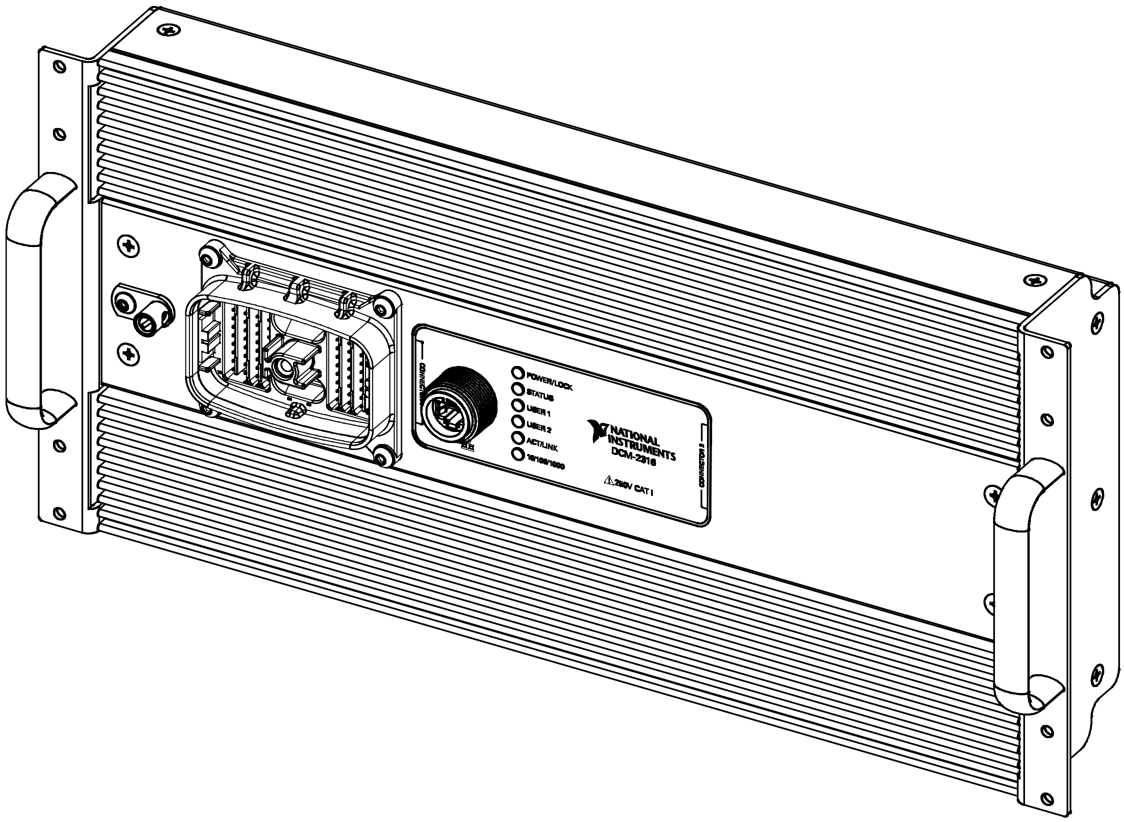
NI DCM User Guide

Embedded automotive drive electronics platform with Real-Time Processor and Reconfigurable FPGA



Safety Guidelines

⚠ **High Voltage** The DCM normally operates at voltages up to 220 V. Take care to protect against shock. Even when the DCM is completely powered off, allow approximately 130 seconds for the internal high voltage to dissipate. Do not touch any of the connector pins or injector terminals while the DCM is powered on.

⚠ **Caution** Do not operate the DCM in a manner not specified in this document. Product misuse can result in a hazard. You can compromise the safety protection built into the product if the product is damaged in any way. If the product is damaged, return it to NI for repair.

⚠ **Caution** Do not disconnect the power supply wires and connectors from the controller unless power has been switched off.

Revision History

Date	Version	Changes
October 24, 2016	1.0.0	Creation

Contents

Introduction

About This Manual

This document provides a detailed guide for using the National Instruments (NI) Powertrain Controls Embedded Direct Injector Control and Measurement (DCM) Device with Real-Time Processor and Reconfigurable FPGA.

Some important topics covered by this manual are:

- DCM hardware and software deployment options
- Connecting power, actuators and sensors to the DCM
- Understanding the various direct-injector and pump actuator modes of operation
- Configuring current and voltage profiles for various injector types
- Using the general purpose half-H-bridge drivers, analog inputs and digital IO
- Using the communications ports
- Using DCM software utilities
- Using DCM accessories

For a complete guide to setting up DCM for the first time, refer to the *Getting Started with NI DCM* document. For a complete list of technical specifications and certifications, refer to the device-specific specifications document. See the Related Documentation section below for information on where to find these documents.

Nomenclature and Conventions

ADC	Analog to Digital Converter
AI	Analog Input
AO	Analog Output
DAC	Digital to Analog Converter
CAS	Combustion Analysis System software
DI	Direct Injector
Diff-IO	Differential digital Input / Output
DCM	Direct-injector Control and Measurement device
DRVP	DRiVer Power
DSI	Default Software Image
ECS	Engine Control Software

HH	General purpose Half-H-bridge
FPGA	Field Programmable Gate Array
MAX	NI Measurement & Automation Explorer
NI	National Instruments
PCG	Powertrain Controls Group
PFI	Port Fuel Injector
RIO	Reconfigurable Input / Output
SCM	Software Calibration Management toolkit
SoC	System on Chip
SOM	System On Module
VI	Virtual Instrument

Related Documentation

Hardware Documentation

- *Getting Started with NI DCM* – This document explains how to install and configure NI DCM devices. This document is available at ni.com/manuals.
- *NI DCM-2301 Specifications* – Lists the specifications of the NI DCM-2301 device. This document is available at ni.com/manuals.
- *NI DCM-2316 Specifications* – Lists the specifications of the NI DCM-2316 device. This document is available at ni.com/manuals.

