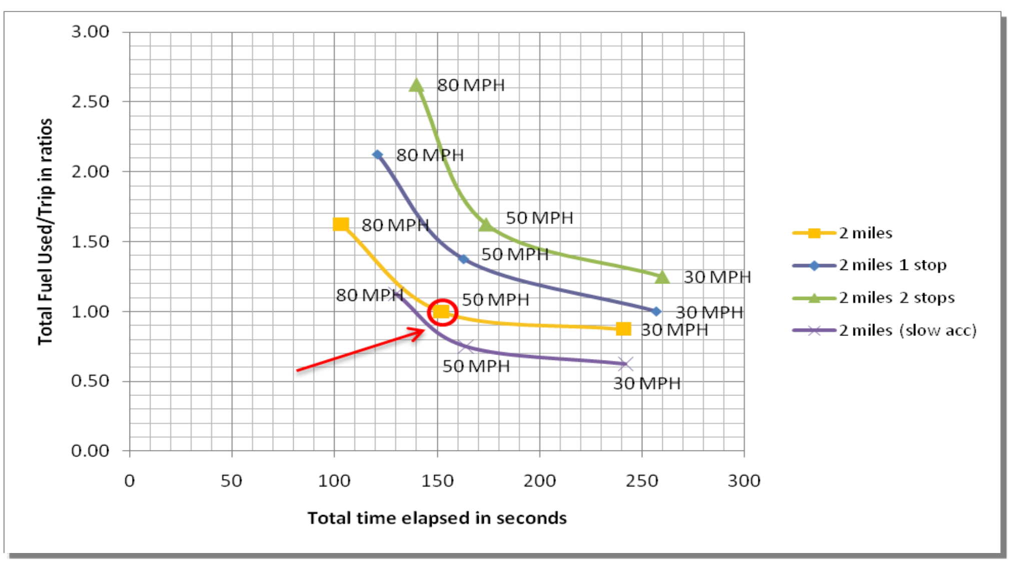


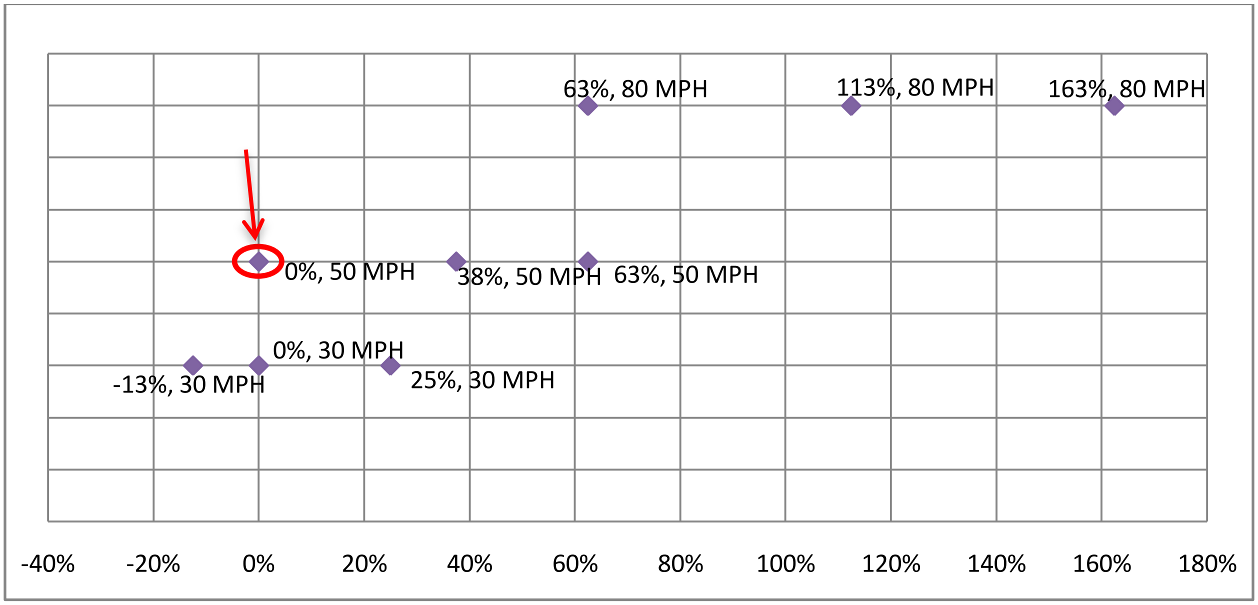
Figure 16. Two Miles with 2 Stops

The simulated vehicle takes 15 sec to accelerate from 0 to 60 MPH, which is slightly above the average parameters of a modern sedan. The fuel consumption of each of the test, and the time it took for the vehicle to reach the 2 miles marks were recorded and then normalized to the 50MPH mark of the first test with no stops.



