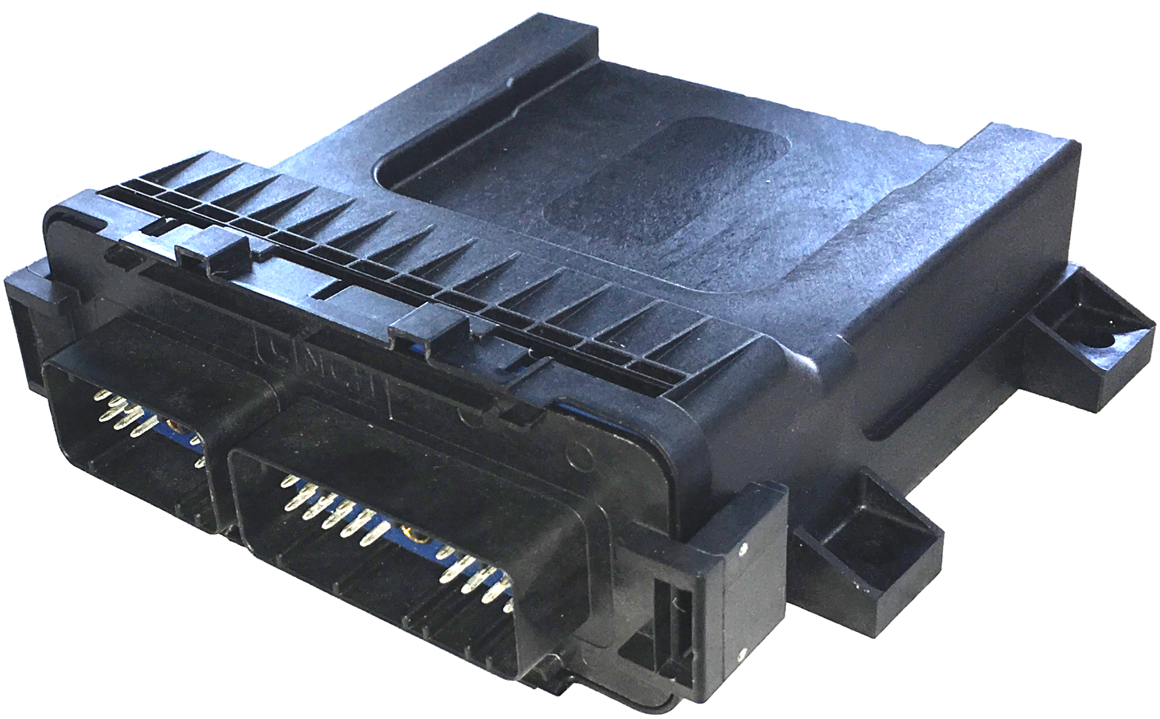
Generalized Electric Vehicle Control Unit

GEVCU

Version 6.22



LEGAL DISCLAIMER

This manual describes a hardware device produced by EVTV Motor Werks LLC. The **G**eneralized **E**lectric **V**ehicle **C**ontrol **U**nit or **GEVCU** is an experimental educational device designed to allow students and enthusiasts to explore and learn about electric vehicle control issues in automotive development – particularly using drive train components used by automotive manufacturers.

The device in and of itself performs no particular or specific function and is not designed for commercial or automotive use.

It comes preloaded with one of many versions of the GEVCU open source software project available at http://github/collin80/GEVCU. This software, created entirely by enthusiasts outside of the control of EVTV, can be downloaded as source code in its latest versions, modified by anyone anywhere, including the end user or owner of this hardware device, for any reason or at whim, and installed on this hardware and essentially embodies the entire functionality of the device.

As such, EVTV Motor Werks has no control over what the device can do, what it is used for, how well or poorly it does it, or why. EVTV Motor Werks disclaims any liability arising from the purchase and use of this hardware and makes no claim of fitness for any particular purpose.

The GEVCU hardware is offered solely for the educational use of the purchaser. Purchasers of this particular offering of the open source GEVCU hardware agree to defend and hold harmless EVTV Motor Werks from any claims by any party arising from their purchase and use of the GEVCU device.

This document is intended to generally represent the GEVCU hardware sold and distributed by EVTV specifically. It reflects the software installed on the GEVCU hardware at the time of shipment. Obviously, if other software or modified software is loaded onto the GEVCU hardware, or indeed if the software is modified by the end user to provide other functions, the printed document and the device and its software would naturally be in conflict. This conflict could potentially pose certain safety issues to the end user.

It is both foreseeable and intended that other entities will also produce alternate GEVCU hardware and other forks or versions of the GEVCU software. Indeed this is already the case. Those entities should produce their own original documentation illustrating how THEIR version actually works at the time they shipped it. And they are specifically precluded by statute from distributing THIS document or any part of it with alternate hardware and/or software designs.

Table of Contents

1 Introduction

For 40 years and more, individual tinkerers and innovators have been modifying existing automobiles to electric drive and often building electrically powered vehicles from scratch.

The early "controllers" that evolved to replace simple switching and resistive controls to control the speed of the driver motors were mostly pulse width modulated (PWM) devices to provide an averaged DC signal to a series DC motor. These simple chopper voltage control devices were generally referred to as "controllers" and translated driver input from "controls" such as the accelerator pedal, ignition switch, and brake to this motor driving voltage to control its speed and direction – and consequently the vehicle.

There are of course many other types of motors such as separately excited DC motors, brushless DC motors, permanent magnet motors and AC induction motors. Most of these polyphase motors require 3 phase "inverters" to convert the DC power of the battery pack into three-phase AC drive signals varying the voltage (for torque) and frequency (for speed) of the power to the motor to accomplish the same thing.

Most of the DC "controllers" received the inputs directly by wiring from the sensors or controls in the cars.

In recent years, among automobile manufacturers, the use of the Bosche Controller Area Network (CAN) protocol has been adopted for many of the items in the automobile, including the internal combustion engine – often called an **Engine Control Unit** or a **Vehicle Control Unit** which forms the central computer or "brains" of the car. It is connected to various sensors and controls by wire but communicates to other subsystems of the vehicle such as the instrumentation, ABS system, transmission, environmental system using this CAN bus as the common link.

Automakers have eschewed the DC motor in favor of either permanent magnet AC motors or AC induction motors. And the "inverters" developed to drive these were interfaced to this same CANbus model for control input.

Because of the varying nature of the cars, the ECU or VCU would be specifically designed for THAT particular make and model. In this way the inverters and AC motors can be somewhat generic to work in any car. The intelligence moved OUT of the inverter and into the VCU, which contained all the vehicle specific information.

The VCU would be specifically designed and software specifically written for that vehicle. And all the particulars for that make and model would reside in the software for the VCU. This was hardcoded into flash memory and defined the operation of the vehicle. No end user input or options were provided. Firmware updates or changes are normally accomplished by revising the code, recompiling, and having the controller reflashed with the new binaries at the dealership during normal maintenance.

And so thousands of these VCUs could be flashed when built, with the software specific to that particular vehicle.

The particular VCU/software combination would of course be completely inappropriate and non functional in any other vehicle make or model.

As many automakers are experimenting with product introductions of plug-in electric vehicles and hybrid gasoline/electric vehicles, many of the components used in these vehicles are becoming available when the cars are salvaged and are recycled through salvage yards and such online services as eBay.

As such, they will become a resource to individual tinkerers and those converting existing cars to electric drive. Fortunately, most are somewhat generic and almost all of these components were designed to be controlled by CANbus signals from the Vehicle Control Unit that came with the original car.

It would be a serious advantage, to have a more **generalized** vehicle control unit that could produce these CAN commands to drive existing power switching inverters, chargers, dc-dc converters and other equipment gleaned from the many parts available in salvage. But to be truly useful, it should allow some **basic configuration** by the end user allowing these conversions to modify operation of the VCU to accommodate THEIR vehicle without the need to entirely rewrite the software and flash the VCU. Just change a handful of variables specific to the car.

In December 2012, Jack Rickard of Electric Vehicle Television http://evtv.me first proposed a program to develop such a GENERALIZED Electric Vehicle Control Unit or **GEVCU** using the then just introduced **Arduino Due** platform with an 84 MHz 32-bit ARM CORE3 processor. And he elected to do this as an **open source** project anyone could not only use, but modify further with regards to either hardware or software to meet their own particular needs.

As such, the GEVCU could serve as the central computer or “brains” of any electric car, and flexibly drive ANY available inverters, motors, battery management systems, throttles, brakes, sensors, etc in the car. This modular approach would to some degree commoditize many of the major components of the vehicle, while the specifics were held in a central, open source device that anyone could change, adapt, and extend as necessary.

A number of EVTV viewers began contributing code and hardware designs and by late summer 2013, EVTV first drove a 1974 VW Thing, with a Siemens 1PV5135 AC induction motor and DMOC645 inverter from Azure Dynamics, all entirely controlled by the GEVCU. It featured controlled regenerative braking on both throttle and brake, a controllable precharge procedure for applying power to the DMOC, and control of the cooling fans on the liquid cooling system.

Along the way, the original Arduino Due hardware morphed into a somewhat more hardened hardware design capable of surviving the automotive environment, while retaining the full compatibility with the Arduino software development environment.

A selected subset of Arduino input and output pins was brought out to a single weather resistant AMPSEAL 35 pin connector for example. Various strategies and components were used to isolate the inputs and outputs from the multicontroller chip itself to "harden" the device to EMP and EMI and the noise inherent in vehicle 12v systems. But the essential Arduino programming environment and compatibility were retained.

The result was a powerful multicontroller device with TWO programmable CAN bus channels, wireless Internet access, a variety of analog and digital inputs and outputs, and beyond the ability to reprogram the device entirely using the Arduino IDE, the original design allows the end user to easily configure some of the basic aspects of throttle and brake and so forth without really learning to program at all.

This document describes the use and configuration of the **Generalized Electric Vehicle Control Unit**. The multicontroller hardware allows connection of the basic sensor set necessary to drive the car such as throttle signals, brake signals, ignition signal, and control the basic common outputs such as brake lights, fuel level, rpm, power usage, while serving in the central role of converting these inputs to CAN messages for the inverter to actually drive the AC motor and thus the car.

The operation of this device can be modified, within fairly narrow constraints, by a simple configuration "menu" style input that non-programmers can access and make changes to, in order to interface the VCU to the particular car they want to convert.

Note that the GEVCU program is both open software and open hardware with the schematics and board layouts published for all. As such, THIS document ONLY applies to the EVTV produced GEVCU hardware and the software preloaded onto it before shipment.

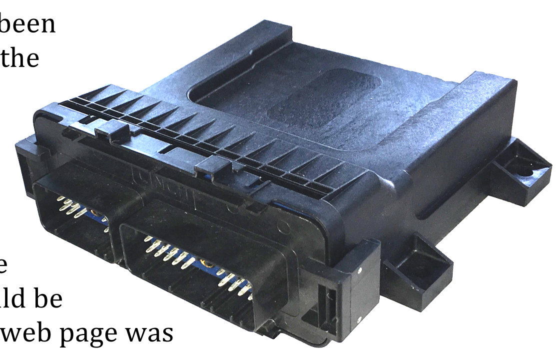
This document will be updated from time to time to reflect changes in hardware or software that EVTV adopts in their release of the product. But by necessity, it cannot cover changes in hardware or software made by other parties or the end user. This should be obvious.

But we think the end user will find SOME documentation of the baseline EVTV shipped version useful as a starting point.

Because of these variations, this manual is copyright 2013 EVTV Motor Werks and other developers producing hardware and software variants are specifically precluded from including this manual, or any excerpted portion thereof. Inevitably, this manual will not properly describe those variants.

GEVCU VERSION 6.22

While numerous software upgrades to the original GEVCU have been released under EVTV, and many more by other programmers of the device, the basic hardware of GEVCU has served remarkably well for over three years.



In 2016 Collin Kidder and Jack Rickard of EVTV embarked on a redesign effort for the device. Assembly of the original device was detailed and costly. While quite resistant to the rigors of the automative environment and weather, a full IP67 enclosure would be better. The Israeli wifi board used to produce the configuration web page was costly, hard to source, had a high failure rate and was difficult to configure. More importantly, other and improved interface devices had emerged.

And so GEVCU version 6.2 was developed. Improvements include:

1. Modice CINCH enclosure for IP67 environmental resistance.

2. Improved Analog to Digital Conversion inputs using 24-bit SPI converters.

3. Addition of isolated high voltage battery pack voltage measurement inputs.

4. A shunt input to allow measurement of high voltage system currents.

5. Blutooth 4.0 BLE data communications for iOS iPhone and iTablet and Android connectivity using the AdaFruit Bluefruit LE SPI module.

6. Optional GSM cellular data communications module using the Particle Electron.

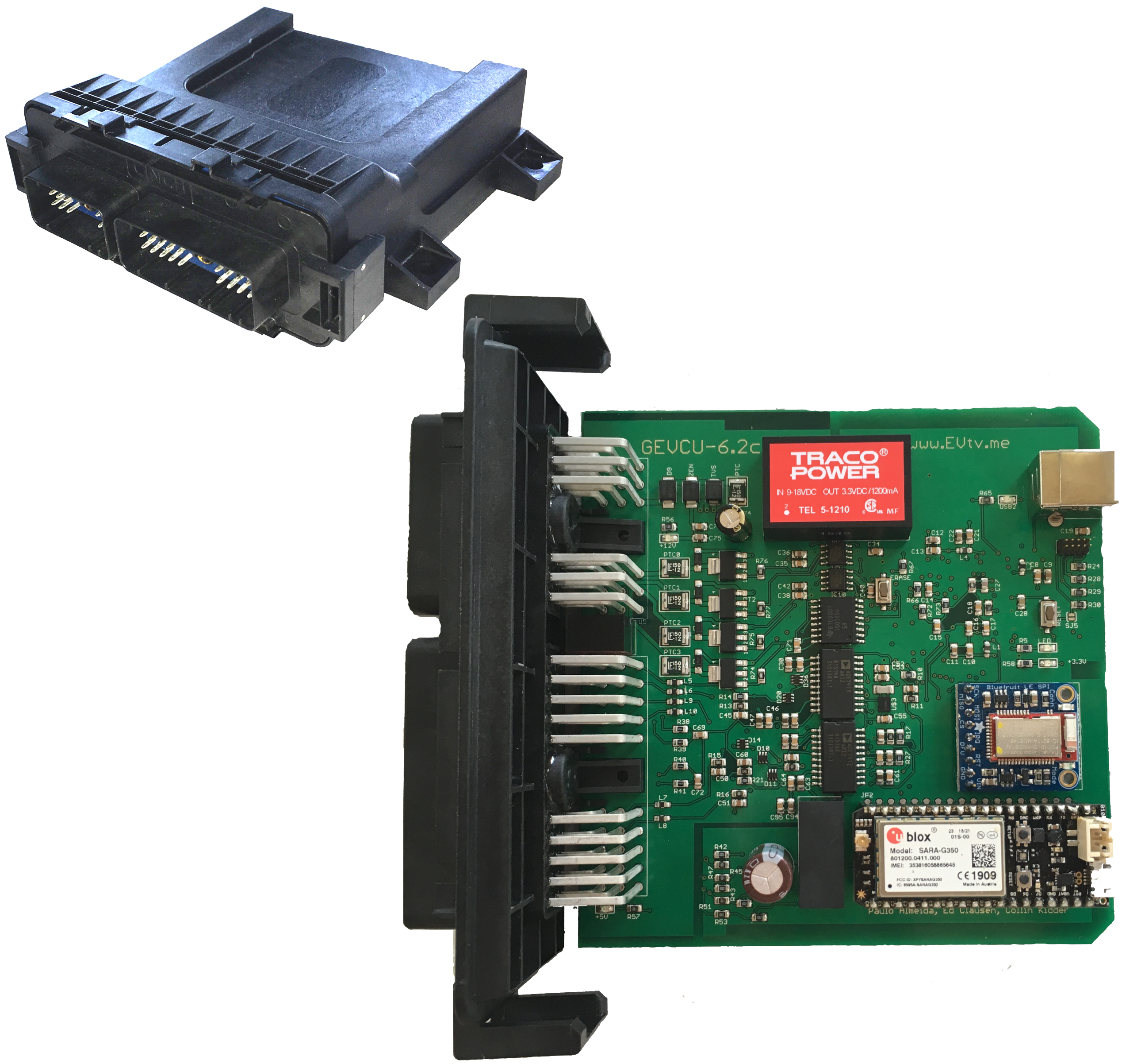
7. Improved digital output control.

There were of course some casualties as well. The original concept of a built in web server for configuration was one of the central tenets of the device. No specific configuration program was required – any browser on any device could be used to configure it.

The USB port was exposed on the back of the unit. This was the main issue making the device vulnerable to weather and moisture. But it was very handy to plug into with a laptop to update software. Some users even extended this with a USB cable to offer USB in the dashboard or rear bumper of their vehicles.

The nature of the Modice CINCH enclosure makes this undoable. You must remove the board from the enclosure to access the USB port to update software.