Software Documentation

- NI Powertrain Controls *Device Drivers User's Manual* – After installing the drivers, select **Help>>Powertrain Controls>>Device Drivers User's Manual** in LabVIEW to view the *Device Drivers User's Manual*. Browse the **DCM** section in the **Contents** tab for information about the DCM API VIs on the FPGA, Real-Time, and user-interface levels.
- *NI DCM Default Software Image User Guide* – Select the Help icon in the Default Software Image (DSI) main user interface panel to view the manual.

Additional Resources

- For additional resources and support, including up-to-date software downloads, visit the NI Powertrain Controls Users group on ni.com/community.
- *National Instruments Example Finder* – For detailed LabVIEW examples which highlight specific features of the DCM and its software API VIs, use the **NI Example Finder** by selecting **Help>>Find Examples** and searching for 'DCM' on the **Search** tab.

What is DCM?

The DCM is an embedded, automotive power electronics device for driving a variety of direct fuel injector and fuel pump actuator types. The direct injector driver channels are supplemented by general purpose half-H-bridge drivers, analog inputs, digital IO, and serial communications. The DCM can be operated as a stand-alone controller, or integrated with a larger system of I/O. The digital processing core of the DCM is an NI sbRIO-9651 System-On-Module (SOM). The SOM features a dual-core 667MHz ARM processor and FPGA.

Common Use Cases for DCM

Fuel System Testing

The DCM is well-equipped for complete fuel system actuator testing applications, such as production-line and durability testing. The DCM electronics and packaging are designed to handle high-load durability test configurations. The DCM can also accommodate a wide variety of actuator types due to its flexible LabVIEW-based software platform. Between 4 and 16 injectors can be operated by a DCM-2316, depending on the type of injector and mode of operation. Therefore, it is possible to use a single device across multiple test engineering groups within an enterprise, enabling efficient collaboration and training processes.

Fuel System Research and Development

The hardware and software architecture of the DCM is also designed to enable sophisticated fuel system R&D projects. Since the digital processing core of the DCM contains a large FPGA with a high IO count, it is possible to bring many injector control functions, previously implemented in hardware ICs, into LabVIEW FPGA for high-speed parallel processing. Similarly, functions that were previously implemented in LabVIEW Real-Time loops are now implemented in LabVIEW FPGA. The integrated 4-channel oscilloscope enables the DCM to acquire voltage and current traces from any of the injector channels, as well as auxiliary information from external analog sources (e.g., fuel pressure, injector needle lift). Maximizing the use of FPGA resources enables areas of research previously not possible.

Engine Control

Another common use case for the DCM is engine control. The DCM provides all power electronics required to actuate most engines. In addition to its DI capabilities, the DCM can drive the following actuators with its array of general purpose Half H-bridge (HH) channels:

- Port fuel injectors
- Electronic throttle bodies

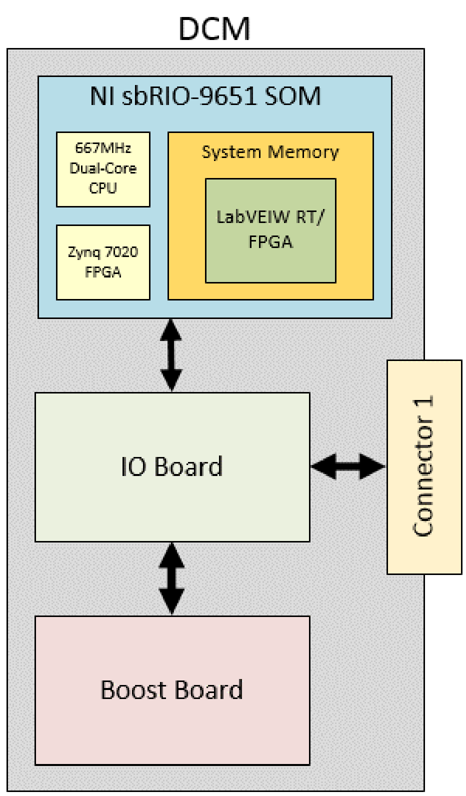
- Exhaust gas recirculation valves
- Fuel pump metering valves
- Variable valve timing actuators

Differential Digital I/O channels can be used to actuate “smart” ignition coils (output) or read crankshaft and camshaft Hall Effect sensor signals (input) to track engine position. Analog input channels can be used as feedback for control algorithms or safety monitoring (e.g., engine pressures and temperatures).

DCM Architecture

Internally, the DCM is comprised of three main components: controller, IO board, and boost board. The controller is the NI sbRIO-9651 SOM and plugs into the IO board. The IO board contains all input and output-driver circuitry which interfaces to the external Connector 1. The boost board also plugs into the IO board. The boost board receives external battery and driver voltage from Connector 1 and boosts it to a programmable voltage setpoint as high as 220 V. The boosted power supply is used by the IO board DI driver channels to achieve current profiles required by direct injectors. Figure 1 shows a more detailed diagram of the DCM hardware and software architecture.

Figure 1 DCM Architecture Diagram



One of the key enabling features for the DCM is the NI sbRIO-9651 SOM, which contains a dual-core processor and FPGA within a single chip. The LabVIEW RT operating system executes high-level, real-time algorithms on the dual-core processor and interfaces with many parallel LabVIEW FPGA functions on the FPGA. The FPGA is a LabVIEW-programmable digital logic matrix, consisting of millions of inter-connected logic gates, flip-flops and memory blocks which can be reconfigured for specific tasks.

A DCM software application consists of engineering-level calculations performed on the Real-Time processors at frequencies as high as 1 kHz, and counter-timer-type calculations performed on the FPGA at much higher frequencies (e.g., 40 MHz). Two specific examples of FPGA tasks on the DCM are engine position tracking, and precise control of current and voltage waveforms to direct injectors. All I/O related to injection is directly connected to the FPGA, allowing great flexibility in injector control.