Graph 2. Graphical Representations of the Results in Ratios

It can be observed on Graph 2 that while increasing the speed of the elapsed time to cover the distance is shortened the fuel usage increases. It should also be pointed out that at the optimal speed of 50 MPH the slope of the fuel consumption curves starts decaying. This proves that at a certain point the slower the vehicle is moving necessary correlates with greater efficiency. Adding more stops requires accelerations which add to the fuel usage.



Graph 3. Percentage Change per Stop

Comparison of the results, using 50 MPH as an optimal speed on our 2 mile course with no stops, provides vital information about the impact cost of a stop. Graph 3 above shows that each additional stop adds 38% to the fuel consumption, and this number keeps increasing with additional changes in speed and number of stops.

These results came out as expected although factors such as vehicle mass, engine load, air drag and even tire pressure have not yet been taken into an account. This explains why driving up or downhill were not simulated. In an actual environment, the data points at speeds lower than 30 MPH are expected to have a positive slope. This means that even more fuel will be consumed for longer times of travel. The results sustained that accretive accelerations can significantly influence the amount of fuel used and why the Driver's Efficiency Analyzer can be a handy tool.

The Driver's Efficiency Analyzer was designed for a 1997 BMW M3 E36. Many interesting facts were discovered during the process of testing the DEA and acquiring the ideal reference relationship between MPG and MPH. Most importantly, DEA has always assumed an operation in a vehicle with automatic transmission since there is no easy way of keeping track of gear shifts in a manual transmission. However, with acquiring the data it was possible to assist the driver with optimal shifting points. The DEA creates a virtual driving profile that people can use to “learn” driving efficiently.

8. Societal Impact

The core purpose of developing the Driver’s Efficiency Analyzer is to introduce a device that optimizes the environmental friendly operation of current automotive vehicle. The project has the potential of becoming a mandatory part of the automobile in the future. The current version of the Driver’s Efficiency Analyzer has a rigid prototype design with a PCB layout. The color system display is offering minimum distraction to the driver. Proper utilization of the Driver’s Efficiency Analyzer should help reduce, in a minor fashion, environmental pollution.

9. Summary

The Driver’s Efficiency Analyzer is an advisor that provides feedback based on reference data. It utilizes instantaneous vehicle speed and fuel consumption. Based on these readings it gives the driver a meaningful feedback via color system display. Being an OBD-II complaint device makes it a highly marketable tool.

The project has been previously developed to the stage of software simulation in LabVIEW. Developing this project provided me with a unique opportunity to work in-depth in a field of great interest to me. In addition, the Driver’s Efficiency Analyzer was presented at IEEE R1 Paper Contest in March 2011. The project won 2nd place.

10. Acknowledgments

Pr. Bruce Land, Cornell University, has been my advisor during my Master of Engineering degree providing me with the opportunity to continue developing the Driver’s Efficiency Analyzer.

Pr. Chathan Cooke, MIT, has been my undergraduate mentor and has been actively participating in the development of the idea and the design of my undergraduate Senior Project.

Pr. Petar Vasilev, my father, has been a great inspiration and support for all my work. Without him I wouldn't have been able to achieve academic excellence.

Thanks to Avi Aisenberg and Mike Andromalos for their work in ECE 4760 on an OBD-II project that uses ELM 327 IC and ATmega 644. Their work was a great starting point for the integration of microOBD 200 with ATmega 644.