2 Specifications



GEVCU PIN DEFINITIONS

18 PIN CONNECTOR

	1	2	3
A	+5v	+5v	GND
B	+5v	+5v	+5v
C	+12VIN	GND	+5v
D	DOUT0	DOUT1	DOUT3
E	DOUT2	DOUT4	+12v
F	DOUT5	DOUT6	DOUT7

30 PIN CONNECTOR

	1	2	3
A	AIN0	CANH0	GND
B	AIN1	CANL0	GND
C	AIN2	CANH1	GND
D	AIN3	CANL1	GND
E	PACKHI	PACKMID	GND
F	PACKLO	SHUNTL	GND
G	DIN0	SHUNTH	GND
H	DIN1	+12v	GND
J	DIN2	+12v	GND
K	DIN3	+12v	GND

Table 2. Absolute Maximum Rating

Parameter	Symbol	Value	Units
Supply Voltage	VIN(+12V)	16	V
Regulated +12V output	+12V	1.5	A
Regulated +5V output	+5V	1*	A
Digital Outputs	DOUT0… DOUT7**	1.7	A
CAN BUS	CAN0 HI/LO; CAN1 HI/LO	–27 to 40	V
Analog Inputs	AIN0… AIN3	12	V
Digital Inputs	DIN0… DIN3	15	V

*Total value for all pins
**Applying any voltage directly to any of these PINs will cause permanent damage to the GEVCU

MICROCONTROLLER

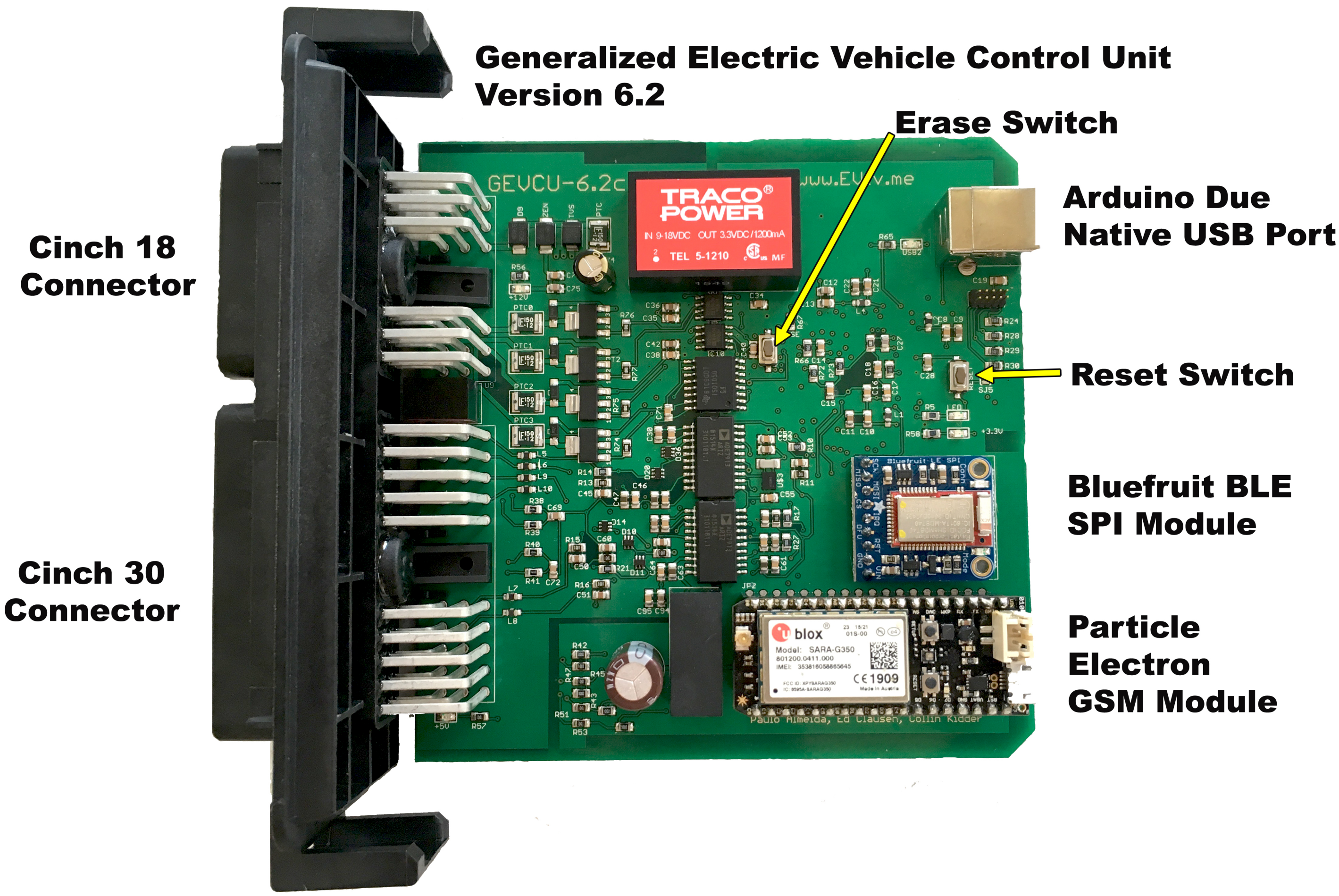
Atmel SAM3X8E ARM Cortex-M3 CPU
32-bit core
CPU Clock at 84Mhz.
96 KB of SRAM.
512 KB of Flash memory for code
256KB EEPROM for persistent data.
Operating Voltage: 3.3v
Input voltage: 6-16v
CAN network channels: 2
Universal Serial Bus Port: 1
Isolated Analog Inputs: 4
Isolated Digital Inputs: 4
Isolated PWM or Digital Outputs: 8
Programming Environment: Arduino Due IDE 1.5.4

ADAFRUIT BLUEFRUIT LE SPI FRIEND MODULE

ARM Cortex M0 core running at 16MHz (Nordic nRF51822)
256KB flash memory
32KB SRAM
Transport: SPI at up to 4MHz clock speed
5V-safe inputs (Arduino Uno friendly, etc.)
On-board 3.3V voltage regulation
Bootloader with support for safe OTA firmware updates
Easy AT command set tunneled over SPI protocol to get up and running quickly
23mm x 26mm x 5mm / 0.9" x 1" x 0.2"
Weight: 3g
https://learn.adafruit.com/introducing-the-adafruit-bluefruit-spi-breakout

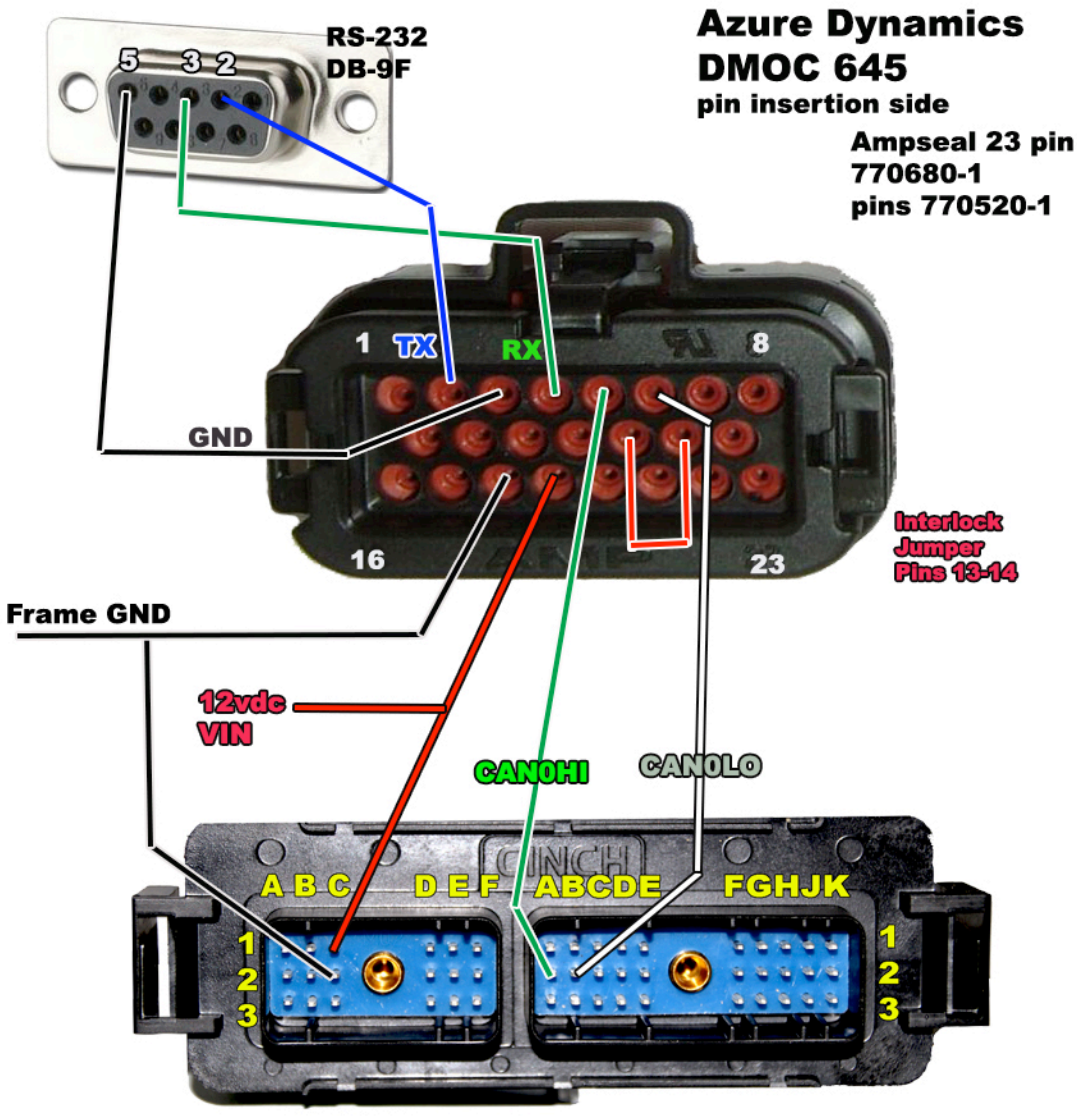
PARTICLE ELECTRON MODULE (optional)

STM32F205 ARM Cortex M3 microcontroller
1MB Flash, 128K RAM
Cellular modem: U-Blox SARA U-series (3G)
36 pins total: 28 GPIOs (D0-D13, A0-A13), plus TX/RX, 2 GNDs, VIN, VBAT, WKP, 3V3, RST
Board dimensions: 2.0" x 0.8" x 0.3" (0.5" including headers)
https://www.particle.io



3 Wiring and Connections

The GEVCU must of course be connected to the car and the inverter/controller by wire. The entire interface is accomplished through two Modice CINCH connectors.



Provided with each GEVCU unit from EVTV is a basic wiring harness. The original genesis of GEVCU was the Arduino Due which featured a very large number of input and output pins.

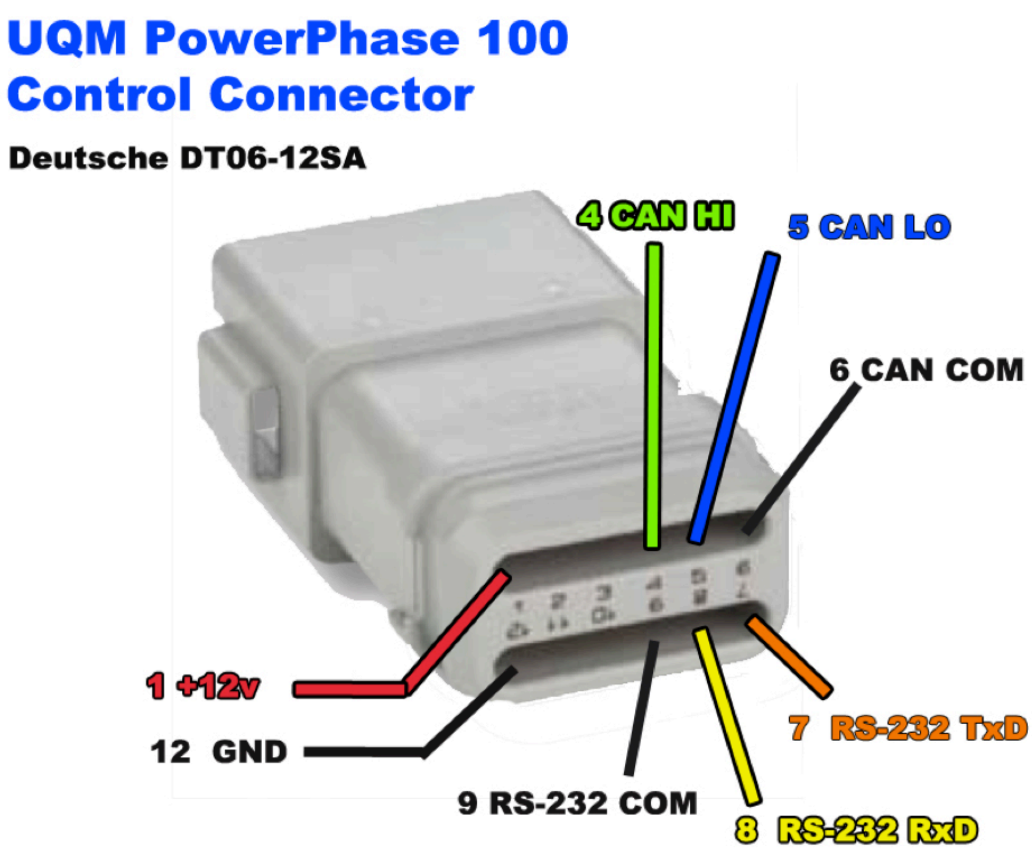
The two Modice CINCH connectors provide but a subset of that but features inputs for 12v vehicle power, two CAN lines to the DMOC645 AMPSEAL 23-pin connector, four analog inputs, four digital inputs, up to eight digital outputs and isolated 12v and 5v outputs to power sensors.

GEVCU was originally devised for the Azure Dynamics DMOC645 Inverter and the basic wiring to this inverter is shown in the accompanying diagram. This is typical of the wiring necessary to connect the GEVCU to an inverter/controller.

Two connectors are provided with GEVCU with 18-inch wires already inserted. You may need to fabricate your own for your installation. Use the following Modice part numbers:

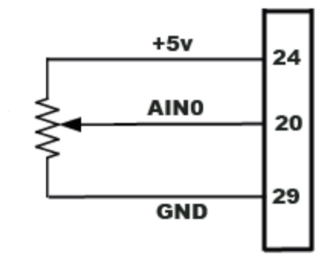
1. **18-pin connector: 538-581-01-18-023**
2. **30-pin connector: 538-581-01-30-029**
3. **18-gage terminal pins 538-425-00-00-873**

This cable would need to be modified for other controller/inverters such as the UQM Powerphase 100.



While the GEVCU has a limited number of digital and analog inputs and outputs, they are really quite capable of handling a number of necessary duties in controlling a vehicle. And the unit does feature TWO CANbus ports, one typically rather dedicated to the motor inverter but the other quite free to interact with the vehicle. In this way, GEVCU can be extended with other CAN equipped multicontrollers used for battery monitoring, informational displays, charging issues, etc.

BASIC THROTTLE WIRING



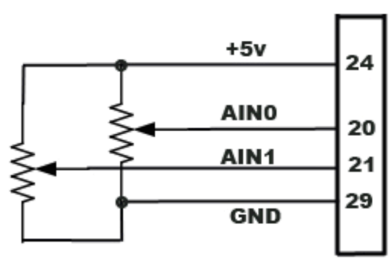
BASIC THROTTLE POTENTIOMETER

As an example, we will describe some basic throttle wiring for the GEVCU as this is the minimum necessary application to control a motor.

A basic throttle potentiometer is shown in the diagram . The potentiometer is a variable resistor that basically "divides" a voltage based on varying the point along a linear resistance where the voltage is sampled. This signal output is tied to our 1st analog input line AIN0 at pin A1 of the 30-pin CINCH connector. The voltage to be divided is provided by tying one end of the pot to our +5v output available on several pins for convenience – on the 18 pin connector 5v is available on A1/A2 and B1/B2/B3. The other end of the pot is tied to our reference ground at any row 3 pin of the 30-pin connector.

In this way, as you press on the accelerator, the potentiometer is varied, increasing the voltage from zero to five volts at maximum pedal. In practice, this is usually something like 0.80v to 4.50 v.

Hall Effect pedals work on a different principle than variable resistors – magnetic inductance. But from a wiring standpoint are no different. They still need a 5v power source and reference ground. And they still provide a signal output that we tie to one of our analog inputs.



TWO-WIRE THROTTLE POT

Many modern throttles have two pots or hall effect modules and provide TWO signal outputs.

This is to provide a "sanity check" to make sure the throttle input is valid. For example, if the signal output and the 5v lines were shorted, this might be read as a max throttle input and the vehicle accelerate uncontrollably.

Two wire throttles provide two different outputs and they usually are NOT identical. For example, one output might vary from 0.8 to 4.5v while the second varies from 1.5v to 3.4v. The sanity check association in comparing those two signals must be handled in software. Indeed, one signal might vary from 0.8 at idle and 4.5v at max, while the other is inverted, showing 3.5v at idle and 1.2v at max pedal. Again, this association must be controlled by the software. GEVCU software currently supports all of these modes. You will have to select 1 wire or 2, and whether the values are linear or inverted.

USING EXISTING VEHICLE DRIVE BY WIRE THROTTLES

Many modern vehicles already feature an accelerator that is wired for producing these signals. It is relatively easy to locate the signal lines and tap into them for connection to the GEVCU. Generally it is good practice to use both signal outputs where available. That the pedal gets 5v from the normal

ECU is not a problem as 5v is more or less 5v regardless of source. But it does have to be **referenced to the same ground.** So generally, you want to tap both accelerator outputs AND connect the associated return from the pedal to one of the GND input pins on the CINCH connector,

BRAKES

Most electric cars map both acceleration and regenerative braking to the throttle, using the first part of pedal travel for regenerative braking and the latter portion of pedal travel for forward acceleration. You will rather quickly learn to not only drive this way, but usually decelerate to a stop using the regenerative braking and it becomes kind of a single-footed driving pattern that most drivers find very controllable and natural.

But many want regenerative braking to assist slowing the car when using the brake and some do NOT like the use of regenerative braking on the throttle at all and ONLY want it applied during actual braking.

The only way we have found to controllably vary the DEGREE of regenerative braking from the brake pedal is to use a hydraulic pressure transducer that operates essentially just like a throttle pot. These transducers again require a 5v supply and ground return, and again provide a signal output from 0.5 to 4.5v typically, increasing as the pressure in the brake lines is increased. The transducer has to be connected to the existing hydraulic brake lines.

By convention, GEVCU uses AIN0 for 1 wire throttles, AIN0 and AIN1 for two wire throttles, and AIN2 for brake inputs.

4 USB SERIAL PORT INTERFACE

The key concept in the GENERALIZED vehicle control unit is that it is **generalized**. That is, it can be configured and used in a variety of different vehicles using different drive train and vehicle components.

The open source nature of the GEVCU software allows anyone with basic C++ coding skills to extend this ad infinitum. However, for most users, C++ is a bridge too far. You can easily use GEVCU by changing a few simple variables requiring no programming knowledge whatsoever.

The design philosophy is to avoid specialized software programs that are operating system dependent and require updating. To accommodate future use of GEVCU, we cannot predict what operating systems will be used and we do not want the overhead of updating a specialized "configuration program" in any event. For far too much of our EV equipment, we find outdated buggy software running on obsolete and in some cases hardly available operating systems in order to change a few simple variables.

But everyone that touches GEVCU wants something more and having it be powerful and extensible is certainly desirable. We see two basic interfaces for non-programmer users.

1. USB Serial Port terminal program
2. Mobile tablet or phone interface via Bluetooth BLE

In this way, the USB serial interface can allow us to avoid depending on specific operating systems or programs beyond a basic serial terminal program running on ANY device. And at the same time provide for gorgeous graphic interfaces to actually serve as a Tesla style interface for our vehicles.

GEVCU features a printer style USB port on the rear of the circuit board simply because these appear to be the most physically durable and robust connectors for USB.

On powerup, GEVCU will interface via USB serial port using simple ASCII characters and line feeds. You can interact usefully with GEVCU via any serial terminal program on any laptop or other computer device. This USB bootstrap operation is a central tenet of the Arduino concept.

Serial communications dates back to the early modems and electronic bulletin boards and has its own quirks and foibles. It is so dated that neither Microsoft nor Apple actually include a serial terminal program with their operating system. But because the need for basic serial communications never quite goes away, terminal programs for both are still readily and in most cases freely available.

There are some basic terminal settings that must be set on most terminal programs in order to "talk" to the GEVCU.