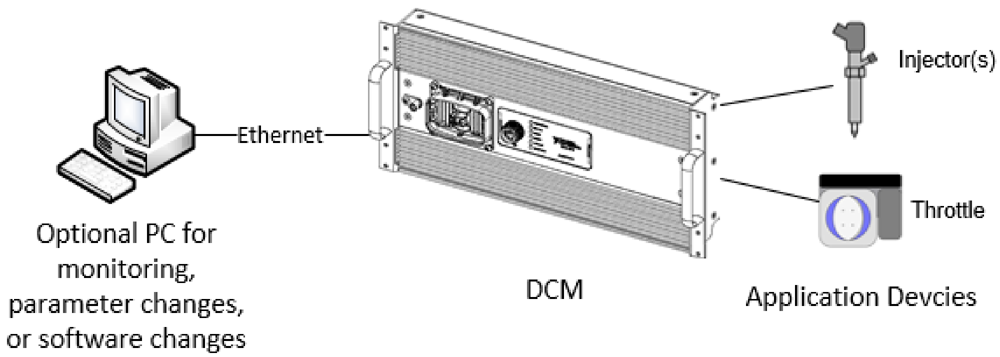
Hardware Deployment Options

The DCM can be deployed in one of 3 basic ways described and illustrated below.

Stand-Alone

The DCM can be used as a stand-alone Real-Time controller. It may be connected, via Ethernet, to a user interface PC, or operate headless. All software options support this hardware configuration. It is the most common implementation of the DCM.

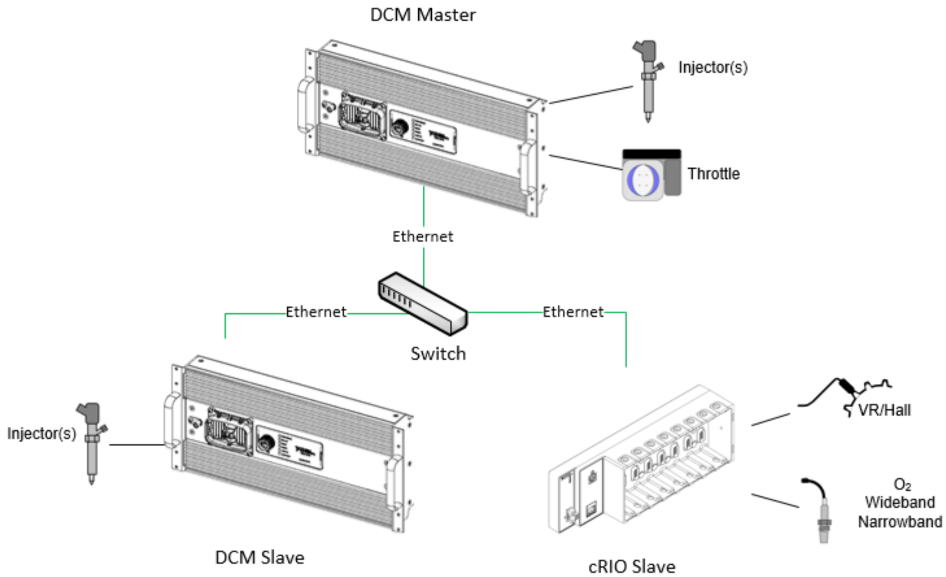
Figure 2 Using the DCM as a Stand-Alone Controller



RIO Ethernet Expansion (DCM Master)

If additional I/O is required, the DCM can be expanded with a cRIO Ethernet Expansion chassis using any of the supported NI C-series modules. In cases where additional injector channels are required, one DCM (master) can be configured to run both its own FPGA and that of an additional DCM (slave) operated as a remote FPGA device.

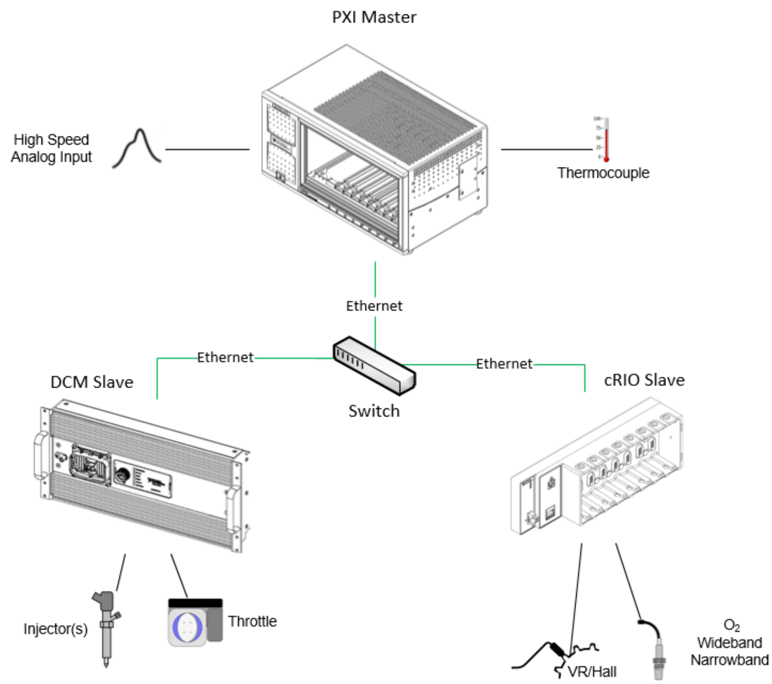
Figure 3 Using the DCM as the Master Controller to a RIO Ethernet Expansion Chassis and/or additional DCM



RIO Ethernet Expansion (DCM Slave)

In some cases, additional processing power is required to perform complex tasks like combustion feedback control. In this case the DCM is used as a slave to a more powerful PXI-based Real-Time controller. The DCM is then configured as a remote FPGA device. If additional injector channels are required, multiple DCMs may be used as slave devices.