11. References

• Kiencke, Uwe, Lars Nielsen. Automotive Control Systems: For Engine, Driveline, and Vehicle. Springer, 2000

• "On-board diagnostics". Wikipedia. 2010. Wikimedia Foundation Inc.. 20 Nov 2010 <http://en.wikipedia.org/wiki/On_Board_Diagnostics>

• "OBD-II PIDs". Wikipedia. 2010. Wikimedia Foundation Inc.. 20 Nov 2010 <http://en.wikipedia.org/wiki/OBD-II_PIDs>

Appendix A: OBD-II Signal Protocols

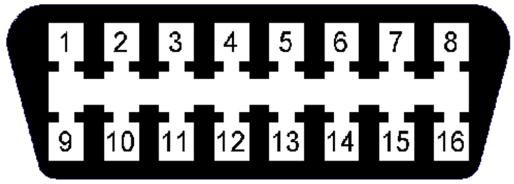


Figure A1 J1962 Connector Pinout

SAE J1850 PWM (pulse-width modulation - 41.6 kB/sec, standard of the Ford Motor Company)

- pin 2: Bus+
- pin 10: Bus–
- High voltage is +5 V
- Message length is restricted to 12 bytes, including CRC
- Employs a multi-master arbitration scheme called 'Carrier Sense Multiple Access with Non-Destructive Arbitration' (CSMA/NDA)

SAE J1850 VPW (variable pulse width - 10.4/41.6 kB/sec, standard of General Motors)

- pin 2: Bus+
- Bus idles low
- High voltage is +7 V
- Decision point is +3.5 V
- Message length is restricted to 12 bytes, including CRC
- Employs CSMA/NDA

ISO 9141-2 this protocol has an asynchronous serial data rate of 10.4 kBaud. It is somewhat similar to RS-232, but that the signal levels are different, and that communications happens on a single, bidirectional line without extra handshake signals. ISO 9141-2 is primarily used in Chrysler, European, and Asian vehicles.

- pin 7: K-line
- pin 15: L-line (optional)
- UART signaling (though not RS-232 voltage levels)
- K-line idles high
- High voltage is Vbatt
- Message length is restricted to 12 bytes, including CRC

ISO 14230 KWP2000 (Keyword Protocol 2000)

- pin 7: K-line
- pin 15: L-line (optional)
- Physical layer identical to ISO 9141-2
- Data rate 1.2 to 10.4 kBaud
- Message may contain up to 255 bytes in the data field

ISO 15765 CAN (250 kBit/s or 500 kBit/s). The CAN protocol is a popular standard outside of the US automotive industry and is making significant in-roads into the OBD-II market share. By 2008, all vehicles sold in the US will be required to implement CAN, thus eliminating the ambiguity of the existing five signaling protocols.

- pin 6: CAN High
- pin 14: CAN Low

All OBD-II pinouts use the same connector but different pins are utilized with the exception of pin 4 (battery ground) and pin 16 (battery positive).

Appendix B: PID Codes

Modes

There are ten modes of operation described in the latest OBD-II standard SAE J1979. They are, the 0x prefix indicating a hexadecimal number:

0x01. Show current data
0x02. Show freeze frame data
0x03. Show stored Diagnostic Trouble Codes (DTC)
0x04. Clear Diagnostic Trouble Codes and stored values
0x05. Test results, oxygen sensor monitoring (non CAN only)
0x06. Test results, other component/system monitoring
0x07. Show pending Diagnostic Trouble Codes (detected during current or last driving cycle)
0x08. Control operation of on-board component/system
0x09. Request vehicle information
0x0A. Permanent DTC's (Cleared DTC's)

Vehicle manufactures are not required to support all modes.

PID Codes

Below is included a small portion of the Parameter ID table for Mode 01.

Mode (hex)	PID (hex)	Data bytes returned	Description	Min value	Max value	Units	Formula*[1]
01	00	4	PIDs supported [01 - 20]				Bit encoded [A7..D0] == [PID 0x01..PID 0x20]
01	02	2	Freeze DTC				
01	03	2	Fuel system status				Bit encoded.
01	04	1	Calculated engine load value	0	100	%	A*100/255
01	0A	1	Fuel pressure	0	765	kPa (gauge)	A*3
01	0B	1	Intake manifold absolute pressure	0	255	kPa (absolute)	A
01	0C	2	Engine RPM	0	16,383.75	rpm	((A*256)+B)/4
01	0D	1	Vehicle speed	0	255	km/h	A
01	0E	1	Timing advance	-64	63.5	relative to #1 cylinder	A/2 - 64
01	0F	1	Intake air temperature	-40	215	°C	A-40
01	10	2	MAF air flow rate	0	655.35	g/s	((A*256)+B)/100
01	11	1	Throttle position	0	100	%	A*100/255

*[1] A is the first byte of the read data, B is the second byte of the read data.