Data Rate: 115,200 bps
Data bits: 8

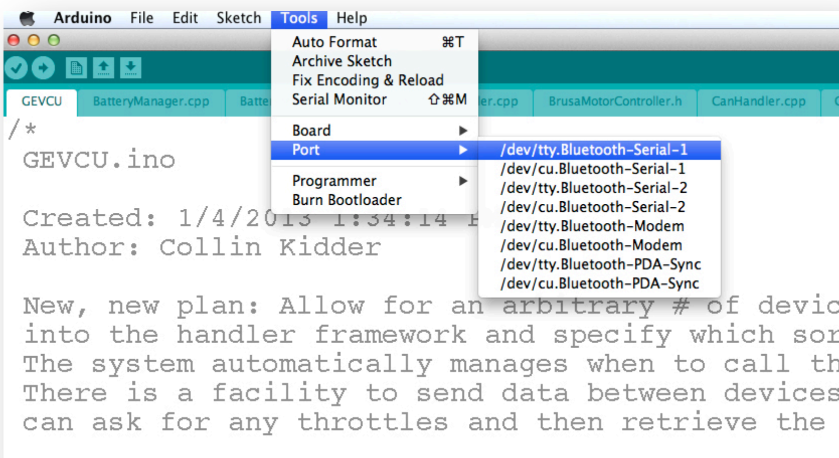
Parity bits: None
Stop bits: 1
Character set: ASCII.

And so to configure GEVCU at its most basic level, you must first configure an ASCII serial data terminal program. Many of these offer many features allowing you to set screen color, font , text size, color. Etc. They can also allow you to "capture" text sent over the port.

GEVCU was born of the Arduino Due educational platform and many actually develop C++ code via the Arduino Integrated Design Environment or IDE. This IDE actually includes a terminal program.

If all else fails, Arduino is freely available for download and installation on Windows, Mac OS X, or Linux fully featured and entirely free of charge. So it may be the easiest way to get and install a terminal program for many users.

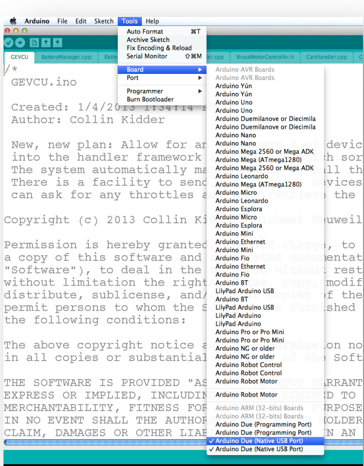
After downloading and installing Arduino. At the top of screen you will find menus. Select TOOLS, and in the submenu BOARD. Then select the Arduino Due (Native USB Port). If this does NOT appear on the submenu, you may have to use the BOARD MANAGER tab to install the SAM3x Arduino Due boards.



Next, select the PORT submenu and select the hardware USB port you have connected to GEVCU.

For Mac OSX or Linux, the available USB ports will appear as CU or TTY entries.

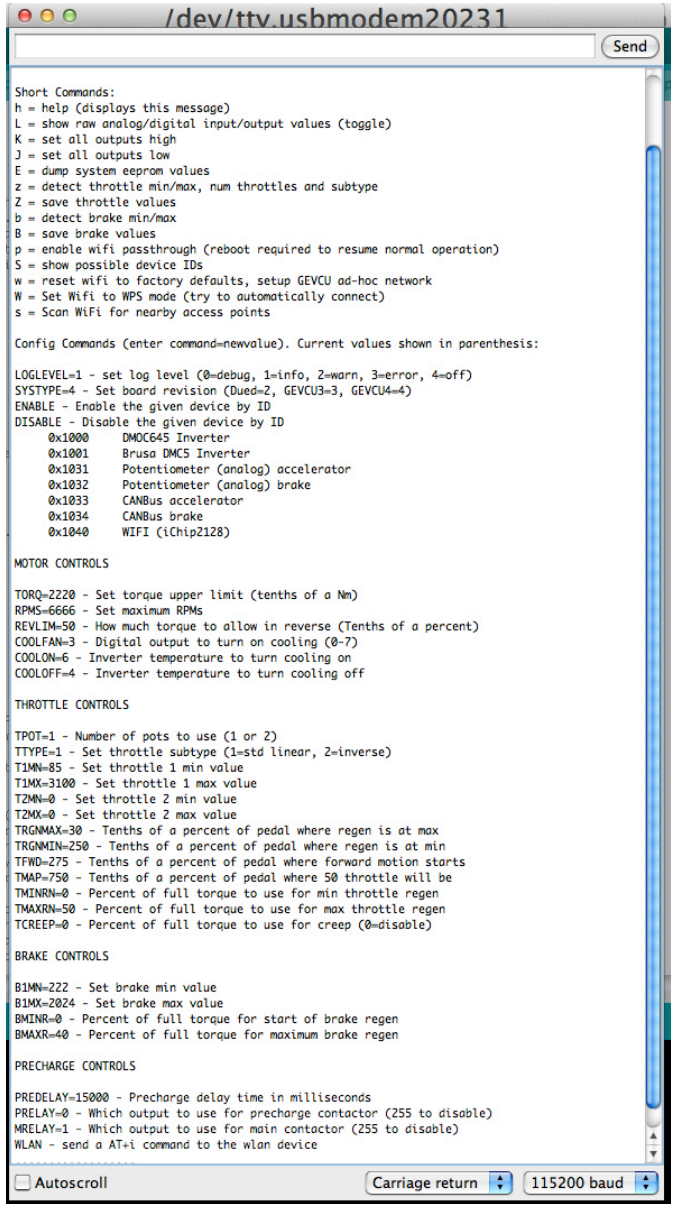
For Windows, more likely something like COM1 or COM2.



Once the port is selected, use the same TOOLS menu to select BOARD for the **ARDUINO DUE NATIVE USB** port. GEVCU actually does not have a PROGRAMMING port but uses the native USB port of the multicontroller chip for both tasks.

Once the port and board are selected, you can use the **SERIAL MONITOR** entry on the **TOOLS** menu to bring up a separate serial terminal window.

This window will feature a data entry field at the top of the screen and a larger display area for text received from the GEVCU.



The only thing you will see initially is most likely a period that appears on screen. Every few seconds, you will see another one. This is the GEVCU "heartbeat."

If you enter a question mark (or lower case h) on the data entry field and press enter or return key you should see a full GEVCU menu in all its gory and hideous glory.

NOTE

You DO have to have some sort of carriage return or line feed turned on for your ASCII terminal program in order to enter commands to the GEVCU

If you actually get garbage or garbled text, make sure the data rate in the lower right hand corner of the terminal program is set for 115,200.

This screen allows you to configure and use essentially all the features of the GEVCU by entering commands in the data field area.

Note that not all menu features will appear until the associated module is enabled as described in Section 5.

.

....Build number: 1056

Motor Controller Status: isRunning: 0 isFaulted: 0

**************SYSTEM MENU *****************

Enable line endings of some sort (LF, CR, CRLF)

Most commands case sensitive

GENERAL SYSTEM CONFIGURATION

E = dump system EEPROM values

h = help (displays this message)

LOGLEVEL=3 - set log level (0=debug, 1=info, 2=warn, 3=error, 4=off

DEVICE SELECTION AND ACTIVATION

a = Re-setup Adafruit BLE

q = Dump Device Table

Q = Reinitialize device table

S = show possible device IDs

NUKE=1 - Resets all device settings in EEPROM. You have been warned.

ENABLED devices: (DISABLE=0xFFFF to disable where FFFF is device number

0x1031 Potentiometer (analog) accelerator

0x1032 Potentiometer (analog) brake

0x1000 DMOC645 Inverter

0x1041 Adafruit BLE

0x3000 VehicleSpecific

DISABLED devices: (ENABLE=0xFFFF to enable where FFFF is device number)

0x1033 CANBus accelerator

0x104F Test/Debug Accelerator

0x1034 CANBus brake

0x1002 Coda UQM Powerphase 100 Inverter

0x1003 CK Inverter Ctrl Board

0x100F Test Inverter

0x1050 Delphi DC-DC Converter

0x1001 Brusa DMC5 Inverter

0x2000 Think City BMS

0x650 ELM327 Emulator over Bluetooth

0x4400 Andromeda Interfaces EVIC Display

0x700 PowerKey Pro 2600

PRECHARGE CONTROLS

PREDELAY=1500 - Precharge delay time in milliseconds

PRELAY=0 - Which output to use for precharge contactor (255 to disable)

MRELAY=1 - Which output to use for main contactor (255 to disable)

MOTOR CONTROLS

TORQ=3000 - Set torque upper limit (tenths of a Nm)

RPM=6500 - Set maximum RPM

REVLIM=255 - How much torque to allow in reverse (Tenths of a percent)

ENABLEIN=255 - Digital input to enable motor controller (0-3, 255 for none)

REVIN=255 - Digital input to reverse motor rotation (0-3, 255 for none)

THROTTLE CONTROLS

z = detect throttle min/max, num throttles and subtype

Z = save throttle values

TPOT=1 - Number of pots to use (1 or 2)

TTYPE=1 - Set throttle subtype (1=std linear, 2=inverse)

T1ADC=0 - Set throttle 1 ADC pin

T1MN=10 - Set throttle 1 min value

T1MX=3000 - Set throttle 1 max value

T2ADC=1 - Set throttle 2 ADC pin

T2MN=0 - Set throttle 2 min value

T2MX=0 - Set throttle 2 max value

TRGNMAX=30 - Tenths of a percent of pedal where regen is at max

TRGNMIN=270 - Tenths of a percent of pedal where regen is at min

TFWD=300 - Tenths of a percent of pedal where forward motion starts

TMAP=750 - Tenths of a percent of pedal where 50 throttle will be

TMINRN=0 - Percent of full torque to use for min throttle regen

TMAXRN=50 - Percent of full torque to use for max throttle regen

TCREEP=0 - Percent of full torque to use for creep (0=disable)

BRAKE CONTROLS

b = detect brake min/max

B = save brake values

B1ADC=2 - Set brake ADC pin

B1MN=100 - Set brake min value

B1MX=3200 - Set brake max value

BMINR=0 - Percent of full torque for start of brake regen

BMAXR=50 - Percent of full torque for maximum brake regen

OTHER VEHICLE CONTROLS

COOLFAN=6 - Digital output to turn on cooling fan(0-7, 255 for none)

COOLON=25 - Inverter temperature C to turn cooling on

COOLOFF=20 - Inverter temperature C to turn cooling off

BRAKELT = 255 - Digital output to turn on brakelight (0-7, 255 for none)

REVLT=255 - Digital output to turn on reverse light (0-7, 255 for none)

NOMV=6553 - Fully charged pack voltage that automatically resets kWh counter

CAPACITY=255 - capacity of battery pack in ampere-hours

kWh=0 - kiloWatt Hours of energy used

ANALOG AND DIGITAL IO

A = Autocompensate ADC inputs

J = set all digital outputs low

K = set all digital outputs high

L = show raw analog/digital input/output values (toggle)

OUTPUT=<0-7> - toggles state of specified digital output

ADC0OFF=185 - set ADC0 offset

ADC0GAIN=1400 - set ADC0 gain (1024 is 1 gain)

ADC1OFF=193 - set ADC1 offset

ADC1GAIN=1024 - set ADC1 gain (1024 is 1 gain)

ADC2OFF=180 - set ADC2 offset

ADC2GAIN=1024 - set ADC2 gain (1024 is 1 gain)

ADC3OFF=217 - set ADC3 offset

ADC3GAIN=1024 - set ADC3 gain (1024 is 1 gain)

ADCPACKHOFF=171 - set pack high ADC offset

ADCPACKHGAIN=65535 - set pack high ADC gain (1024 is 1 gain)

ADCPACKLOFF=89 - set pack low ADC offset

ADCPACKLGAIN=65535 - set pack low ADC gain (1024 is 1 gain)

ADCPACKCOFF=274 - set pack current offset

ADCPACKCGAIN=65535 - set pack current gain (1024 is 1 gain)

....

5 MODULE SELECTION AND INITIALIZATION

With power and flexibility, unfortunately comes complexity. GEVCU is initially designed to drive the Azure Dynamics Force Drive system with a DMOC645 controller and a single input throttle. The very basics were to take throttle commands and convert them to CANbus signals to drive the Digital Motor Controller (DMOC645) to drive the motor. Simple enough.

But the immediate vision of GEVCU from the start was to serve as a modular, object-oriented software program platform that could drive a VARIETY of inverter/controllers and motors. Rather immediately someone wanted such a device for a BRUSA controller. And someone else wanted to interface with a THINK vehicle battery management system. And use it to drive a UQM Powerphase 100 inverter. And so on and on.

There are also a variety of already drive by wire throttles in a variety of modern vehicles out there. Most have TWO inputs that vary similarly, but usually not identically. And some throttles actually have a CAN output or are converted to CAN signals by the ECU in the original vehicle.

As a result, GEVCU could conceivably grow into dozens of object modules to support various throttles, brakes, battery management systems, chargers, instrument clusters, and most of all a variety of inverters/controllers.

Obviously, while everybody needs SOME of these object modules no one will ever need ALL of them on the same vehicle. Some form of object module management is needed.

The current system is admittedly very awkward. Until we get it fixed, you can turn on a module via the serial port with an **ENABLE** command and you can conversely turn it off with a **DISABLE** command. This does not actually take effect until you power cycle the GEVCU. That is, completely remove power from the unit and then bring it back up with 12v power.

This is best done by disconnecting the CINCH connectors entirely and using power over the USB connector. Simply enable the desired module, then unplug the USB connector. Then plug it back in bringing up the system. The new module will be mapped to the system EEPROM and this module will load automatically in the future until it is removed with a **DISABLE** command.

ENABLE=0x1000 Enable the DMOC645 inverter

Successfully enabled device.(%X, %d) Power cycle to activate.

Power reset

ENABLE=0x1031 Enable a normal potentiometer/hall effect style throttle

Successfully enabled device.(%X, %d) Power cycle to activate.

Power reset

ENABLE=0x1032 Enable a normal potentiometer or hall effect brake input

Successfully enabled device.(%X, %d) Power cycle to activate.

Remember to power cycle before making further changes to your GEVCU system.

Available modules are actually listed on screen under either ENABLED or DISABLED. But you can also enter an S command to list all modules available.

A few other housekeeping commands are available to assist in module selection:

a = Re-setup Adafruit BLE

This is a special command to re-initialize the Adafruit Bluetooth LE SPI Friend module which provides the interface to mobile devices. Occasionally it gets "lost" and this command is often curative.

q = Dump Device Table

This command is really a debugging tool to let us see the device table at a technical level.

Q = Reinitialize device table

This command allows us to start over with a fresh table if the device table does become corrupted.

S = show possible device IDs

NUKE=1 - Resets all device settings in EEPROM. You have been warned.

This command is a last resort in the event our EEPROM memory becomes hopelessly corrupted. You have been warned.

6 PRECHARGE CONSIDERATIONS

Almost all power switching devices feature a set of input capacitors to buffer the supply voltage to the power switching electronics. This ensures a stable input voltage for switching purposes, at least at the frequencies common in those circuits.

The nature of capacitors is that they resist any change in voltage by providing or absorbing current. And this leads to a bit of a problem that comes up in electric vehicles in a variety of places – excessive inrush current.

When we first connect a battery pack to any inverter or PWM controller, the voltage of the capacitors will be zero while the voltage of the pack might be as high as 400v. The capacitor will absorb current in an attempt to maintain zero volts until it is forced to 400v. And so the capacitor is said to CHARGE. If the voltage is then removed, the capacitor will PROVIDE current attempting to maintain the voltage until it is discharged.

The amount of current is a function of the applied voltage and the SIZE in FARADS of the capacitor with any resistance serving to limit current into the capacitor. Because these tend to be large capacitors, they can absorb a large amount of initial current for a brief time before their voltage is equalized to the applied pack voltage.

This can lead to very brief, but often HUGE inrush currents when the pack voltage is applied. These currents can be SO large that they arc weld the contacts on contactor relays, and indeed too often result in the destruction and failure of the capacitors themselves – potentially destroying your DMOC645 inverter.

The solution to this is precharging the capacitors up to the pack voltage through some sort of current limiting device – typically a resistor. By ohms law, a resistor will allow a certain level of current based on its resistance and the applied voltage. I = E/R where I is the current, E is the voltage, and R is the resistance.

So for example, if we have a 400v pack, and we precharge through a 100 ohm resistor, we limit the inrush current to 4 amperes. It might take several seconds to charge the capacitor to 400v at 4 amps but this is infinitely longer than the mere milliseconds it will take if the voltage is applied directly.

Of course, even one ampere of current at 400 volts is the equivalent of 400 watts of power. And so we need a large resistor capable of absorbing that amount of power without failure of itself. Since the precharge is only a few seconds, it doesn't need to be 400 watts, a 100 watt resistor would likely do. But the common resistor is typically ¼ watt, and would cinderize instantly. A power resistor is necessary.

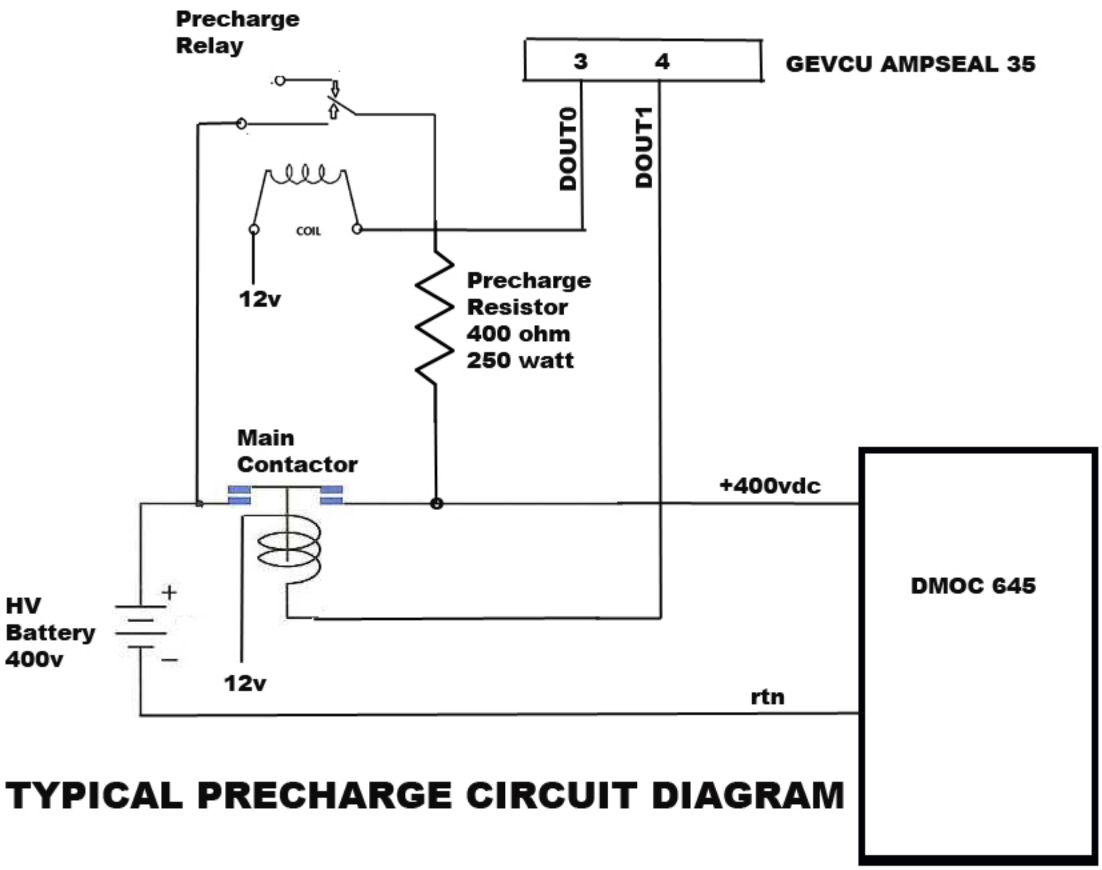
Unfortunately, once the caps are charged and the power switching begins, we don't want ANY resistance in our source voltage. As the switches often do 300 or 500 or even 1000 amps, it would give off a lot of heat and ultimately burn up even the largest resistor.