Figure 4 Using DCM as a Slave RIO Ethernet Expansion Device to a Master Controller



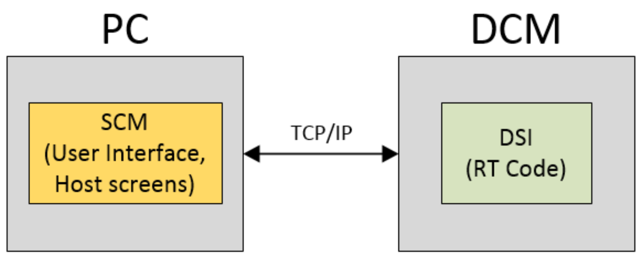
Software Options

DCM Default Software Image (DSI)

The DCM-DSI is a compiled start-up application which is preloaded to the DCM at the factory. When the DCM is first powered from the factory (out-of-the-box), the DSI will begin executing, using safe default settings (all channels disabled). The DSI is a configuration-based tool designed to exercise the DCM's full range of I/O. Users are encouraged to explore the capabilities of this feature-rich, standard application before determining that a custom application is needed. A free deployment license of the NI Software Calibration Management toolkit (SCM) is used to connect to the DCM from the host computer and display a standard user interface. Therefore, no LabVIEW programming and no software licenses are required to use the DCM with DSI. SCM is also used to save and manage calibrations for the DSI application. If the DCM is formatted for use with a different software configuration, the DSI may be downloaded from *ni.com* for free and restored to the DCM. Using the DSI is the easiest way to get started on the DCM and is the fallback option for troubleshooting hardware.

For more information on the DSI for DCM, refer to the *Default Software Image User Guide* as mentioned in Related Documentation section of this manual.

Figure 5 PC to DCM-DSI Interface

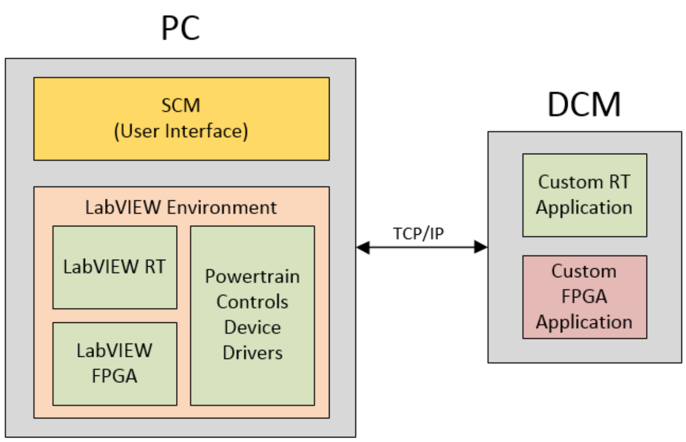


NI LabVIEW Development: Powertrain Controls Device Drivers

The Powertrain Controls Device Drivers are the core LabVIEW API VIs used to interface with DCM hardware in LabVIEW. Distributed as a VI Package using the JKI VI Package Manager, the Device Drivers are the building blocks used in all other software applications on the DCM. Both Real-Time and FPGA VIs are included in the device driver package, as well as an example project which demonstrates a standard implementation of the API. The Powertrain Controls Device Drivers require development licenses for LabVIEW, LabVIEW Real-Time, and LabVIEW FPGA.

For more information on the Powertrain Controls Device Drivers, refer to the NI Powertrain Controls *Device Drivers User's Manual* as mentioned in Related Documentation section of this manual.

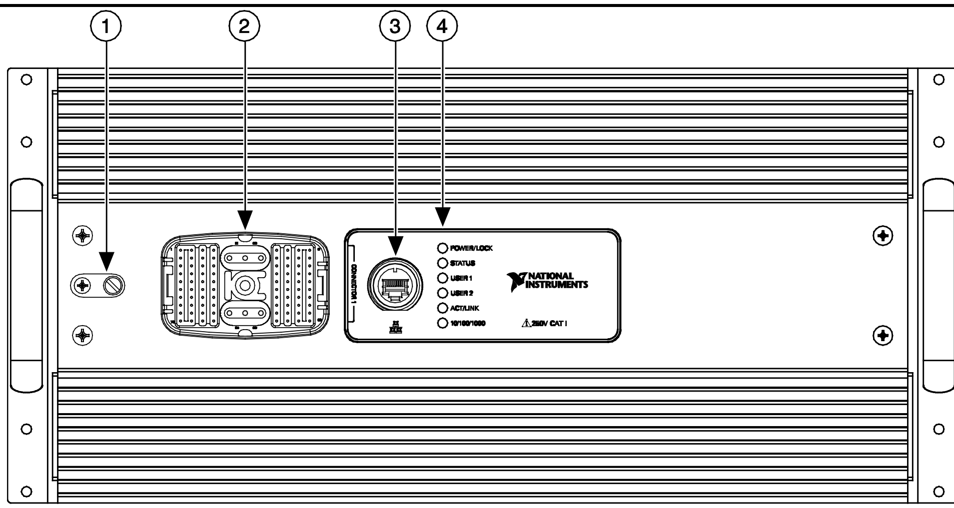
Figure 6 DCM Low-Level Development Architecture



Connectors, Ports, and LEDs

The DCM-23XX has the following connectors, ports and LEDs.

Figure 7 DCM-23XX Ports and Connectors

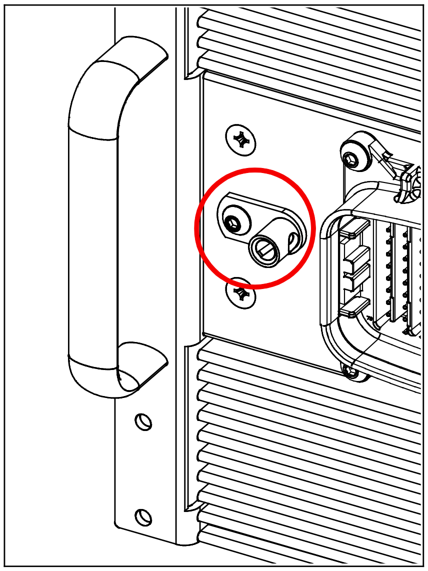


1. Chassis Ground Lug
2. Connector 1
3. RJ-45 Gigabit Ethernet Port
4. LED Indicators

Chassis Ground Lug

The DCM provides a chassis grounding screw.