Appendix C: Reference Data Equation Fit

The reference data representation on the ATmega 644 is modeled with a line equation, parabola and an exponential decay functions. It provides the relationship between speed and fuel consumption for three different ranges. The instantaneous vehicle speed is provided in increments of 1 MPH which will not alter the accuracy of the feedback.

From 5MPH to 40MPH

$$MPG = 0.521215 \times MPH + 8.457627$$

Equation C1

From 40MPH to 69MPH

$$MPG = -0.0261039 \times MPH^2 + 2.791558 \times MPH - 41.181818$$

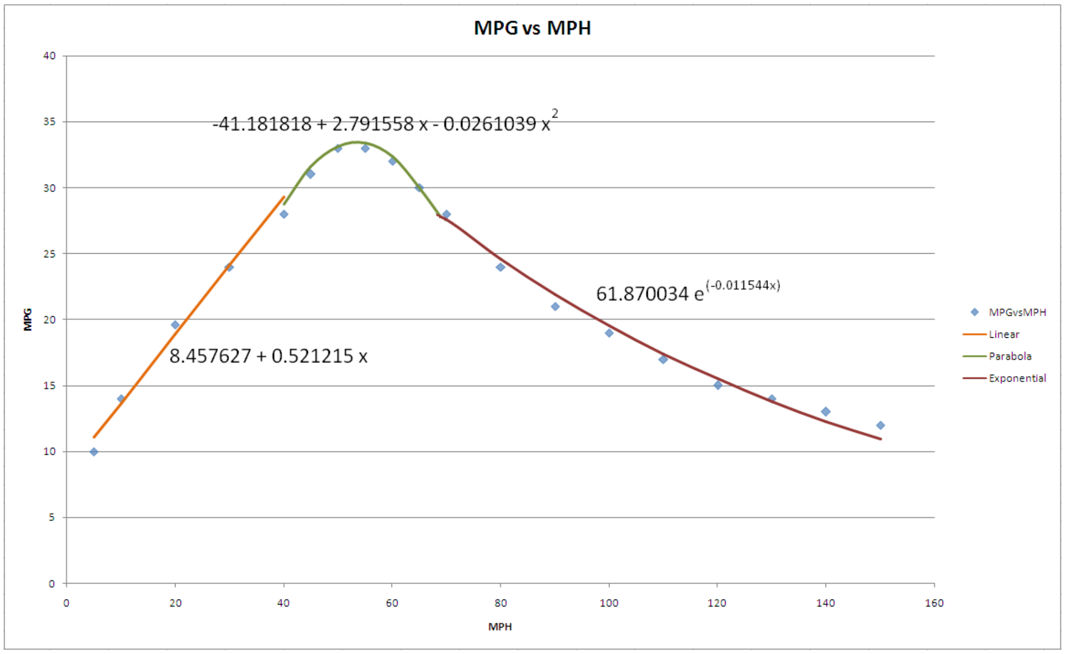
Equation C2

From 69MPH to 150MPH

$$MPG = 61.870034e^{-0.011544 \times MPH}$$

Equation C3

The modeled data for the ranges of vehicle speeds gives a value of fuel consumption that doesn't exceed a 1% error from the already estimated reference data. The data fit is shown in Graph C1, below.



Graph C1. Data Fit and Reference Data

Once a reference MPG is acquired it is compared to the instantaneous reading of the vehicle. The percentage difference from the ideal reference data is then displayed to the driver via the color system implemented by the five LEDs.

Appendix D: LabVIEW interface

The first stage of DEA development was done by programming and establishing a LabVIEW™ interface, and generating the reference data for comparison (Graph D2). More detailed information on the comparison algorithm is discussed in Appendix C. Figure D1 shows the main interface of the Driver's Efficiency Analyzer which was created in the LabVIEW™ environment as a part of the project. In addition, a Software Speed Simulator was developed in LabVIEW™.