Once the capacitors are charged, we can safely connect them directly.

And so the usual process is to use TWO relays, your main contactor and a separate ***precharge*** relay that connects the power resistor across the main terminals of the contactor bypassing it.

And so the precharge process becomes:

1. Close precharge relay applying voltage to input capacitors.
2. Wait until capacitor reaches pack voltage.
3. Close main contactor connecting input capacitors directly to pack.



TYPICAL PRECHARGE CIRCUIT DIAGRAM

In the diagram, note that we use DOUT0 and DOUT1 to activate the precharge and main contactor relays respectively. ALL GEVCU digital outputs are a switched ground MOSFET. When set to 0 it presents an open on the associated CINCH connector pin. When set to 1, it switches the MOSFET ON which connects the pin to ground.

The other end of both relay coils is connected to the ordinary vehicle 12vdc. So when the DOUT MOSFETS are turned on it provides a ground to the coil and closes the relay. These MOSFETS are capable of 2.7 amperes of continuous current and surge currents of up to 7 amperes – sufficient for the largest contactor coil.

Pre-charging is so common in these situations, that there are several variables already programmed into GEVCU software to accommodate precharging. To set these, bring up the serial terminal on the GEVCU and enter the following values:

PREDELAY=1500 This sets the precharge time delay in milliseconds
Setting Precharge Delay to 1500 milliseconds.

PRELAY=0 This sets the precharge relay output to DOUT0.
Setting Precharge Relay to 0.

MRELAY=1 This sets the main contactor relay to DOUT1.

Setting Main Contactor relay to 1

These values will be saved to EEPROM automatically. At any time in the future, when the GEVCU receives 12v on the input and completes its bootup process, it will immediately set the precharge relay output **DOUT0** to on, engaging the precharge relay and applying the 400v through the precharge resistor to the DMOC645.

The program will hold that state for the amount of delay you enter in **PREDELAY** in milliseconds. 1500 ms for example is 1.5 seconds.

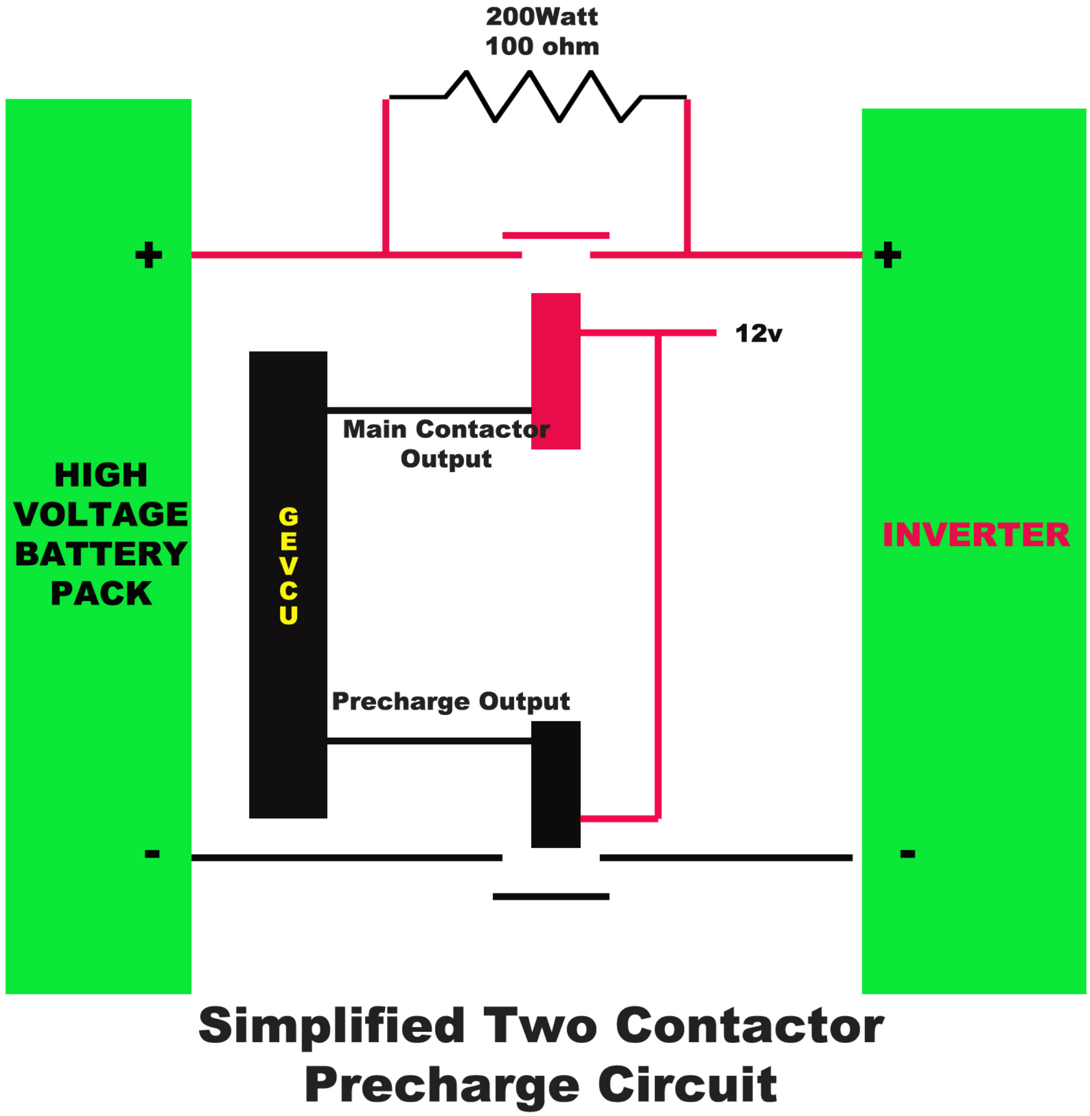
After that time has expired, it will close the **MRELAY** output – in this case DOUT1.

Note that any output can be used for precharge **DOUT0** through **DOUT7** and any output can be used for the main contactor.

If no precharge is desired, simply set **MRELAY** and **PRELAY** to **255**. You can then use those outputs for other purposes. Note also that no precharge is done unless a **PREDELAY** greater than 0 is entered.

AN ALTERNATE PRECHARGE TECHNIQUE

Precharge as depicted above requires a second relay and the usual approach is a much smaller relay to minimize expense – since it is only going to carry 3 or 4 amperes this appears to make sense. And on low voltage systems, it more or less works. But as we increasingly go to higher voltage AC drive systems, it more or less doesn't. The reason is contact arcing. The little 12vdc automotive relays are simply not designed to switch 350 vdc even at low currents. The high voltage potential itself will cause the contacts of these relays to arc – causing pitting and wear and potentially even welding them closed.



The simplified two contactor precharge circuit shown here has several advantages for high voltage systems. First, it provides a redundant safety element as two high voltage contactor relays are used and both must be engaged to power the system. That means in an emergency shutdown scenario you have TWO contactors breaking the circuit. If one welds closed, the other one may indeed break the circuit.

But it also eliminates the use of the inexpensive 12v relay from the circuit. Note that one contactor is placed on EACH pole of the battery connection and a precharge resistor is permanently wired across the terminals of the positive contactor.

In order to precharge the inverter, the contactor on the NEGATIVE pole is closed, completing the circuit through the resistor and applying pack voltage to the inverter through that resistor.

Once the precharge delay has been accomplished, the main contactor on the positive pole is then engaged – effectively taking the resistor out of the loop by bypassing it directly.

In this way, we can avoid the use of small failure prone relays in our precharge circuit. GEVCU will always leave the precharge output on after the main contactor is closed in order to provide for this type of precharge configuration.

When the GEVCU is powered down, both contactors open, removing all possibility of charge on the inverter.

7 THROTTLE CALIBRATION AND MAPPING

The concept of a "vehicle control unit" can cover a multitude of sins. But the most central issue, certainly with electric vehicles, is "controlling" the amount of power applied to the electric motor and drive train.

Early vehicles used a simple switch to apply power to the motor or not. By switching it in and out, the driver could kind of/sort of control the forward motion of the vehicle.

Later versions featured large potentiometers that consumed much of the power as heat but provided variable voltage to the motor.

Various switching schemes were used to switch batteries in various combinations to get different voltages to the motor.

But the objective is always to give the driver control of the forward motion of the machine.

In modern electric vehicles, we need to use the accelerator or throttle (we avoid calling it the gas pedal actually) to control the application of power to the electric motor to go forward. In most AC polyphase systems, this is complicated a bit by the fact that the AC drive motor can be used as a generator when coasting or slowing down. This is generally referred to as regenerative braking or simply "regen".

Regen doesn't just happen. We can control the AMOUNT or degree of power generation for any given turn of the wheels by varying the excitation current in the motor stator windings.

Most modern vehicles feature both forward acceleration control AND regenerative braking control using the throttle. Most drivers quickly become accustomed to this and learn to use it to great advantage with one pedal control right up to a full stop at the stop light. Some drivers do NOT like this feeling and do not want regen on the throttle at all.

The result is that the CENTRAL function of GEVCU is to translate throttle pedal position into motor control signals. It is also the most complicated concept to grasp as we need to accommodate as many combinations of pedal position, acceleration, and regenerative braking as possible to accommodate a variety of vehicles and driver preferences.

You will find that "tuning" the throttle map is THE most effective way available to tune the "feel" of your electric car when driving. And that driving "feel" is part of the magic of electric drive. Depending on the throttle map settings, your vehicle can provide a seamless interface where you actually feel like part of the car and control it effortlessly and without conscious thought. Done poorly, it can render a barely controllable vehicle prone to parking lot accidents and uncontrolled accelerations – a hazard to the driver and everyone on the public right of way.

HOW GEVCU DETECTS THROTTLE POSITION

GEVCU detects throttle position by voltage. Throttles may be potentiometers, hall effect devices, and of either one signal or two. GEVCU provides these sensors with a 5v supply and a ground reference return and receives from it a signal or signals indicating pedal position by voltage.

This signal is optically isolated, buffered, filtered, and scaled from the 0 to 5 volt signal from the pedal to a 0-3.3v signal that can be read by the multiprocessor. This signal is then sampled by the Analog to Digitial Converter and presented as a number between 0 and 4096 digitally.

So a 0v signal would produce a digital output of 0 and a 5v signal from the throttle would produce a value of 4096.

This is not a precise art. Sampling issues, noise on the wires, electromagnetic interference all have an effect on such small signals. So the software "averages" this input value continuously.

Programmatically, it then converts this digital value to a "throttle percentage" between 0 and 100 to some precision for use by the various program elements.

And so for example, the throttle at rest might put out a voltage of 0.83 and that is scaled and converted to a digital value of 95 which is then defined in software as 0% throttle.

With the pedal fully depressed, the throttle sensor might put out a voltage of say 4.62 volts. This is scaled, buffered, filtered, and converted to a digital value of 3785 and we then define that as 100% throttle.

THROTTLE TYPES

GEVCU rather arbitrarily divides the world of throttles into two types, single input and dual input. This is defined by the variable **TPOT** with **TPOT=1** indicating a single input throttle and **TPOT=2** indicating a dual signal throttle.

IF TPOT is set to 2, there is another consideration. Does the 2nd signal vary in voltage in the same direction to the first signal or is it inverted. **TTYPE=1** for a linear relationship and **TTYPE=2** for an inverted one.

THROTTLE CALIBRATION

It's an imperfect world. Whatever sensor is selected or used, the output read at the analog input to the GEVCU is going to vary depending on wire lengths, manufacturing variations etc. So it is important to have a means of calibrating the throttle.

For single input throttles two variables are provided – T1MN and T1MX. You simply enter the digital values read by GEVCU while the pedal is at rest (T1MN) and fully depressed (T1MX). We assume it will be more or less linear between those two points.

For two wire throttles, a second input is provided, T2MN and T2MX. If a single input is used, we want to set these values to zero.

To get the numeric values, we have to use our USB serial port terminal program to view the digital value "read" by GEVCU for the throttle positions. Enter the letter **L** and the serial monitor will begin to provide a text read out that is updated every few seconds.

Motor Controller Status: isRunning: false isFaulted: false

AIN0: 81, AIN1: 81, AIN2: 87, AIN3: 77

DIN0: 0, DIN1: 0, DIN2: 0, DIN3: 0

DOUT0: 0, DOUTO1: 0, DOUT2: 1, DOUT3: 0,DOUT4: 0, DOUT5: 0, DOUT6: 0, DOUT7: 0

Throttle Status: isFaulted: false level: 0

Throttle rawSignal1: 81, rawSignal2: 80

Brake Output: -200

Brake rawSignal1: 87

This display gives us quite a bit of information. Note the line AIN0: etc. This lists the actual digital values derived from our four analog inputs 0-3.

By convention, we usually wire the primary throttle signal to AIN0 and the secondary to AIN1 with brake inputs on AIN2.

The next line actually indicates the current status of digital inputs 0 through 3 as DIN0: etc.

And the next line will provide information on the current status of the eight digital MOSFET outputs DOUT0 through DOUT7.

So calibrating the throttle becomes quite easy to do manually:

1. Enter **L** to get the screen logging shown above.
2. Ensure throttle is at rest (idle).
3. Note numeric value appearing in **AIN0**.
4. Press throttle to full acceleration.
5. Note new numeric value appearing in **AIN0**.
6. Enter the first value using the command **T1MN=xx** where **xx** is the value displayed. Actually you should enter a value slightly HIGHER than the value displayed to ensure that with no throttle input, we truly read 0 % throttle
7. Enter the second value noted using the command **T1MX=xx** where **xx** is the value displayed. And actually you would enter a value just a few points LOWER than what you read to ensure we have a 100% value at full throttle.

For dual signal throttles, this procedure can be repeated for **AIN1** using the variables **T2MN** and **T2MX**.

THROTTLE MAPPING

Throttle calibration simply establishes the "end points" of the throttle map. We establish the actual digital readings for an idle and max throttle condition. This is then mapped to a normalized 0 to 100% throttle value.

GEVCU actually provides a rich set of variables to map that 0-100% in an almost endless number of combinations to "tune the curve" or tune your throttle action to vary the feel of the car while driving. The basic list of variables includes

TCREEP – amount of forward torque applied at idle. This can be useful with automatic transmissions for instance or to duplicate the feel of an automatic transmission ICE vehicle that wants to "creep" forward if you release the brake.

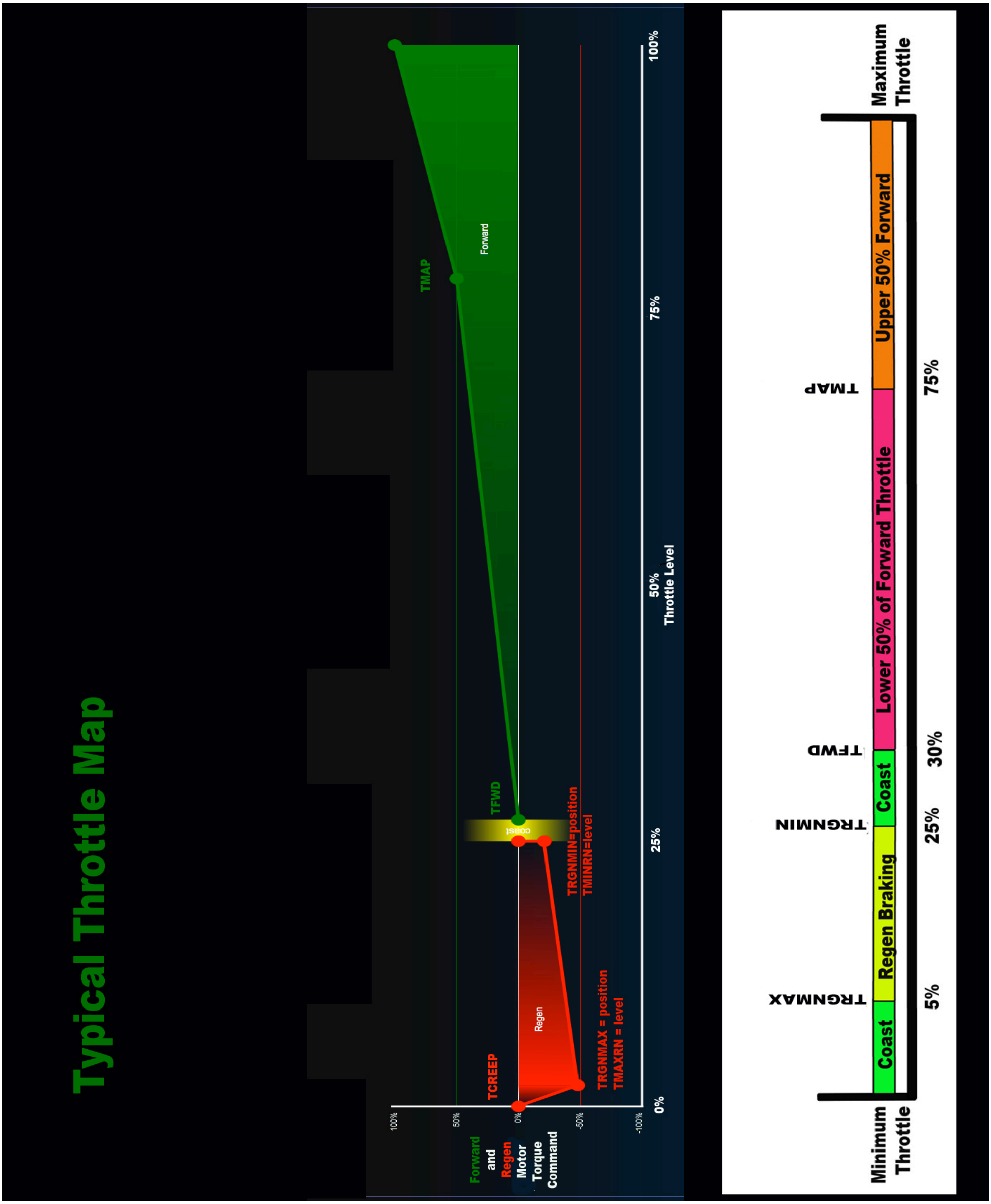
TRGNMIN – defines the point on the throttle where the minimum regenerative braking torque is applied. The minimum regen torque level is defined by an associated variable **TMINRN** which is the percentage of full torque.