Figure 8 Chassis Ground Lug to Facility Ground



Connector 1

Connector 1 on the DCM is an 86-pin Deutsch industrial automotive connector system. The mating connector part number is DRCP28-86SA. For a detailed list of associated Connector 1 parts, tools, and specifications, see the *DCM Accessories* section. Mating connector and tooling accessory kits can be purchased at ni.com.

DCM-23XX Connector 1 Pinout and Pin Descriptions

Figure 9 DCM-23xx Connector 1 Drawing

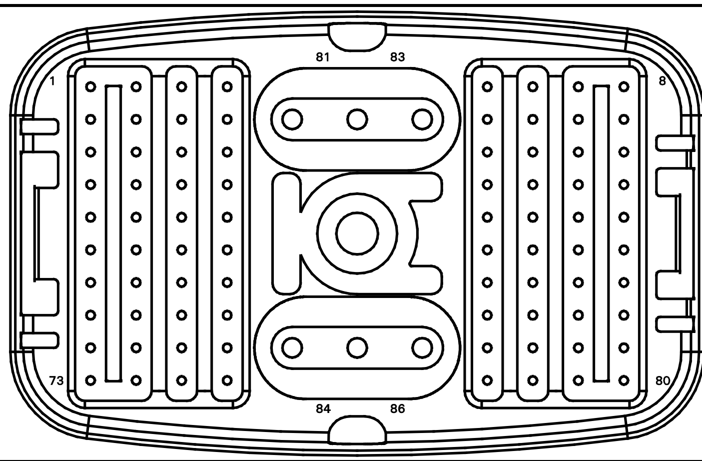


Table 1 DCM-2316 Connector 1 Pinout

HH1	1	DI_S_A1	2	DI_P_A1	3	DI_L_A1	4
HH2	9	DI_S_A2	10	DI_P_A2	11	DI_L_A2	12
HH3	17	DI_S_A3	18	DI_P_A3	19	DI_L_A3	20
HH4	25	DI_S_A4	26	DI_P_A4	27	DI_L_A4	28
HH5	33	HH6	34	HV_A	35	DI_L_AP	36
HH8	41	HH7	42	HV_B	43	DI_L_BP	44
HH9	49	DI_S_B4	50	DI_P_B4	51	DI_L_B4	52
HH10	57	DI_S_B3	58	DI_P_B3	59	DI_L_B3	60
HH11	65	DI_S_B2	66	DI_P_B2	67	DI_L_B2	68
HH12	73	DI_S_B1	74	DI_P_B1	75	DI_L_B1	76

PGND	PGND	PGND
81	82	83
84	85	86
DRVP	DRVP	DRVP

DIO1a	5	DIO2a	6	DIO3a	7	BATT	8
DIO1b	13	DIO2b	14	DIO3b	15	MPRD	16
DIO4a	21	DIO5a	22	DIO6a	23	KEY	24
DIO4b	29	DIO5b	30	DIO6b	31	IO_LOCK+	32
DIO7a	37	DIO8a	38	DGND	39	IO_LOCK–	40
DIO7b	45	DIO8b	46	AGND	47	CAN_H	48
AI4	53	AI18	54	AI12	55	CAN_L	56
AI3	61	AI17	62	AI11	63	IGND	64
AI2	69	AI6	70	AI10	71	RS232_TX	72
AI1	77	AI5	78	AI9	79	RS232_RX	80

Table 2 DCM-2301 Connector 1 Pinout

HH1	1	DI_S_A1	2	DI_P_A1	3	DI_L_A1	4
HH2	9	DI_S_A2	10	DI_P_A2	11	DI_L_A2	12
HH3	17	DI_S_A3	18	NC	19	NC	20
HH4	25	NC	26	NC	27	NC	28
NC	33	NC	34	HV_A	35	DI_L_AP	36
NC	41	NC	42	NC	43	NC	44
NC	49	NC	50	NC	51	NC	52
NC	57	NC	58	NC	59	NC	60
NC	65	NC	66	NC	67	NC	68
NC	73	NC	74	NC	75	NC	76

PGND	PGND	PGND
81	82	83
84	85	86
DRVP	DRVP	DRVP

DIO1a	5	DIO2a	6	DIO3a	7	BATT	8
DIO1b	13	DIO2b	14	DIO3b	15	MPRD	16
DIO4a	21	DIO5a	22	DIO6a	23	KEY	24
DIO4b	29	DIO5b	30	DIO6b	31	IO_LOCK+	32
DIO7a	37	DIO8a	38	DGND	39	IO_LOCK–	40
DIO7b	45	DIO8b	46	AGND	47	CAN_H	48
AI4	53	AI18	54	AI12	55	CAN_L	56
AI3	61	AI17	62	AI11	63	IGND	64
AI2	69	AI6	70	AI10	71	RS232_TX	72
AI1	77	AI5	78	AI9	79	RS232_RX	80

Table 3 DCM-23XX Connector 1 Pin Descriptions (x represents channel number)