Figure D1. Virtual Dash in LabVIEW™

The idea behind the Software Speed Simulator (SSS) is to simulate acceleration, braking and speed. These three objectives were achieved by using exponential growth in the form shown below:

$$Vinstant[t] = Vfinal(1 - e^{-t/\tau})$$

Equation D1

Vfinal stands for the speed value that is going to be reached at the end of the exponential growth. *Vinstant* is the speed value calculated as a function of time. The same formula is applied for braking however with a much smaller value for τ (Figure D2). In addition, there are two different values for τ for the acceleration depending if the vehicle is acceleration or coasting.

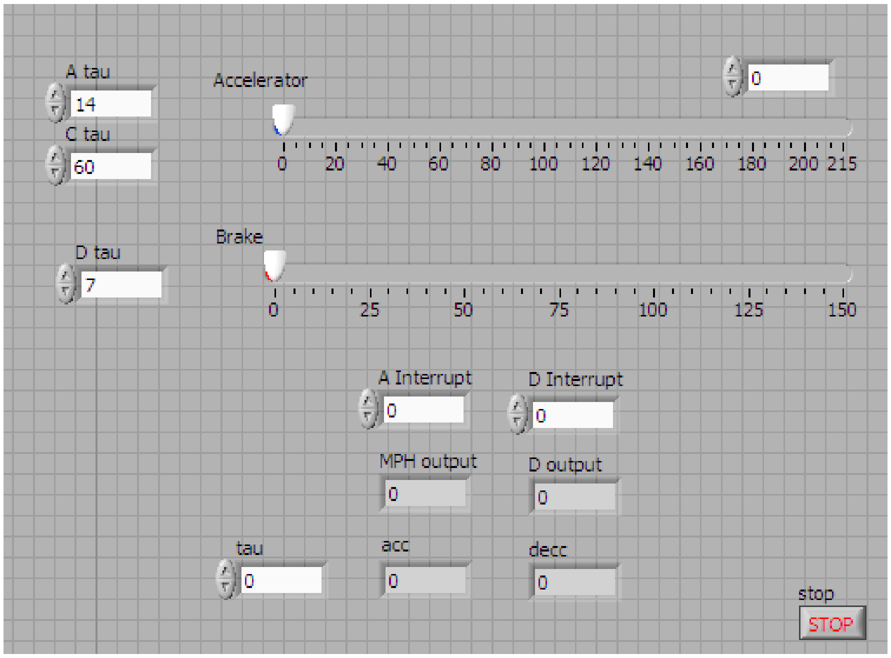


Figure D2. Software Speed Simulator Control Interface

The accelerator provides the MAF coefficients. A relationship between MAF (g/sec) and VSS (kph) was introduced based on Equation 2 and the ideal reference data (Graph D2). A perfect data fit was developed where the VSS was a function of the MAF (Graph D1). This was very important in order to observe matching of the reference data later on with the Driver's Efficiency Analyzer. In addition, it was observed that the speed values from 5-50 MPH were in the range of 7-13 g/sec.