TRGNMAX is the pedal position where maximum regenerative braking is felt and this maxiumum is defined by **TMAXRN** which is a percentage of full torque.

TFWD is the point on the throttle map where forward drive torque is applied.

TMAP is the point on the throttle map where 50% of available forward torque is applied.

Refer to the throttle map diagram.


Typical Throttle Map
Forward and Regen Motor Torque Command
100%
50%
0%
-50%
-100%
TMAP
Forward
TFWD
coast
TRGNMIN=position
TMINRN=level
Regen
TCREEP
TRGNMAX = position
TMAXRN = level
0%
25%
50%
Throttle Level
75%
100%
TRGNMAX
TRGNMIN
TFWD
TMAP
Minimum Throttle
Coast
Regen Braking
Coast
Lower 50% of Forward Throttle
Upper 50% Forward
Maximum Throttle
5%
25%
30%
75%

The first thing to understand about the throttle map is that regenerative braking is a function of the forward motion of the car, fed through the axles and transmission to the motor, is used to generate electricity.

No matter what we set our variables to, there is no regenerative braking if the wheels are not turning.

So in the diagram depicted, the first 25% of the pedal does NOT cause us to go in reverse. It is simply dead pedal.

In starting off, **TFWD** defines the point in the pedal where forward motion begins. In this example, perhaps at 27% throttle.

Torque is then mapped from 27% to 100% throttle with one modification. It is scaled nonlinearly by the variable **TMAP** which defines the percentage of throttle where 50% torque occurs.

This is a nice feature actually. We can define 27% to 85% percent of throttle for the first 50% of available torque, with the remaining 50% torque mapped from 85 to 100%.

Why would we want to do this? It dramatically EXPANDS our resolution and control on the lower half of the available torque curve. In this way, we can markedly improve "feel" at low speeds when parking and maneuvering.

Typically, in driving the difference between hard acceleration and REALLY hard acceleration doesn't really matter very much. You're kind of foot down or not for max power. But for minimum power, a finer level of control is an asset.

Regenerative braking comes into play when we are already rolling and we begin to back off on the throttle. The kinetic energy of the car keeps it moving forward and left to its own devices will roll quite freely some distance. But this energy can be recaptured by using the motor as a generator and feeding the current back into the batteries.

Generally, as you back off the throttle you want to gently begin applying a minimum level of regenerative braking and increase that amount the more you back off on the pedal.

TRGNMIN defines, in tenths of a percent, the position on the throttle map where regenerative just begins to be felt. The associated variable **TMINRN** defines the percentage of maximum torque that is called for at that point.

The maximum regenerative torque is defined by **TMAXRN** and the point on the throttle at which this occurs is defined by **TRGNMAX**. In this example, we get max regenerative braking at about 5% throttle.

And so the further you reduce the pedal, the stronger the regen effect is felt, slowing the car.

Note a couple of gaps. We have nothing defined at all from 25% our minimum regen point, and 27% , the beginning of forward acceleration torque. This provides a little "coast" zone where no forward torque is applied and no regen torque is produced. You can make this zone as wide or as narrow as you like or not have one at all. I personally quickly find this "notch" in the pedal and often use it to coast freely down a hill for example.

Note too that **TRGNMAX** comes in at about 5% throttle. From that point to full idle is a second "coast" zone where no regen is produced and no forward torque either. Again, a matter of personal preference.

Again, **TCREEP** allows you to define a level of forward torque produced at 0% throttle.

Note that throttle input more than about 15% below the minimum you calibrated the throttle with will result in a fault condition and to about the same 15% tolerance any input ABOVE the **T1MX** will likewise result in a fault.

These variables are at first confusing and seem unnecessarily complicated. Worse, it will take you a number of "tuning drives" where you go drive the car, come back and change some variables, go drive the car, come back and repeat.

But you will quickly see that these variables allow you to achieve a custom level of feel and nuance in the way the vehicle drives that is really quite the central feature of GEVCU.

8 BRAKE CALIBRATION AND MAPPING

Brake calibration and mapping is very similar to that for the throttle, but much simpler as there is usually only one brake input.

Braking issues revolve around the concept of regenerative braking described in the Throttle section of this manual. With most AC drive systems, the traction motor can be used as a generator during deceleration converting the kinetic energy held in the forward motion of the car into electrical current, which is in turn fed back into the batteries to "restore" a bit of energy.

In theory, this sounds like we can recover a significant amount of energy and extend our range. In almost all of our actual comparison tests, we've found the realized energy efficiencies of regenerative braking in all cases much less than advertised, and really quite meager when demonstrated. The reasons for this are a bit complex, but involve the fact that WITHOUT regenerative braking, you drive the car quite differently and quickly learn to take advantage of "free roll" which is a very different feel from normal ICE vehicle operation. In an internal combustion engine, when you take your foot off the throttle, the compression of the engine acts as a kind of a brake. When you remove your foot from the throttle of an electric car, an electric motor HAS no engine compression and so does not. As a result, you can often roll for a long distance using no electricity at all.

If we measure energy OUT of the battery when accelerating, and energy IN to the battery during regenerative braking, there APPEARS to be a considerable energy savings. But without regenerative braking, we find we drive the car quite differently, and the energy OUT to drive the car changes considerably. As a result, comparing the same actual drive WITH regenerative braking and without regenerative braking simply does NOT show those kinds of efficiency gain.

So why use regenerative braking at all? It actually puts more load and stress on the motor, the inverter, the transmission, and indeed the batteries. It's a good question.

But over time, we've learned we just LIKE the feel of regenerative braking and it DOES reproduce the feeling of engine compression in a more conventional car feel. Even better, we soon learn to use just the throttle to modulate between forward acceleration and regenerative braking giving us a new kind of one foot control of the vehicle that many electric car enthusiasts strongly prefer.

With GEVCU You can easily turn regenerative braking off entirely for either or both the throttle and brake. But you can also use regen for either or both the throttle or the brake.

Regenerative braking on the brake gives us a sense of power brakes. We usually tune this so that just a little brake pressure will give us quite a bit of regenerative braking pressure and this increases with pedal pressure up to a point. But at the point where the mechanical hydraulic brakes actually come into play, we often cut off the regen entirely. In this way, a light brake pressure gives us some regen deceleration, heavier foot pressure mostly giving us just mechanical braking.

To use regenerative braking on the brake, you will need some sort of 5v sensor indicating brake pedal travel. We actually strongly prefer using a hydraulic brake pressure transducer that provides a 0-5 output based on hydraulic pressure felt in the actual brake lines. This sensor usually has three connections, 5v, GND, and the output signal. GEVCU provides several 5v and GND outputs to choose from. From there, it is an easy matter to tie the brake pressure transducer output signal line to one of our analog inputs. By convention, we use the first two analog inputs, 0 and 1 for the throttle. And so we normally use input 2 for braking.

Note that regenerative braking on manual brake systems can be quite pleasant to use. Generally using regenerative braking on power brake systems is of much lower usefulness in tuning a car for ideal braking feel.

Calibrating the brake becomes quite easy to do manually:

1. With a terminal program, bring up the serial port screen display.
2. Enter **L** to get the screen logging shown above.
3. Ensure brake pedal is at rest .
4. Note numeric value appearing in **AIN2**.
5. Press brake pedal to maximum.
6. Note new numeric value appearing in **AIN2**.
7. Enter a value JUST ABOVE the first value noted with the brake off, using the command **B1MN=xx** where **xx** is the value displayed.
8. Enter a value JUST BELOW the second value noted using the command **B1MX=xx** where **xx** is the value displayed.

.This sets the minimum and maximum input levels GEVCU will see on AIN2.

BRAKE MAPPING

Brake calibration simply establishes the "end points" of the brake map. We establish the actual digital readings for an off brake and max brake condition. This is then mapped to a normalized 0 to 100% brake value.

Two additional variables are used to establish the level of regenerative braking to be used. **BMINR** represents the minimum level of regenerative braking we want to exhibit while braking while **BMAXR** establishes the maximum degree of regenerative braking . The valued entered will indicate PERCENT of available regenerative braking torque to be applied. Values of 0 will turn off regenerative braking on the brake pedal.

In applying regenerative braking, GEVCU will map **BMINR** to **B1MN** to give minimum regenerative braking when you just start to press the pedal. It will linearly apply regenerative braking up to **BMAXR** occurring at the pedal position you identified as **B1MX.**

BRAKE LIGHTS

One of the advantages of ac induction motors and polyphase brushless dc motors is that it is very easy to switch roles from being a drive motor to acting as a generator. Indeed, when you remove power from the motor but continue to turn its shaft from the forward motion of the vehicle, it basically reverts to acting as a generator.

We can control this with our inverter determining how much power is produced, and thus how much of a slowing effect it will have on our car. Indeed we provide variables in the GEVCU to allow you to tune how much regenerative braking occurs when you put on the foot brake, and indeed how much occurs when you back off the throttle and specifically where on the throttle that occurs. In fact, an inordinate amount of the setup of GEVCU is devoted to this one issue – regenerative braking.

This gives rise to an anomaly you may want to consider. When you put your foot on the brake of most automobiles, an electrical switch closes turning on the brake lights on the rear of the car. This switch is usually located on the master cylinder and reacts to hydraulic pressure, but on some vehicles it is actually on the brake pedal itself. In either case, when you start to brake, two big red lights on the rear of the car, required by the National Highway Traffic Safety Administration, light to warn drivers behind you that you are slowing down.

This is an important safety feature to prevent large trucks from cohabitating in your trunk with your spare tire.

The issue is with throttle-based regenerative braking. Most electric vehicle builders and drivers eventually discover a pleasant level of control of the vehicle that can be obtained using regen on the throttle. They quickly learn they can slow almost to a stop just using the accelerator and almost never have to take their foot off the throttle to brake. Indeed, one of the ways you can spot an EV conversion is to look for the rusty brake disks. Some EVs simply do not ever have to have new brake pads because the braking system is almost never used.

While regen on the throttle can be used to dramatically slow the car, it doesn't inherently light the brake lights. And so some EV drivers find they always seem to have people climbing their tailgate. The reason is the other drivers were not provided sufficient warning of your decreasing speed during regenerative braking.

GEVCU makes provisions for this with the BRAKE LIGHT output. You can designate any of the 8 digital outputs as a brake light output. The system will monitor the actual torque output reported by the inverter to the GEVCU via CAN. In any event where this torque is NEGATIVE and exceeds 10 Newton Meters of torque, the brake light output is set to ON.

Via serial terminal, this value is set with the BRAKELT variable.

BRAKELT=5 This sets the brake light output to output 5.

Brake light output updated to: 5

If you do not need a brake light output, set this value to **255**.

This variable is also available on the wireless website configuration page.

Like other digital outputs, this is a switched MOSFET ground. When the torque value goes negative to more than 10 Newton Meters, the output pin is grounded. Otherwise it is open.

You can easily use this output to provide a ground to the coil of an ordinary automotive 12v relay and use the relay to bypass the brake light switch on either pedal or master cylinder to switch on the brake lights just as if the brake pedal had been pressed.

In this way, when slowing through regenerative braking, you WILL light the brake lights on the rear of the car, warning drivers behind you that you are slowing.

The 10 nm threshold requirement allows modest regen without tail lights but any substantial regen above this modest threshold will light the tail lights.

9 POWER VALUES

There are a couple of variables having to do with maximum power and rpm for the motor overall. These can be set using the USB serial port and terminal program or the wireless web server.

Torque is a measure of pressure or work of a rotating shaft. It is normally expressed in the United States as ft-lbs and in the rest of the more metric world in Newton Meters. 1 newton meter = 0.737562149 foot pounds. Conversely 1 foot pound = 1.35581795 newton meter.

There are two ways to operate power switching control of AC motors. You can command them to a speed, using all available torque at a certain ramp rate, or you can command torque itself and largely ignore speed. For most automatic operations such as operating pumps and compressors, you would use speed control. You want to set a certain speed and have the motor run at that speed and it will take whatever torque is necessary to reach that speed and maintain it.

But for electric vehicles, we normally use torque control. Your foot commands a certain amount of torque and the speed is left mostly up to the driver to monitor on the speedometer. When starting from a stop, you need maximum torque to accelerate but as you reach your desired speed, you naturally come off the throttle decreasing the applied torque. You don't really care what speed the motor shaft turns out to get there.

The **TORQ** variable establishes the maximum level of torque that GEVCU will command the DMOC645. The combination DMOC645 and Siemens Motor may or may not actually achieve this depending on available battery voltage, gearing, etc. But this is the maximum value, expressed in tenths of a Newton Meter, that GEVCU will command. The DMOC645 actually reports back the ACTUAL value of torque at any one instant.

We think of DMOC645 and Siemens motor as capable of up to 300 Newton Meters of torque. So for maximum torque with this combination, you would enter the following serial command:

TORQ=3000

Note that this is in TENTHS of a Newton Meter and so the value 3000 represents 300 NM.

A second value is established programmatically in a configuration file to set the maximum regenerative braking torque in watts. No idea why this wasn't made an accessible variable, but it will typically be set to 40% of whatever the maximum **TORQ** value is.

Other variables specific to the brake and throttle actually establish what percentage of THAT value Is applied at specific brake or throttle levels.

It is usual to set a maximum rpm level for the electric motor. Regardless of WHAT level of torque you command, the DMOC645 won't apply it if this maximum revolutions per minute level is achieved. This is set by the command

RPM=6000

For example this command would set the max rpm at 6000 rpm.

An odd variable included is the percent of torque available when in REVERSE. The DMOC645 does not actually know when you have placed the transmission in reverse unless you use one of the inputs to note that and wrote software to do this. But there are some provisions for using a digital input to put the motor direction in reverse. And this variable would establish a separate maximum torque when backing up using the reversed electric motor. This is expressed in tenths of a percent.

REVLIM=500

This command would limit maximum torque WHEN in reverse to 50% of maximum available torque. Note that this would be the reverse selected by a digital input actually signifying that the electric motor should run in reverse. It has nothing to do with a reverse gear in a mechanical transmission.

The **TORQ** command can actually be quite useful. For example, by setting **TORQ=750**, you might limit the motor output to 75 NM. You can then map your throttle and brake and test drive them without much of anything getting away from you because you have strongly limited the power output of the motor. Once your braking and throttle feel right, even though the vehicle is a little docile, you can then return **TORQ=3000** for 300 NM of torque for full power.

10 Analog Inputs

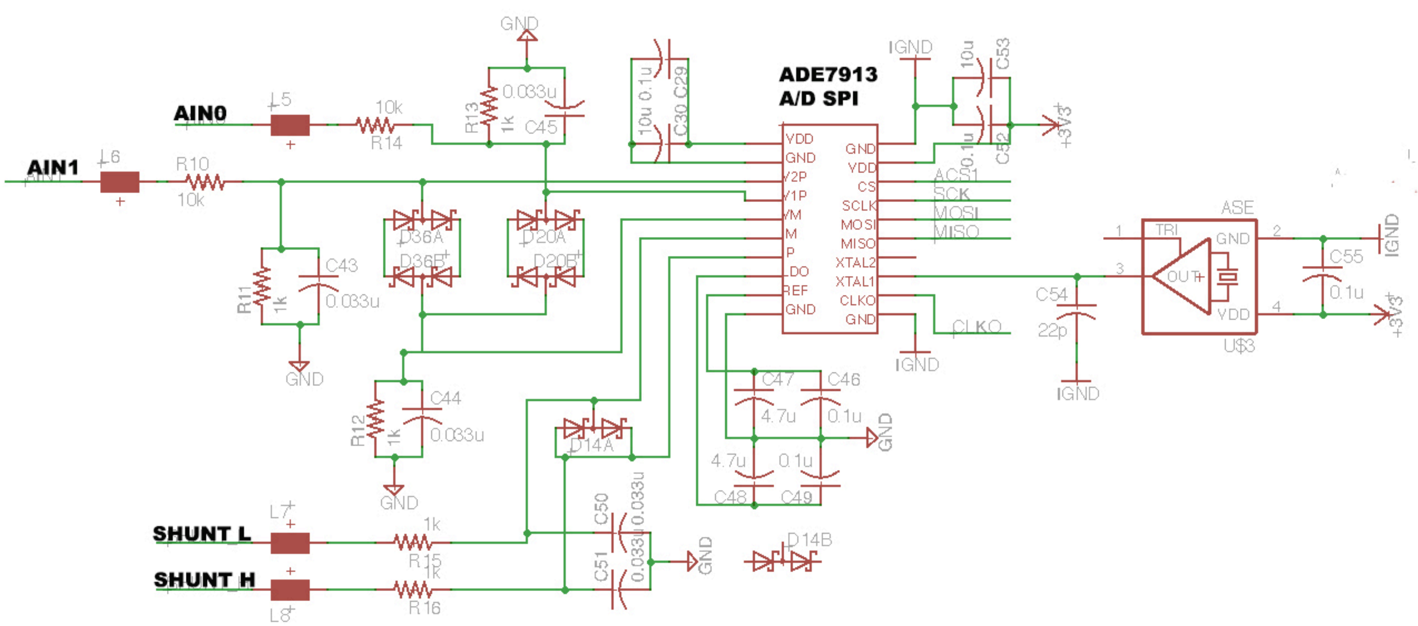
Since the central role of the GEVCU is to allow control of the power applied to the motor as directed by the throttle input, we have invested a serious amount of design in the analog inputs to the microprocessor.

The SAM3X microprocessor features 12 bit analog to digital conversion inputs. But these inputs are limited to the processor operating voltage of 3.3volts which poses a bit of a problem as almost all automotive sensors are 5v devices. This A/D input works by sampling the input to produce a digital numeric value between 0 and 4096 representing a voltage of 0 to 3.3v. In an ideal circuit this represents a precision of 0.8 millivolts per digit.

In order to protect the microprocessor from the harsh noisy environment of automotive wiring, we need to optically isolate the input – essentially removing any direct electrical connection.

In version 6.2, we have rather seriously upgraded the analog input capability of the GEVCU. We have replaced the previous circuit with a series of three Analog Devices 3-channel, isolated, Sigma Delta 24-bit analog to digital converters with Serial Peripheral Interface (SPI) communications.