Pin Name	**Description**
HH*x*	Connector 1 provides up to 12 general purpose Half-H-Bridge (HH) driver channels. Each channel has a single associated pin, HH*x*. Each HH driver channel can be configured via software to operate as a high-side switch to DRVP or a low-side switch to PGND. Adjacent channels can also be software-linked to operate as a Full-H-Bridge driver for a bipolar current driver.
DI_S_A*x*	Direct Injector Bank A provides up to four high-side driver channels intended for driving the high-side of direct-injectors. Each Bank A high-side driver channel has an associated pin, DI_S_A*x*, primarily for inductive-load solenoid direct-injectors. In other operating modes, these pins are used to support driving capacitive-load piezo direct-injectors.
DI_P_A*x*	Direct Injector Bank A provides up to four high-side driver channels intended for driving the high-side of direct-injectors. Each Bank A high-side driver channel has an associated pin, DI_P_A*x*, primarily for capacitive-load piezo direct-injectors. These pins provide an internal series inductor to assist with current control to capacitive loads.
DI_L_A*x*	Direct Injector Bank A provides up to four low-side driver channels intended for driving the low-side of direct-injectors. Each Bank A low-side driver channel has an associated pin, DI_L_A*x*, used in all direct-injection modes.
DI_L_AP	Direct Injector Bank A includes an additional low-side driver channel, with associated pin DI_L_AP, intended for driving the low-side of an engine-synchronous high-pressure fuel pump solenoid. The high-side to the pump solenoid must be connected to DRVP externally.
HV_A	Direct Injector Bank A uses a dedicated internal high voltage boost power supply as a drive source to the high-side driver channels. Pin HV_A provides an alternate external high voltage source to DI Bank A. Internally, pin HV_A connects to the Bank A high-voltage capacitance through a series diode.
DI_S_B*x*	These pins on Bank B are identical in function to the corresponding pins on Bank A. See pins DI_S_A*x*.
DI_P_B*x*	These pins on Bank B are identical in function to the corresponding pins on Bank A. See pins DI_P_A*x*.

DI_L_B*x*	These pins on Bank B are identical in function to the corresponding pins on Bank A. See pins DI_L_A*x*.
DI_L_BP	This pin on Bank B is identical in function to the corresponding pin on Bank A. See pin DI_L_AP.
HV_B	This pin on Bank B is identical in function to the corresponding pin on Bank A. See pin HV_A.
BATT	The BATT pin is intended to power the internal processing core and related support circuits. An Internal DRVP trickle-charge circuit allows current from the BATT pin to charge the internal DRVP circuit capacitance at a controlled rate to minimize inrush current after voltage is applied to the DRVP pins. The BATT pin must always be powered prior to DRVP.
DRVP	There are three Driver Power (DRVP) pins. These pins are connected internally. To minimize inrush current to the DRVP circuit capacitance at power-up, voltage should not be applied to DRVP pins prior to BATT. Furthermore, an external relay should be used with DRVP, controlled by the MPRD lowside switch. The NI DCM Starter Harness and PDU-2300 accessories implement this circuit.
PGND	There are three Power Ground (PGND) pins. These pins are connected internally. These pins should be connected to the negative terminal of the external DC power supply.
DGND	The Digital Ground (DGND) pin is internally connected to PGND. DGND should only be used as a ground reference for differential digital input/output channels. Do not use DGND as a primary ground return to the external DC power supply.
AGND	The Analog Ground (AGND) pin is internally connected to PGND. AGND should only be used as a ground reference for analog input channels. Do not use AGND as a primary ground return to the external DC power supply.
IGND	The Isolated Ground (IGND) pin is electrically isolated from PGND, DGND, and AGND. IGND should be used as a ground reference for CAN and RS232 communication channels.
DIO*x*a DIO*x*b	Connector 1 provides eight independent differential digital input/output channels. Each channel can be configured individually as input or output via software. Channel direction changes require approximately 1 ms. Each channel uses a RS485-compatible transceiver.

	In output mode, the a/b-pins drive 0 V or 5 V in complimentary manner. The a-pin is 5 V when output logic is TRUE, and 0 V when output logic is FALSE. The b-pin is 0 V when output logic is TRUE, and 5 V when output logic is FALSE. In input mode, the a/b-pins are internally weakly biased to approximately 1.6 V, and read as logic FALSE when both pins are externally disconnected. When the a-pin is connected to a higher voltage than the b-pin, a logic level TRUE is received. When the a-pin is connected to a lower voltage than the b-pin, a logic level FALSE is received. This logic applies to a/b-pin voltages in the range of 0 to 5 V.
AI*x*	Connector 1 provides up to twelve, 12-bit, 0 V to 5 V analog inputs. The twelve channels have an aggregate sample rate of 1 MSPs and are referenced to AGND. Each channel has a high input impedance and a 100 kHz low-pass filter. In software, any of these channels can be directed to the internal 4-channel DI Scope.
MPRD	The Main Power Relay Driver (MPRD) pin is a low-side switch to PGND, dedicated to energizing an external Main Power Relay (MPR) for DRVP pins.
KEY	The KEY pin is an analog input dedicated to measuring the status of an external Key switch, in the range of 0 V to 48 V. Internally, the pin has a 10 kΩ pulldown resistor. The action taken, based on the voltage at KEY, is determined by user software.
IO_LOCK+ IO_LOCK-	The IO_LOCK+ and IO_LOCK- pins lock and unlock the DI and HH driver channel operation at the hardware level, via external contact closure. **IO Locked (driver circuits disabled):** Contact open between IO_LOCK+ and IO_LOCK-. **IO Unlocked (driver circuits enabled):** Contact closed between IO_LOCK+ and IO_LOCK-.
CAN_H CAN_L	The CAN_H and CAN_L pins are connected to an internal fault-tolerant high-speed CAN transceiver. The ground reference for the CAN channel is IGND and is electrically isolated from PGND, DGND, and AGND. A termination resistor between CAN_H and CAN_L is not provided internally.
RS232_RX RS232_TX	The RS232_RX and RS232_TX pins are connected to an internal fault-tolerant RS-232 transceiver. The ground reference for the RS-232 channel is IGND and is electrically isolated from PGND, DGND, and AGND.