From 7 g/s to 27 g/s

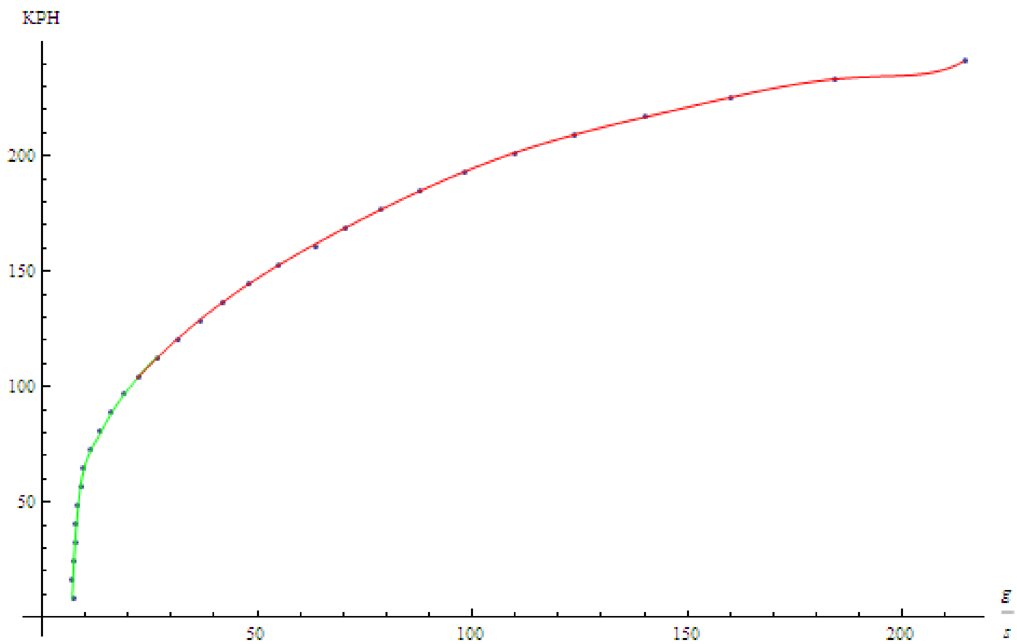
$$VSS = 65.2574 + 0.8459 \times MAF + 0.0895 \times MAF^2 - 0.0032 \times MAF^3 + 0.000052 \times MAF^4 - 4.9133 \times 10^{-7} \times MAF^5 + 2.5968 \times 10^{-9} \times MAF^6 - 7.26894 \times 10^{-12} \times MAF^7 + 8.3629 \times 10^{-15} \times MAF^8$$

Equation D1

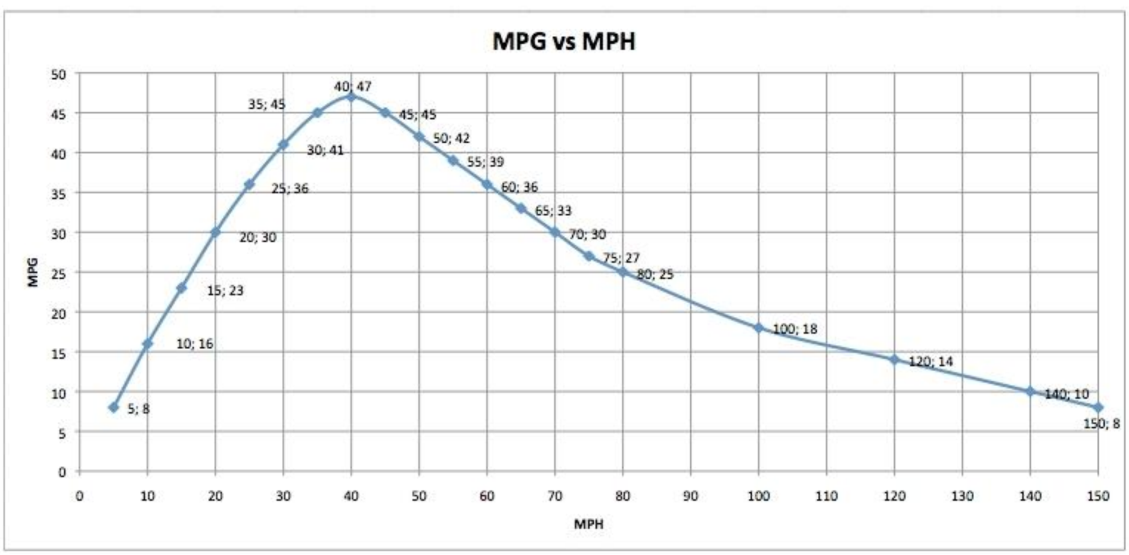
From 27 g/s to 214 g/s

$$VSS = 65.2574 + 0.8459 \times MAF + 0.0895 \times MAF^2 - 0.0032 \times MAF^3 + 0.000052 \times MAF^4 - 4.9133 \times 10^{-7} \times MAF^5 + 2.5968 \times 10^{-9} \times MAF^6 - 7.26894 \times 10^{-12} \times MAF^7 + 8.3629 \times 10^{-15} \times MAF^8$$

Equation D2



Graph D1 VSS (kph) vs. MAF(g/s)



Graph D2. Idealized Reference Data

Appendix E: DEA Source Code

Source Code - upon request from the author.