These devices measure the input with very high 24-bit resolution, and then provide the results to the SAM3X microprocessor over the SPI serial channel. In this way, we rather isolate the microprocessor from the analog inputs.



The first ADC chip has a crystal oscillator input on XTAL1 allowing it to generate a clock for the SPI. This clock output is then provided to the other two ADC chips as well.

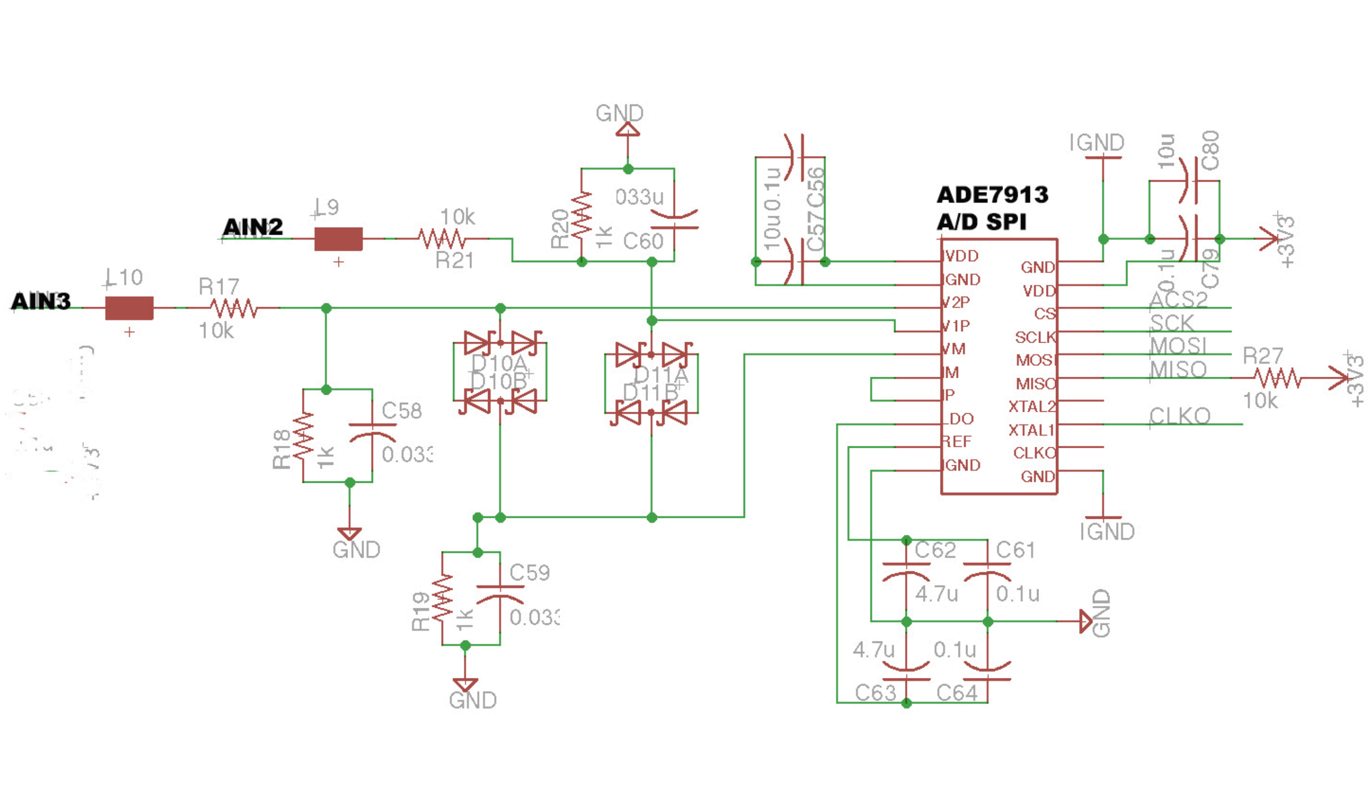
AIN0 and AIN1 are filtered by an inductor and some capacitors and proportioned by a voltage divider to less than a tenth of their input value. The ADE7913 has a maximum voltage input of about 500mv. So about 5v is the maximum input. Some fast Schotkey Diodes safety that at about 820 mv or about an 8 volt input.

These inputs can range both positive and negative and The range of signed integers that can be represented in 24 bits is −8,388,608 to 8,388,607. And so it is theoretically capable of about +/- 8 volts to the microvolt level. As a practical matter, we don't quite achieve that as the noise on a typical wire connecting to the GEVCU would be much greater than a microvolt.

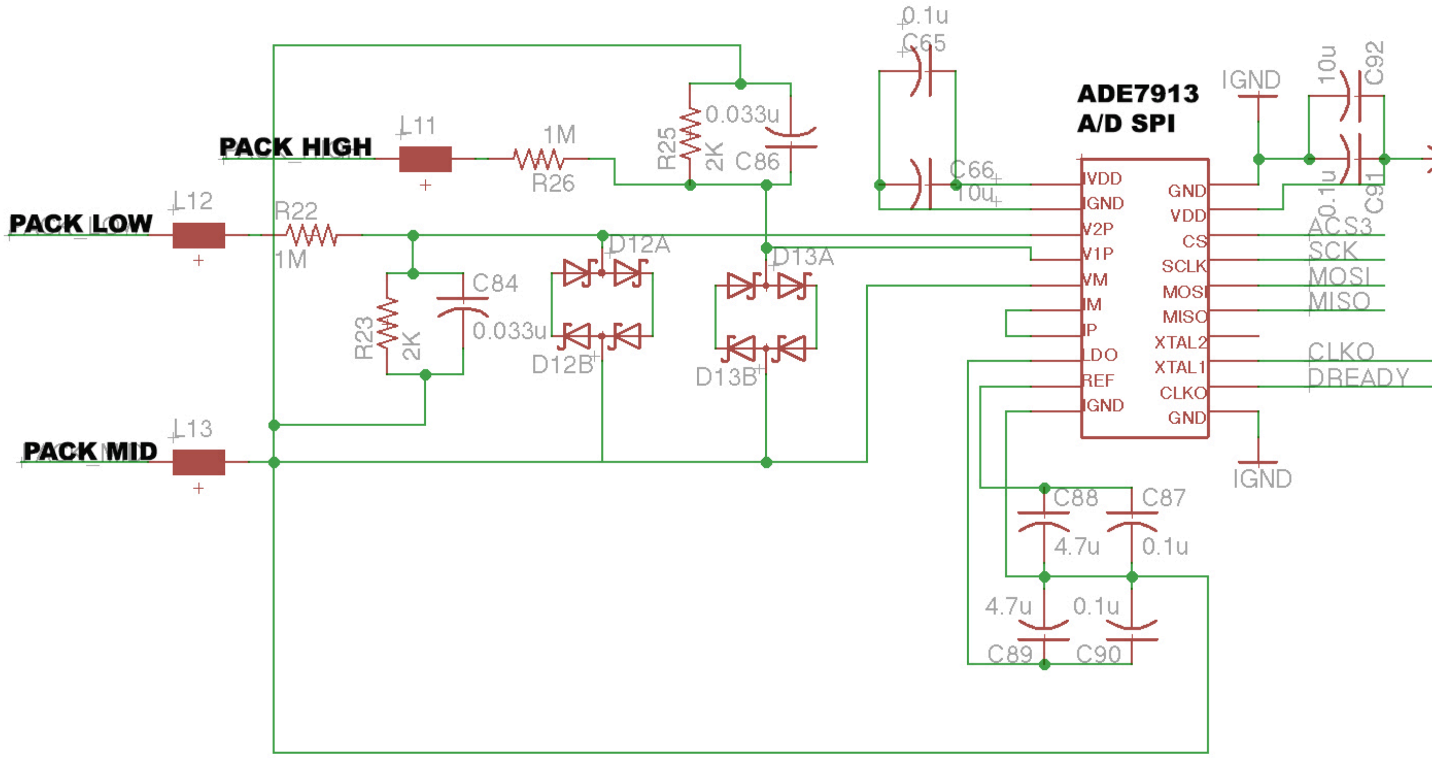
The results are requested by the microprocessor from the ADC chip over the 4MHz SPI bus. This is quite fast.

SHUNT LOW and SHUNT HIGH allow us to connect two wires across the very small resistance of a current shunt – a device typically providing +/- 50mv with the full 50mv representing some current value – we often use shunts with of 400v at 50mv. This is a very low value of resistance −0.050 volts/400A would be a resistance of 0.000125 ohms for example.

The particular pins of the ADE7913 were designed for this and actually are capable of about +/- 31mv. So again we even have to scale this 50mv input. But again, the 24-bit signed range of −8,388,608 to 8,388,607 to represent +/- 50 mv scaled to +/-31mv is pretty good. It can accurately measure values of less than an ampere on a 400A 50 mv shunt.



ADC 2 provides a similar function for the AIN2 and AIN3 inputs. In fact it is essentially identical to the ADC 1 circuit but without a shunt input.



ADC 3 is a bit different. The ADE7913 actually has its own internal isolated power supply operating from the normal VDD input. In the other two chips we have tied the resulting ground reference to frame ground. Here we leave it isolated and for a reason. This chip is used to read 3 inputs from our high voltage pack. You would typically connect PACK LOW to the negative terminal of your high voltage pack, and PAKC HIGH to the high voltage terminal. PACK MID could be connected to the middle of the pack dividing it precisely in two, but it isn't necessarily. You can connect it to any intermediate point in the series pack.

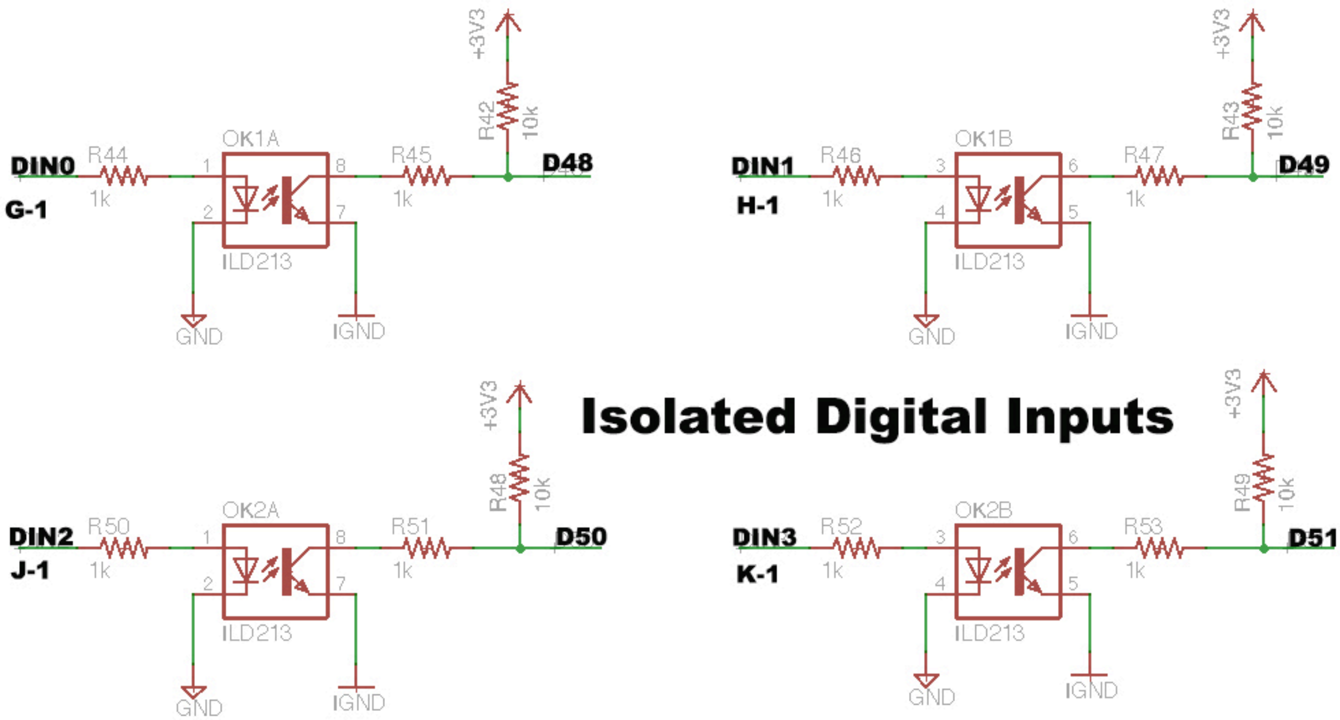
The results are presented as two voltages which can be compared in software in various ways. And the purpose of the floating and isolated ground is to prevent frame leaks – a connection from our high voltage pack to frame ground – a potentially dangerous situation.

The GEVCU also provides a series of 5v and GND connections at the Modice CINCH connector. These can be used to power and reference the external brake and throttle sensors.

In this way, the GEVCU can monitor four analog signals and convert them to digital values, but the microprocessor is entirely optically isolated from external components and appropriate noise suppression is provided at the same time. This should provide stable and safe analog input readings.

So far, by convention we have used inputs AIN0 and AIN1 for throttle, input AIN2 for brake and input AIN3 is available.

11 Digital Inputs



The GEVCU provides four optically isolated digital inputs. By digital, in this case we are not referring to TTL level inputs but rather switched 12v inputs that can be read and acted on.

A 1kohm current limiting resistor allows about 12ma on the input to an ILD213 opto-isolator chip. This lights an LED which puts a phototransistor into conduction.

The output uses a 10k pullup resistor to the isolated 3.3v supply of the SAM3X microprocessor to present a TTL high on the microprocessor input pin which is driven low by the input signal which switches the transistor into the on state. A 1k current limiting resistor on the output causes about 0.3v on the microprocessor input which is read as a low. From the perspective then of the GEVCU software, these inputs are active low – essentially inverting the 12v on 0v off input.

GEVCU DIGITAL INPUT	CINCH30 PIN	ARDUINO INPUT
DIN0	G-1	D48
DIN1	H-1	D49
DIN2	J-1	D50
DIN3	K-1	D51

The table above shows the GEVCU digital inputs, associated Modice CINCH 30 pin number and the Arduino Due digital input equivalent. When specifying digital inputs on serial port configuration items, simply enter the DIN number 0, 1, 2, or 3.

FEATURE EXAMPLES

ENABLE SIGNAL

Normally, when 12v power is applied to the GEVCU, it goes through an initialization and precharge procedure and when this is completed it is up and ready to drive the inverter and motor.

We can revise this operation to allow GEVCU operation on power up, but keep the motor/inverter disabled until we actually "turn it on" with a 12v enable signal.

This is done via serial port with the **PINENABLE** command.

PINENABLE=2 will set digital input DIN2 as the ENABLE input. When 12v is present on CINCH pin J-1, the motor inverter will be enabled and when 12v is removed at any time, it will be DISABLED.

This enable function is ONLY active if **PINENABLE** has a value of **0, 1, 2**, or **3**. If you do not need this feature, set **PINENABLE=255**.

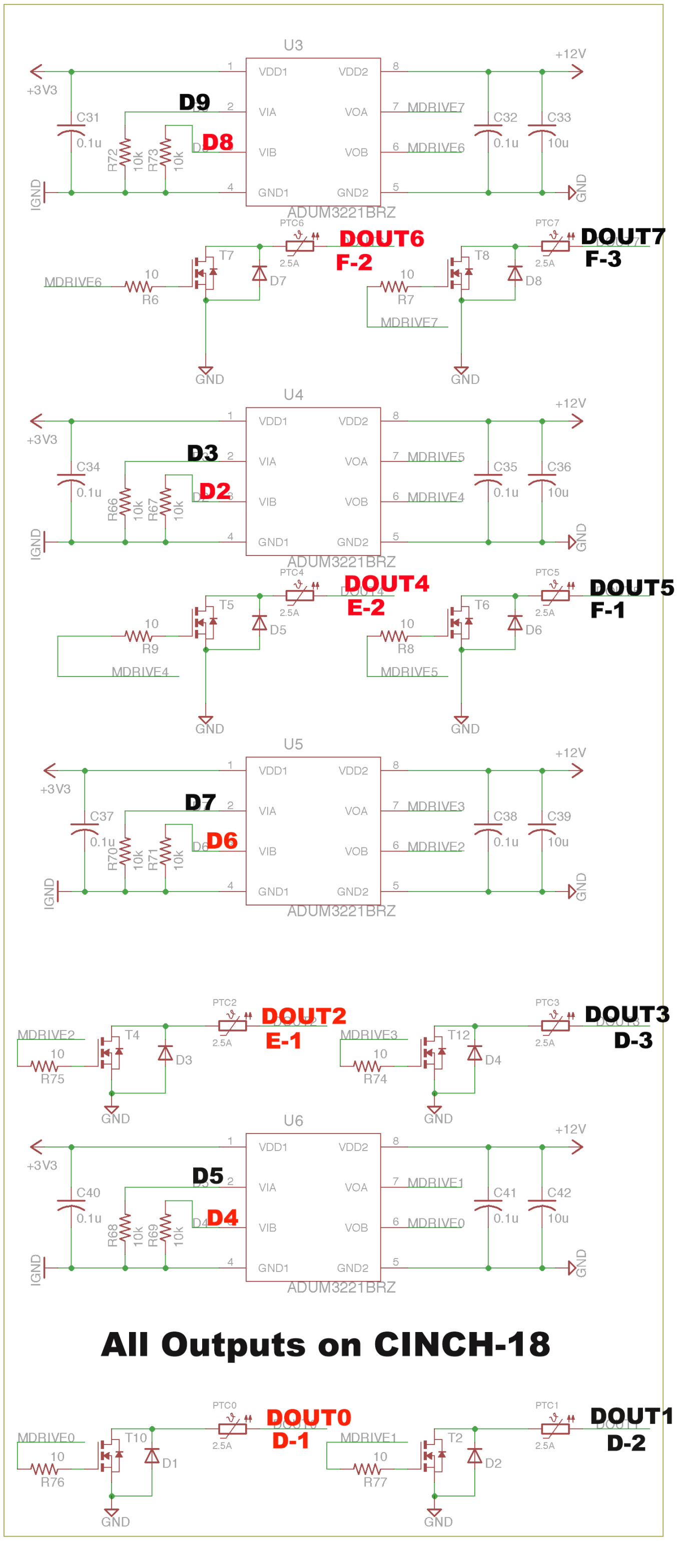
REVERSE INPUT

The default mode of the GEVCU is to turn the motor in the forward direction only. But we can use one of our digital inputs to allow both forward AND reverse operation of the motor by setting a **PINREVERSE** input.

PINREVERSE=2 will set digital input DIN2 as the reverse input. When 12v is applied to CINCH pin J-1 then, the drive signals to the motor will cause the shaft to spin in the REVERSE direction. When the 12v is removed, it will revert to FORWARD operation.

This reverse function is only active if **PINREVERSE** is set to **0, 1, 2,** or **3**. To disable the reverse function, set **PINREVERSE=255.**

12 Digital and Analog Outputs



MOSFET OUTPUTS

GEVCU provides 8 digital outputs any of which can also be used as Pulse Width Modulated (PWM) outputs to simulate an analog output.