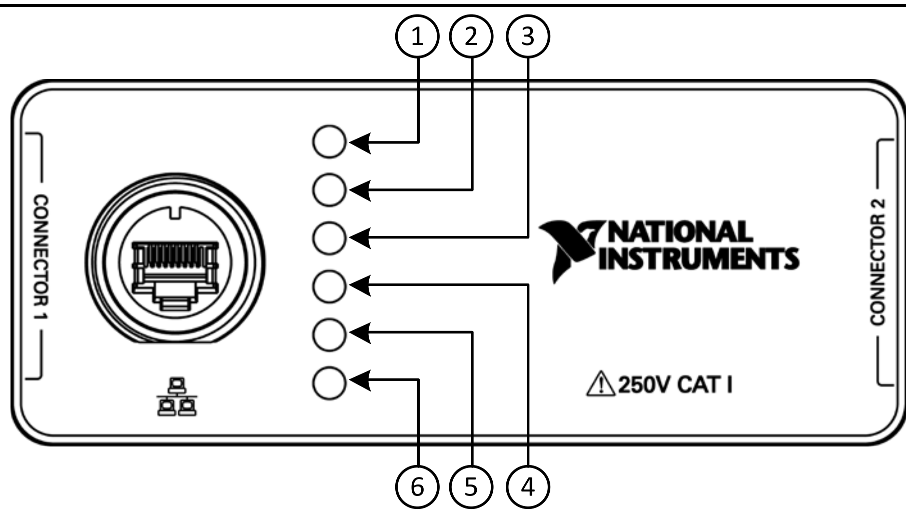
RJ-45 Gigabit Ethernet Port

The DCM has one tri-speed RJ-45 Gigabit Ethernet port that is IEEE 802.3 compatible. By default, the Ethernet port is enabled and configured to obtain an IP address automatically from a DHCP server. The Ethernet port can be configured in MAX. The Ethernet port performs automatic crossover configuration so you do not need to use a crossover cable to connect to a host computer. Ethernet LED Indicator states are described in the LEDs section below.

LEDs

The DCM-23XX has the following LEDs.

Figure 10 DCM-23XX LEDs



1. POWER/LOCK LED
2. STATUS LED
3. USER 1 LED
4. USER 2 LED
5. ACT/LINK LED
6. 10/100/1000 LED

POWER/LOCK LED

The following table lists the POWER/LOCK LED indications.

Table 4. POWER/LOCK LED Indications

LED Color	LED Pattern	Indication
Green	Solid	The DCM is powered on and I/O is Unlocked
Amber	Solid	The DCM is powered on and I/O is Locked
-	Off	The DCM is powered off.

Amber Power LED indicates that the DCM is in a safe state and is not ready to fire injectors.

Green Power LED means that the DCM is ready to fire injectors. At this point, any of the injector pins may be at high voltage and appropriate caution should be exercised.

STATUS LED

The STATUS LED is off during normal operation. The DCM internal SOM controller indicates specific error conditions by flashing the amber STATUS LED a certain number of times every few seconds, as shown in the table below.

Table 5 STATUS LED Indications

Number of Amber Flashes Every Few Seconds	Indication
2	The DCM SOM controller has detected an error in its LabVIEW RT software and device drivers. This usually occurs when an attempt to update the software is interrupted. Reinstall LabVIEW RT software and device drivers on the SOM. Refer to the *Measurement & Automation Explorer Help* for information about installing this software.
3	The DCM SOM controller is in safe mode. Refer to the *Measurement & Automation Explorer Help* for information about safe mode.
4	The DCM SOM controller software has crashed twice without rebooting or cycling power between crashes. This usually occurs when the controller runs out of memory. Review your RT VI and check the memory usage. Modify the VI as necessary to solve the memory usage issue.
Continuously flashing or solid	The DCM SOM controller has detected an unrecoverable error. Contact National Instruments.

USER 1 and USER 2 LEDs

The USER 1 and USER 2 LEDs are utilized by the DCM-DSI to indicated that the application is executing and to indicate various IO fault conditions. Refer to the DCM DSI User Guide for details. When developing custom DCM software, you can define the USER 1 and USER 2 LEDs to meet the needs of your application via the Powertrain Controls Device Drivers for DCM.

Ethernet LEDs

The following table lists the Ethernet LED indications.

Table 6 ACT/LINK LED Indicators

LED	LED Color	LED Pattern	Indication
ACT/LINK	-	Off	No Ethernet Link
	Green	Solid	Ethernet link established
	Green	Blink	Ethernet activity occurring
10/100/1000	-	Off	10 Mbps
	Green	Solid	100 Mbps
	Amber	Solid	1000 Mbps

Connecting Power to the DCM

Selecting a Power Supply

The DCM is powered via the BATT, DRVP, and PGND pins by an external DC power source in the range of 6V to 48V. While a 6V DC power supply will properly power the DCM, it is recommended to use a supply in the range of 12V to 48V, allowing margin for external supply voltage droop during various load conditions. The external DC power source can be a battery, AC-to-DC linear power supply, or AC-to-DC switching supply.

The required current capacity of the external DC supply varies with the load demand. With idle or light load conditions, the recommended minimum current capacity of a 12V DC supply is 15A, which corresponds to 180W. If using a 12V DC supply for heavy load demands, a 50A supply may be required, which corresponds to 600W. The DCM DI Simulation tool can be used to determine the appropriate external power supply required for your application.

Transient Load Response

The DC supply response to pulsing loads is an important consideration when selecting a DC power source. While powering the DCM from 12 V, at no load, the average current draw will be approximately 1 A. However, when enabling the internal boost power supplies, the current draw may pulse to 10 A or greater for short durations (milliseconds at a time). Furthermore, injector operation can increase the power supply pulse loading dramatically. Therefore, it is important to use a DC supply which has additional current capacity and sufficient internal capacitance to maintain voltage stability during the expected pulse load conditions.

If you are operating the DCM, and find that the controller crashes or resets under certain conditions, two causes should be immediately considered: Software bug, and power supply droop. Since the DCM can be used as an open platform for custom software development, it is possible that custom control algorithms create a memory condition that crashes and resets the controller. This situation is beyond the scope of this document. Power supply droop can be diagnosed with the use of an external oscilloscope monitoring the voltage of the DRVP wires. If the voltage ever dips below 6V, then you should investigate one or more of the following: Acquiring a higher capacity power supply, decreasing the length of the power cabling, increasing the diameter of the power cabling, or adding external capacitance close to the DCM. If the DCM is used with the NI PDU-2300 and Starter Harness accessories, then the wire length and size between the PDU and DCM are already optimized. Therefore, the wires between the power supply and the PDU should be investigated. If it is determined that additional external capacitance is needed, consider something in the range of 4700 µF to 22000 µF. There are many options available for capacitors in this range. One to consider is EPCOS B41560A9229M. Critical properties to be aware of are voltage, temperature and ripple-current ratings. If the DCM is used with the NI PDU-2300 and Starter Harness accessories, then additional external capacitance can be easily connected at the battery input terminals of the PDU. External capacitance is illustrated below in Figure 11.