The basic SAM3X microprocessor features many digital outputs which can each source up to 50 ma of current with a maximum of all outputs being further limited. This is inadequate power to drive even small relays or devices found in the automotive environment.

Additionally noise and inductive voltage spikes found on such automotive outputs are essentially instant death to the low voltage (3.3v) SAM3X microprocessor.

GEVCU takes the bare digital outputs from the microprocessor and buffers and isolates them using four Analog Devices Isolated Dual Channel Gate Drivers (ADuM3221). These gate drivers provide full isolation and outputs up to 4 amperes to drive MOSFETs or IGBTs.

The outputs of these gate drivers are used to switch Infineon Technologies BSP295 N-channel MOSFET small signal transistors. These MOSFETs feature a very low forward resistance when ON (0.3 ohms) and can carry up to 1.7 amperes of current continuously with some 7 amperes pulse at voltages up to 50v. This is sufficient power to drive most relays and indeed the contactors we often use to switch high voltage high currents in electric vehicles.

The output is basically an active low. With a digital 1 or high on the output, the MOSFET is switched into conduction effectively connecting the output pin to vehicle ground. You would normally use an external pull-up resistor connected to 12v somewhere external to the GEVCU to power the output.

GEVCU DIGITAL OUTPUT	CINCH-18 PIN	ARDUINO PIN
DOUT0	D-1	D4
DOUT1	D-2	D5
DOUT2	E-1	D6
DOUT3	D-3	D7
DOUT4	E-2	D2
DOUT5	F-1	D3
DOUT6	F-2	D8
DOUT7	F-3	D9

The table above lists GEVCU digital outputs 0 through 7, the associated CINCH-18 pin, and the Arduino software logical pin corresponding.

It is worth noting that in addition to activating relays, lighting LEDs or lamp bulb indicators, with appropriate software any or all of these outputs can also be pulse width modulated.

The SAM3X has the ability to convert a 12-bit digital value between 0 and 4096 into a PWM output on these pins using the AnalogWrite function. The pulse width of the square wave output would be a function of the output specified, with 0 indicating off and 4096 being constantly on. A value of 410, for example, would normally give a 10% duty cycle and on a 12v output that would be about 1.2v.

But do be aware that the active low configuration of the MOSFETS kind of inverts the PWM function. On is off, and off is ON so that the PWM actually varies in reverse with 4096 being off or GROUND all the time at the MOSFET and 0 being ON or 12v all the time. In this case, 4096-410=3686 for a 10% 1.2v analog output.

In this way, a simulation of an analog signal between zero and 12v can be produced on any of these outputs to drive legacy vintage temperature gages or fuel gages for example. As the frequency of this PWM signal can also be programmatically altered from the default 1000 Hz square wave, the analog simulation can be made to be really quite effective.

NOTE

The GEVCU 5 series and earlier has a design flaw effecting digital outputs. When power is first applied to the GEVCU, the digital output MOSFETs may cycle ON for slightly over 80 milliseconds. Operation is normal thereafter.

This generally precludes GEVCU outputs from being used for pre-charge duties or any application where a brief ON output on powerup poses a problem.

This has been fixed in GEVCU Version 6.2 by connecting the digital outputs to pull down resistors.

13 COOLING CONTROL – A DIGITAL OUTPUT EXAMPLE

One of the immediate needs for the DMOC645 and Siemens motor is for liquid cooling. If these devices exceed certain temperatures, the DMOC645 will limit the output current in an attempt to hold the temperature within operational limits. This is one of those very quiet "gotchas". With inadequate cooling, your EV will operate JUST FINE. But you will be completely unimpressed with the power and acceleration of the Siemens Motor and DMOC645 controller.

With adequate cooling, this pair will put out nearly 300 nm of torque, which for anything under 3000 lbs with a transmission will feel VERY responsive. And so if you find yourself disappointed in the performance of this pair, your first examination should be to make sure you have adequate cooling for the system. In general, people grossly underestimate how much heat these devices give off and how much cooling is required.

On the VW Thing, we run the inverter and the motor on separate cooling loops using a Piersburg pump which does about 17 liters per minute through the AN-6 braided nylon hoses. Well and good enough. But the trick is you have to REMOVE the heat from the system. We use TWO Denali heat exchangers with quite powerful fans on them to do this.

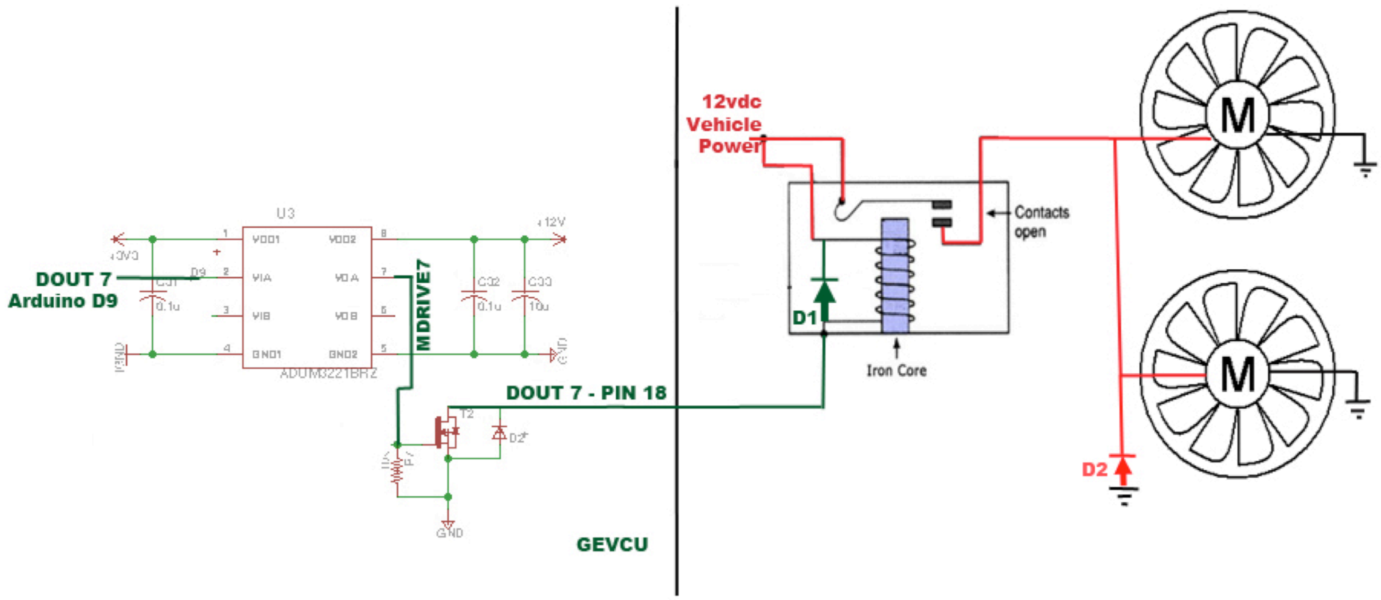
Of course, the fans not only use quite a bit of 12v energy, but they also are uncomfortably noisy. This is not so much a factor on the highway, but tooling around town it's a little loud.

Oddly, tooling around town we do not NEED much cooling. The circulating pump and the heat exchangers operating without the fans works just fine. But if we DO go out on the highway and operate the motor and controller for more than 10 or 12 minutes, we will go into current limit. With the fans, adequate cooling is provided and we do not.

Similarly, July temperatures of 100F ambient don't help our cause. But January's 15F temperatures render cooling needs almost moot.

And so we have built in a cooling control function that gets Inverter temperature from the DMOC645 via CAN message, and compares it to set limits. If the temperature goes higher than the COOLON temperature we designate, we set DOUT7 to on to activate our fans.

If the temperature should later fall below the value we set as COOLOFF, the digital output is turned off, and so the fans are taken offline. In this way, we can use the fans on the Derali heat exchangers only when they are needed. This saves energy, and allows us a very quiet car when maneuvering at low speeds, while providing maximum cooling on the freeway.



The diagram above shows the external connections to the GEVCU. When DOUT7 is set to ON, it causes the MOSFET driver to send a drive signal to the output MOSFET switching it into conduction. This is connected to pin F-3 on the CINCH 18-pin connector which is routed to the ground side of the fan relay. 12vdc from the vehicle is connected to the other end of the coil AND to the common terminal.

When the MOSFET is turned on, this completes the path for the 12v through the coil, energizing the relay. This applies 12vdc to the two heat exchanger fans through the relay.

Note the use of diodes D1, across the relay coil, and D2, from the fans to ground. These are coil suppression diodes. When we turn cooling off, the coil in the relay will seek to continue the current flow. This can cause spurious voltage spikes that can rise to hundreds of volts and could even damage the MOSFET output circuit in the GEVCU. Diode D1 provides a path for current flow from the inductance of the coil and this energy is dispersed harmlessly.

The fans are of course driven by electric motors, but the fan blades themselves have inertia. Not only do the primary windings of the fans have high levels of inductance, but the kinetic energy in the fan blades will keep them turning briefly after the relay opens removing power. In this sense, they act like generators and again voltage spikes are the norm. Diode D2 provides a current path for those, shunting them harmlessly to ground.

There are three configuration variables in GEVCU that control cooling output, **COOLFAN**, **COOLON**, and **COOLOFF**. These can be set using the serial terminal.

COOLFAN=7 This sets the specific digital output to use for cooling (0-7).

Cooling fan output updated to: 7

COOLON=45 This sets the temperature at which the output goes active.

Cooling fan ON temperature updated to:45

COOLOFF=35 This sets the usually lower temp at which the output becomes inactive..

Cooling fan OFF temperature updated to: 35

You can avoid the fans cycling quickly off and on by setting **COOLOFF** somewhat lower than **COOLON**. In this way, the fans will come on and stay on for a while until the coolant temperature really comes down. It will then go off and remain off until the temperature again rises to the **COOLON** temp.

15 CANBUS COMMUNICATIONS AND OBDII

A central concept of the Generalized Vehicle Control Unit is that it interfaces with other automotive devices using the Controller Area Network or CAN protocol. CAN was originally proposed by Bosche in 1987 specifically for automotive applications.

More specifically, GEVCU is designed to control three-phase AC inverters – power switching electronics designed to drive AC induction and brushless DC motors – essentially all modern motors used in OEM electric car design. These "inverters", including those from Toyota, Nissan, General Motors, UQM, Rinehart Motion Systems, Tritium, Tesla, and many others all use sensor management devices to gather driver inputs, and communicate that information to the "inverters" via CAN bus in the form of torque or speed commands to drive the motor.

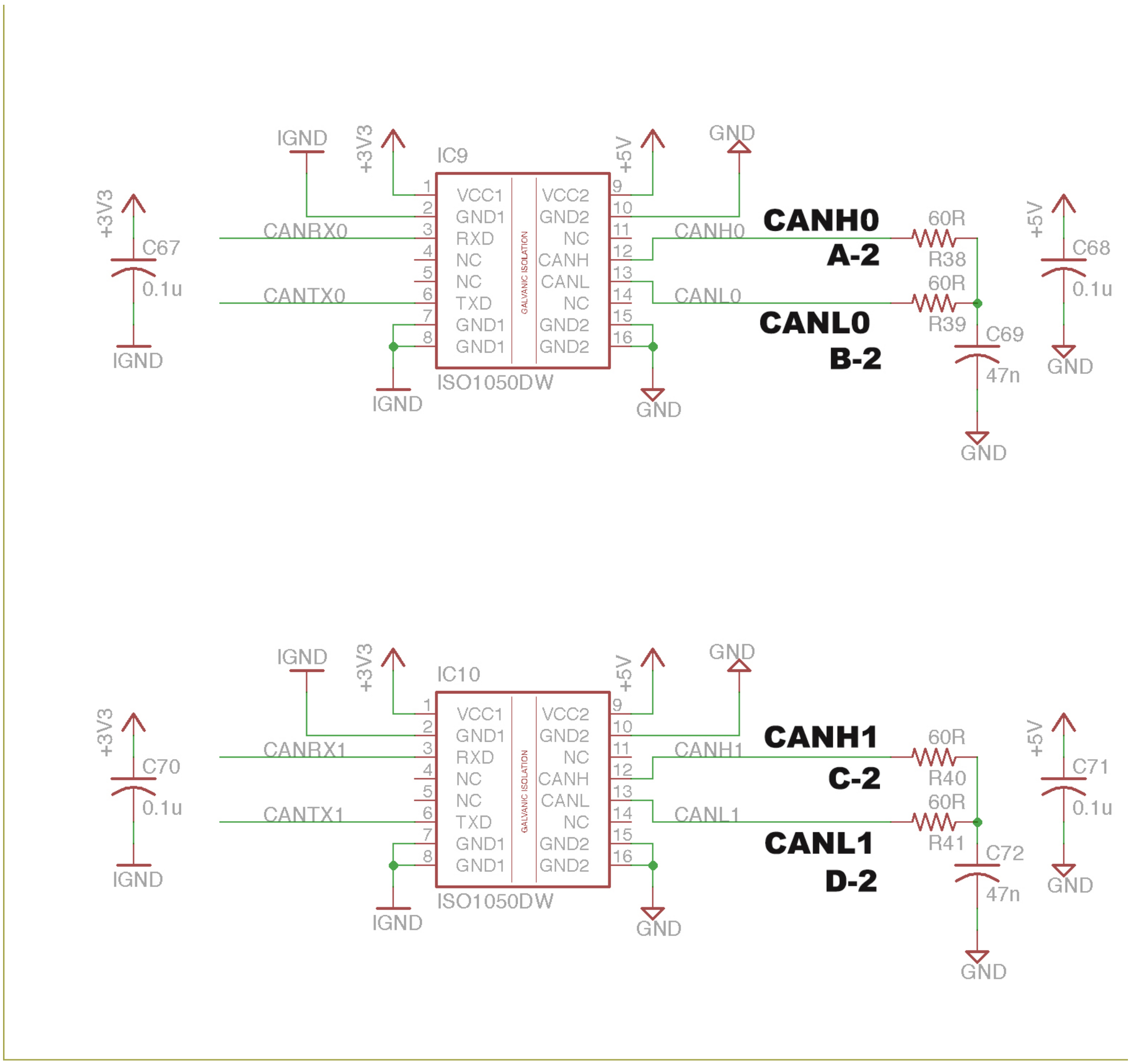
The Atmel SAM3X8E ARM Cortex-M3 CPU used in the GEVCU actually has TWO independent CAN bus controllers built IN to the chip itself. But these controllers represent HALF of the necessary hardware to perform CAN communications. They also need CAN TRANSCEIVERS – devices that actually create the transmitted pulses on the bus.

GEVCU uses two Texas Instruments ISO1050 galvanically isolated CAN transceivers that meet the specifications of the ISO11898-2 standard. The device has the logic input and output buffers separated by a silicon oxide ($SiO2$) insulation barrier that provides galvanic isolation of up to 5000 VRMS for ISO1050DW and 2500 VRMS for ISO1050DUB.

Used in conjunction with isolated power supplies, the device prevents noise currents on a data bus or other circuits from entering the local ground and interfering with or damaging sensitive circuitry.

As a CAN transceiver, the device provides differential transmit capability to the bus and differential receive capability to the Atmel CAN controller at signaling rates up to 1 megabit per second (Mbps). Designed for operation in especially harsh environments, the device features cross-wire, overvoltage and loss of ground protection from –27 V to 40 V and over-temperature shut-down, as well as –12 V to 12 V common-mode range.

We refer to the two CAN buses as **CAN0** and **CAN1**. **CAN0** has a differential transceiver output available on pins A-2(CAN 0 high) and B-2 (CAN0 lo) of the CINCH-30 pin connector. **CAN1** similarly appears as CAN1 high on pin C-2 and CAN1 lo on pin D-2 of the CINCH-30 connector.



CANBUS

For GEVCU end users, there is nothing you need to know about CAN. The wiring harness provided with the GEVCU already connects the GEVCU to the DMOC645 CAN bus, handles all terminating resistor issues, and has been tested repeatedly to drive the DMOC645 and Siemens motor combination. There is really nothing to configure here.

But a bit of detail is provided here to illustrate the future growth and possibilities inherent in the GEVCU device.

The details of the CAN transmission are basically handled first at the transceiver level, and then at the CAN controller. But to effectively use all the mask and filter capabilities provided by these chips, and make CAN communications easier to program, a special software library is required to do CAN. This is the **due_can** library available at https://github.com/collin80/due_can. This allows fairly simple C++ commands to manage CAN communications quite effectively.

The ability to manage two CAN channels separately provides enormous flexibility. Of course, it could conceivably operate two separate inverters this way, each driving a different motor for example.

More commonly, it would be used as a CAN bridge, porting data from one CANbus to another. It is not uncommon to have CAN buses operating in the same vehicle at different speeds, one at 250 kbps and one at 500 kbps for example. Using GEVCU, it is relatively trivial to port data from one to the other.

The basic and immediate design of GEVCU is to command the Azure Dynamics DMOC645 controller directly via CAN. This is a 250kbps CAN bus that is simply two wires between GEVCU and the DMOC645.

The second bus would more likely be connected to the vehicles' **Onboard Diagnostics Version II** or **OBDII** bus. This has been required in virtually all vehicles worldwide since the late 1990s. Originally using a variety of manufacturer specific protocols, it has evolved in recent years ever more towards simply a J1939 standard CAN bus.

At the very basic level, the CAN protocol most often uses a 29 bit address and up to eight bytes of data. ANY device on the bus can transmit these packets and ALL devices on the bus can receive them. In broadest terms, the 29 bit address identifies WHICH device is sending the data, and often the specific nature or type of data it is sending. The eight data bytes then contain the data.

Using filters and masks, any specific device on the bus might set up to basically "look for" packets from another specific device, with specific data in it. It would ignore all other signals on the bus. And the software in the device would intelligently recognize not only the packet, and the eight databytes, but specifically the format and significance of every bit of the eight byte data payload.

Collision detection and priority are rather cunningly handled in the address itself.

And so we wind up with a bus, that might have two, but also might have two hundred devices, all more or less blindly sending packets and receiving packets. But by selectively filtering packets at the chip level, the receiving devices only get data they are interested in and know how to act on. The air conditioning controls on the dash have no use for inverter information generally speaking. The gear selector doesn't need any information at all, it simply transmits lever position periodically. The variable steering device only looks for RPM from the inverter. And so it goes.

Sending devices are more less simply "announcing" data that might be of interest to others by forming the data in agreed format, and sending it with the right identifying address – more or less one assigned to that device. Note the address is NOT who it is sending it to. It's just a message identifier showing the source device and nature of the message.

So GEVCU is completely capable of announcing drive commands from the address and in the format that is expected by the DMOC645. And it can also receive packets from the DMOC645 that contain data on inverter temperature, motor temperature, motor current, motor voltage, pack voltage, pack current, and much more.

Normally, GEVCU would get accelerator position from a hall effect pedal as an analog input. But it is not only completely possible, but has already been done, to connect the second bus to an OBDII bus and “capture” pedal position from the CAN bus signals transmitted by a CAN capable accelerator/throttle assembly. That data is then used to form drive commands going out the first CAN bus to the DMOC645.

It would be entirely feasible to program the GEVCU, using the PWM output of one of its digital outputs, to drive a vintage gas gage in a 1957 Porsche. But it is JUST as feasible with GEVCU, to put the proper address and data format together on the OBDII bus to drive the gas gage in the instrument cluster of a 2014 Porsche.

This opens up enormous flexibility. For example, there are a number of devices on the market for trivial amounts of money ($20-40) that plug into the OBDII connector under the steering wheel of a modern car that transmit data from the CAN bus over either 802.11b/g Wifi or Bluetooth wireless. And there are already multiple versions of programs for the Apple iPhone, iPad, and Android tablets as well to capture CAN data from the vehicle and display that data on attractive and highly customizable gage displays. In this way, an Apple iPad could rather easily serve as a graphic display for your electric car, displaying kWh, amperes, battery state of charge, motor rpm and current, inverter temperature, and much much more.

The implications for CAN are actually hard to get your head around. For example, conventional thinking would indicate that GEVCU is quite limited with only 4 analog inputs and 4 digital inputs, and 8 outputs. Those accustomed to Arduino having over 50 inputs and outputs would find this very limiting.

In automotive applications, an evolution has occurred that is quite fascinating and perfectly logical. Look at the wiring harness that comes with the GEVCU. It is already sufficiently complex and enormous that we have individually colored each wire AND inscribed the logical label of the wire along the wire length – encased it in nylon braid, and it is STILL quite a thing to deal with in a car. It causes a lot of wiring.

The CAN philosophy is to reduce all that to two wires. If you need more than 4 analog inputs an 4 digital inputs and 8 digital outputs, you basically need ANOTHER CAN device closer to its logical purpose.

And so you would not incorporate measurement of battery voltage and temperature and current and state of charge in GEVCU. You would more likely devote an ENTIRELY SEPARATE device, located right AT the battery, and connect it to GEVCU with precisely TWO wires, the CAN bus wires. And so basically you have two wires running through the car, connecting dozens of highly specialized devices whose only wiring is very very short and very very local to just what it is doing.

Actually you COULD use two GEVCUs. One with the GEVCU software in it, and the other with battery monitoring software in it. The CAN bus is how they would communicate.

How far can this be taken? To the extreme. On modern cars, if you look at the 4 window controls on the drivers door, you will find it is a CAN device all by itself, and it communicates with three others – the window controls in the other three doors. The Chevy Volt actually has a total of **104**

microcontrollers in the vehicle, each with its own built in software and function. But they can all communicate with each other. The future of automotive technology looks like, sounds like you could check to see if any of your car windows were down, from your pocket phone, while in a building 112 miles away. Better yet, you could roll them up.

And so the real power of GEVCU, beyond giving us access to existing inverters and motors, is the two CAN bus channels. And added functionality is not so much a function of hanging more wires on GEVCU, but on intelligently designing and placing devices in the car to talk over the CAN bus. Fortunately, beyond perhaps a battery monitoring system, modern cars already have CAN for throttles, windows, door locks, radios, gas gauges, air conditioning, auxiliary fans, window washers, temperature sensors, and all of this is increasing at a logarithmic pace. If we can determine the address and commands, the open source nature of the GEVCU software will allow us to command it. Bosche actually invented CAN to REDUCE the weight and cost of copper in the wiring in an automobile. That was the original purpose of CAN. And it works.

Back to earth a bit, the GEVCU was born to drive the Azure Dynamics DMOC645 inverter and paired Siemens motor. But from the first instant of conception, we envisioned a very modular object oriented design leveraging the power of the C++ object-oriented language.

As such, a class **motorController**, is available. An object, inheriting from that class, is the **dmocMotorController**. It is actually a very small bit of program that intelligently takes concepts such as forward torque and regenerative torque, voltage, current, and temperature, and keys that to the SPECIFIC CAN messages and addresses EXPECTED by the DMOC645 already. And it intelligently knows how to recognize messages from the DMOC645, by address, and how to decode them to get actual torque, actual rpm, inverter temperature, battery pack voltage, etc.

To customize GEVCU to work with an inverter from UQM or Rinehart or Nissan Leaf, if you have the documentation defining the addresses and data formats used for those devices, it is a very doable if non-trivial programming task to add an object, much like **dmocMotorController**, to the **motorController** class. Ideally it's a single file. Call it **uqmMotorController**. The SPECIFICS for any controller are confined to really a tiny part of the GEVCU software. You don't need to know very much about how the rest of the program works, or why, to do this.

In the case of a UQM or Rinehart, these CAN data digests are actually published documents. In the case of the Nissan Leaf, it might be a little more difficult requiring some reverse engineering – basically driving a LEAF and sniffing out CAN codes on the CAN bus to the inverter. That's how we did it for the Azure Dynamics DMOC645. Actually that's how we did it for the UQM Powerphase 100 as well.

But in this way, we hope to open the door to cogently reusing the cornucopia of excellent components deriving from the salvage of many many cars developed by the OEM manufacturers. Electric motors and controllers can conceivably operate for DECADES of use. But one tree planted in just the right place 30 years ago can take out a Nissan Leaf in a split second. The Tesla Model S is such a delight to drive, and will indeed do 0-60 in a little over 4 seconds. In fact it will do 0-45 and 45 BACK to zero in LESS than 4 seconds if it hits the right tree. And the Model S owners are out there desperately trying to prove us right on this theory.

And so we see a future land strewn ocean to ocean with glittering motors and inverters and battery packs that are virtually brand new, lacking only a car – and a device to talk to them nicely in a language they understand – GEVCU CAN.

16 CANBUS INPUT/OUTPUT CONTROL

As described earlier in this manual, GEVCU features 4 analog inputs, 4 digital inputs, and 8 digital outputs. Version 5.22 of the software provides for some CAN access to these inputs and outputs.

This can be very useful. Another CAN device on the bus might have access to information or sensor data not available on GEVCU, but be limited in input and output capability. Via CAN message, it could manipulate GEVCU inputs and outputs.

For example, we recently came across a very nice switch panel made by DNA termed the Powerkey Pro 2400. It features 8 configurable switches with LED backlights. The switch position is transmitted via CAN and the LED light state can be controlled by CAN.

Similarly, another device may want to know what the state of GEVCU digital input 3 is at any particular time. It can easily retrieve this information from the GEVCU.

CAUTION

This ability does engender some danger of conflict. If you use digital output 4 to close your contactor, and then use CAN to set output 4 to zero, it is hard to predict whether internal algorithms or the CAN command will win and for how long. So make sure to coordinate any use of input and output with your assignments of digital inputs and outputs in the normal GEVCU configurations.

GEVCU is configured to use four CAN bus message IDs to deal with inputs and outputs.

0x606 Received by GEVCU to set digital outputs 0 through 7
0x607 Transmitted by GEVCU to advise state of digital outputs 0 through 7.
0x608 Transmitted by GEVCU to advise state of analog inputs 0 through 3.
0x609 Transmitted by GEVCU to advise state of digital inputs 0 through 3.

GEVCU normally does NOT transmit **0x607** or **0x608**. It will ONLY produce these advisories if it receives a **0x606** message.

You may quite commonly wish to retrieve data on the state of GEVCU I/O without actually commanding a switch. You can easily do this by transmitting a **0x606** with all eight data bytes set to zero.

NOTE

The message IDS used by GEVCU for CAN I/O management are arbitrary. It will come with these set to these addresses. But this information is configurable. The file config.h contains defines for CAN_SWITCH, CAN_OUTPUTS, and CAN_INPUTS. You can change these values in the source code to whatever you like. But you must recompile and reupload the software for these changes to take effect.

GEVCU normally has two CAN busses configured and they maybe configured at different speeds. Understand that CAN IO commands can be sent and received on EITHER bus at any time. No configuration of this is required. Advisory responses will appear on the SAME bus the command came in on.

SETTING GEVCU DIGITAL OUTPUTS

Setting GEVCU digital outputs is limited to simply setting them to 1 (high) or 0 (low). No PWM capabilities are provided via CAN.

The message should in all cases be 8 bytes long with byte zero corresponding to GEVCU digital output 0 and byte 7 corresponding to GEVCU digital output 7.

There are three recognized commands for EACH digital output.

0x00	Make no changes. Do not disturb this output
0x88	Set this output to 1 (HIGH) no matter what its current state is.
0xFF	Set this output to 0 (LOW) no matter what its current state is.

By way of example, consider the following message:

```
0x606  00  00  FF  00  00  88  88  00
```

On receipt of this message, GEVCU would set digital output 2 to 0 and digital outputs 5 and 6 to high (1). Note that it would not disturb outputs 0, 1, 3, 4, and 7 at all.

READING GEVCU DIGITAL OUTPUTS

On receiving a **0x606** command, GEVCU not only sets the digital outputs, but also produces two messages – **0x607** advising GEVCU digital outputs and **0x608**, advising GEVCU inputs.

Message ID 0x607 is basically a modified echo of 0x606 showing the state of each of the eight outputs.

0x606 88 88 FF FF FF 88 88 FF

In this example, outputs 0, 1, 5 and 6 are all set to zero (low) while outputs 2, 3, 4 and 7 are set to high.

You can use this to minimize traffic on the CAN bus. For example, you might send the following message:

0x606 00 00 00 00 00 88 00 00

You can send this message periodically until you receive a message 0x607 showing output 5 as set.

0x607 88 88 FF FF FF 88 88 FF

At this point, we see that output 5 is 88 indicating a set condition. We really don't need to transmit anymore. And if we don't transmit, GEVCU doesn't reply either.

You could also use byte 5 of this message to turn on the backlight LED behind the switch, or another LED indicator showing the state of this output.

Anytime you subsequently just want to check the state of the outputs, or inputs for that matter – simply send a **0x606** with no changes

0x606 00 00 00 00 00 00 00 00

This will cause an automatic transmission of all advisory response messages

READING GEVCU ANALOG INPUTS

Anytime GEVCU receives a **0x606** message, it will also output a CAN message **0x608** containing the measured values on the four analog inputs to the GEVCU. These are two byte integers with the high byte first and the low byte second (MSB/LSB). To convert this to a readable number, multiply the high byte by decimal 256 or hexadecimal FF and add the low byte to the total.

All GEVCU analog inputs are read in 12-bit mode and so will appear as a digital value between 0 and **0x0FAC** (4012 decimal).

0x608 0F 21 0A F0 10 E9 22 C7

In this example, Analog input 0 appears as the first two bytes 0 and 1 as **0x0F21** or **3873**.

Note that you can freely read these instantaneous values at any time, even if they are used for example for throttle input without interference. But these are raw instantaneous values – not the highly averaged and smoothed values used for actual throttle control.

READING GEVCU DIGITAL INPUTS

Anytime GEVCU receives a **0x606** message, it will also output a four-byte CAN message **0x609** containing the measured values on the four digital inputs to the GEVCU.

This will use the same FF/88 signaling as our other digital outputs.

`0x609 FF FF 88 FF`

Here we see that digital inputs 0, 1, and 3 are all zero but digital input 2 is active (high).

17 UPDATING GEVCU SOFTWARE

The adoption of the Arduino Due as the basis for GEVCU has been fortuitous. It provides plenty of memory and speed and we've found that some of the inverters need CAN packets as often as every 12 msec, which precludes slower processors.

The adoption of the Arduino Due within the Arduino community has been oddly spotty however. Part of this is the move to 3.3v architecture which obsoletes many of the existing Arduino shields. The software too is somewhat different. And so for whatever reason, the Due version has not swept the Arduino community by storm.

The ARM3 Cortex is also a new platform software wise for the Arduino developers

So you can of course download the Arduino Due Integrated Design Environment (IDE), install it on your personal computer, and then download the latest GEVCU software and compile and load it. The last known IDE version successfully used to compile GEVCU version 5.22 was Arduino 1.65.

But this may be beyond the ambition of many of the GEVCU users. And so we've developed a kind of shortcut method to update the software that many will find easier.

The Generalized Electric Vehicle Control Unit is an open source hardware and software device designed to empower builders and experiments in their efforts to build or convert one-off custom electric vehicles.

A version of the GEVCU hardware is produced and sold by Electric Vehicle Television.

The software of GEVCU is developed in and is fully compatible with the Arduino Due Integrated Design Environment (IDE). It uses a very C++ syntax with full object-oriented architecture.

The development of this software is ongoing and continuous with numerous contributors adding features, object modules and utility to the original software package.

EVTV maintains a github account with the latest source code for GEVCU that is certified to work with the GEVCU hardware that EVTV provides. This can be found at http://github.com/jrickard/GEVCU.

The MASTER version of the GEVCU software with a number of forks and variants is maintained by Collin Kidder at http://github.com/collin80/GEVCU.

Since the software changes on almost a continuous basis, you will from time to time desire to update the software held in flash memory on your GEVCU device.

For the programming savvy, this easily accomplished by downloading the desired version of GEVCU source code and compiling and uploading to the GEVCU device using the Arduino IDE.

But for many GEVCU users, C++ is a bridge too far and they want to be able to use the many features of GEVCU and indeed the latest version, without installing the Arduino IDE or doing any compiling.

For those, we have developed a very easy binary software update procedure that is very quick and basically involves a single click of the mouse to update a GEVCU connected to a personal computer via USB cable.

There are two versions of this software update package – one for Mac OSX and the other for Microso-oft Windoze.

APPLE MACINTOSH OSX VERSION 10.9 AND LATER

The following procedure applies to the Apple Macintosh MAC OSX operating system.

1. Copy the **GEVCUupdate.zip** file into your **Documents** directory. This Documents directory MUST be located in the first level below your user directory. This directory is normally created automatically by default in MAC OSX. If you don't have one, create it.
2. Click on **GEVCUupdate.zip** to unpack it into the **GEVCUupdate** directory.
3. Connect your GEVCU device to any available USB port on your Macintosh computer.
4. In FINDER, click on the **GEVCUupdate.command** file in the **/Documents/GEVCUupdate** directory.

This will spawn a small terminal window looking something like this:

```
MARIONs-Mac-Pro:~ mjrickard$
/Users/mjrickard/Documents/GEVCUupdate/GEVCUupdate.command ; exit;
/Users/mjrickard/Documents/GEVCUupdate
Device found on cu.usbmodem2021
Erase flash
Write 102880 bytes to flash
[==============================] 100% (402/402 pages)
Verify 102880 bytes of flash
[==============================] 100% (402/402 pages)
Verify successful
Set boot flash true
```

```
logout

[Process completed]
```

Basically this indicates that the **GEVCUupdate.command** script has used the included BOSSAC program to upload the new binary file **GEVCU.cpp.bin** to the GEVCU via the USB port.

5. Powercycle the GEVCU by disconnecting the USB cable and reconnecting it.

6. You can now use any terminal program to verify the software version by entering "**h**" and pressing return. It should print out a menu with the new software version listed at the top.

..Build number: 1051

Motor Controller Status: isRunning: 1 isFaulted: 0

System Menu:

Enable line endings of some sort (LF, CR, CRLF)

Short Commands:

h = help (displays this message)

L = show raw analog/digital input/output values (toggle)

K = set all outputs high

J = set all outputs low

E = dump system eeprom values

z = detect throttle min/max, num throttles and subtype

This indicates that the GEVCU is indeed operating and you should be able to note the Build Number has changed from the previous software version.

TROUBLESHOOTING

Occasionally, the updater seems unable to automatically locate a GEVCU connected by serial port. This usually produces the following output on the terminal screen.

```
Auto scan for device failed
Try specifying a serial port with the '-p' option
logout

[Process completed]
```

The first thing to try is to simply run it again.

If that doesn't work, note that the Arduino Due board usually features TWO USB ports. Notice that the GEVCU features a single USB port.

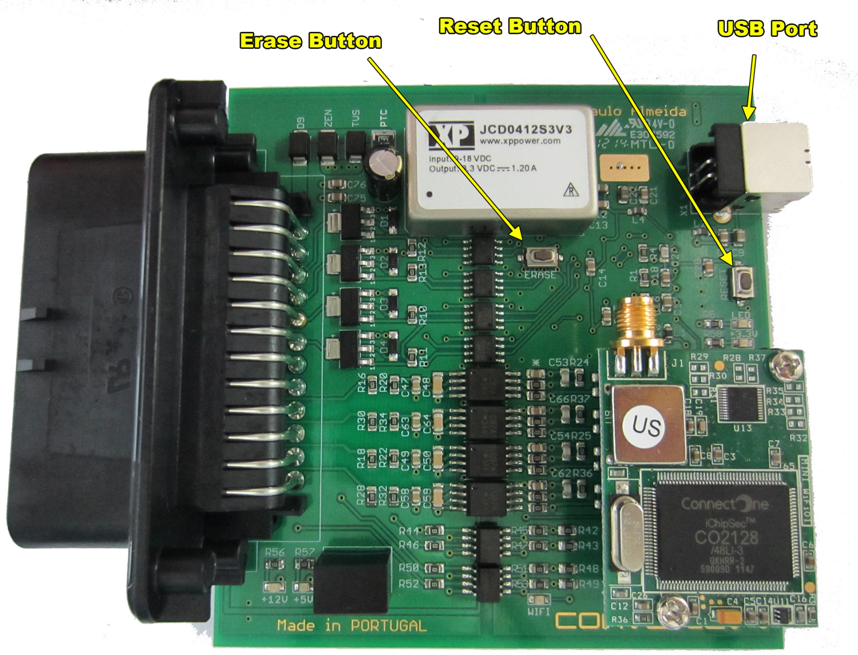
The SAM3 chip used by both Arduino and Due has a built in or "native" USB port actually in the multicontroller chip. We have used this port on GEVCU.

Arduino Due has a second USB port complete with a separate UART chip and reset circuitry usually referred to as the "programming" port.

By limiting GEVCU to a single USB port, we reduced the parts count and physical size of the device, and reduced the cost as well. But occasionally, it just seems to "get lost" in its duties as an access port.

Resolving this is actually fairly easy, but it will require you to open the enclosure.

1. Disconnect the USB port cable from the GEVCU rear panel.
2. Remove four screws securing the rear panel of GEVCU enclosure
3. Reconnect the USB port cable to the GEVCU.
4. Carefully reach inside the enclosure with your forefinger and press the ERASE button for three seconds.
5. Press and release the RESET button.



6. Power cycle GEVCU by removing the USB cable momentarily and then reconnecting it.
7. Again click on the **GEVCUupdate.command** file and expect to see success.

8. Once you see the proper response and can load the menu, reinstall the rear panel and secure with four screws.

MICROSOFT WINDOWS

(TBS)