Figure 11 Adding external capacitance to the DCM to minimize supply voltage droop

DCM Power Supply Comparison

Above, we mentioned three general types of DC power supplies: Battery, Linear AC-DC, and Switching AC-DC. These supplies will have different responses to pulse loads. Generally, the AC-DC supplies have active voltage control circuitry to respond quickly to transient load conditions. The performance of various brands will vary. Automotive batteries will provide a very low noise power source, but since they are not electronically controlled, they will droop continuously during load conditions. The amount of droop will depend on the state of charge. Battery charging systems are required to maintain the battery. The DCM installation environment and operating conditions will determine which type of power supply is best for your application. Table 7 below, is a comparison of the three power supply types mentioned here. The comparison statements are very general with respect to power requirements for the DCM. Actual results greatly depend on the design and manufacturing quality.

Table 7 Comparison of DC power supply types for DCM

Power Supply Type	Automotive LA Battery	Linear AC-DC	Switching AC-DC
Transient Recovery	Good	**Best**	Better
Low Ripple Voltage	**Best**	Better	Good
Low EMI	**Best**	Better	Good
Efficiency	**70-85%**	40-60%	**70-85%**
Serial Programmable	No	Uncommon	**Common**
Cost	**Low**	Medium	High
Weight	Heavy	Heavy	**Light**
Portable	**Yes**	No	No

Light Load or Desktop Operation

When operating the DCM at your desk, or operating with light load, NI recommends three popular low-cost AC-DC power supplies. Two are available through ni.com and all are listed in Table 8 below. These supplies are not programmable, but incorporate several safety and protection features. They are also relatively easy to setup quickly for bench-top operation. Two are nominal 12 VDC supplies, and the other is a nominal 24 VDC supply. Keep in mind that the PDU-2300 accessory must be configured differently for 12 V or 24 V operation.

Table 8 NI Recommended AC-DC supplies for bench-top or light load operation

AC-DC Supply	Tripp Lite PR-15	PULS QS10.121	NI PS-17
Part Number	PR-15	783168-01 (ni.com)	781095-01 (ni.com)
Technology Type	Linear	Switching	Switching
AC Input	120 VAC	100-240 VAC, 50-60 Hz	100-240 VAC, 50-60 Hz
DC Output	13.8 VDC	12-15 VDC, 12-15 A	24-28 VDC, 17-20 A
Output Power	200 W	180 W	480 W
Adjustable	No	Yes	Yes

Heavy Load or Special-Deployment Operation

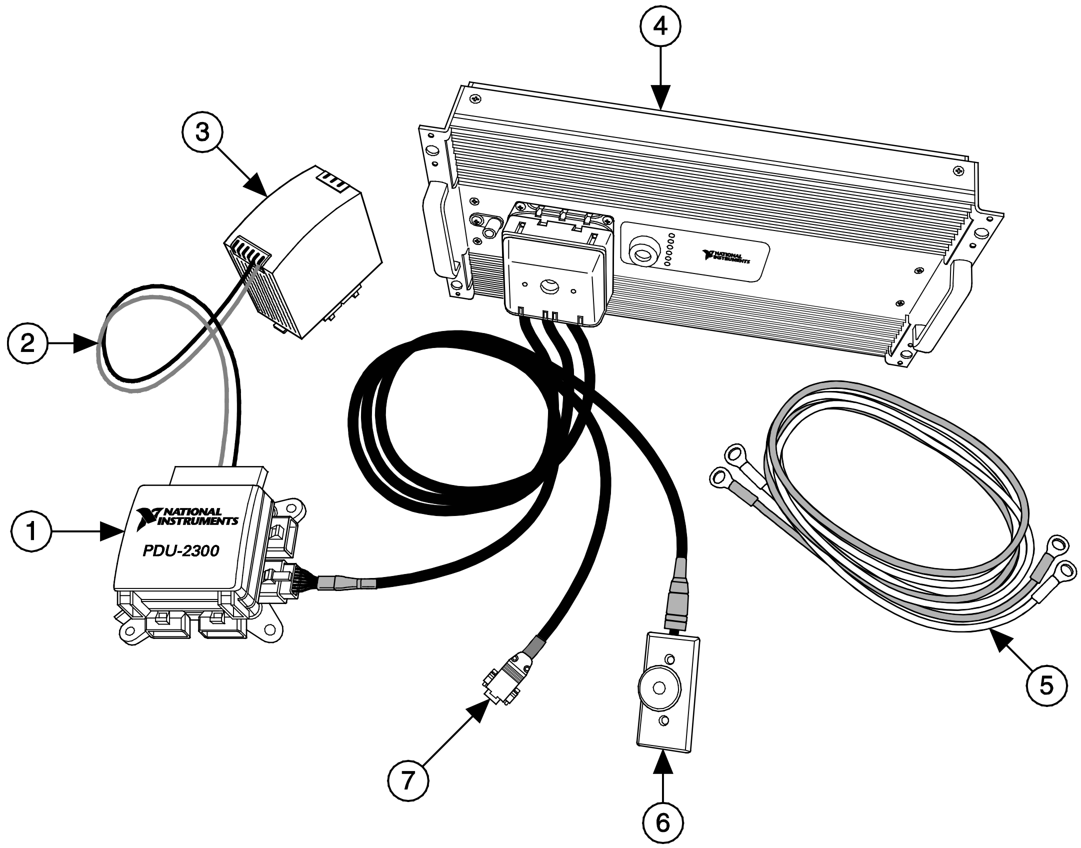
When operating the DCM at heavy load, or if the DCM installation requires more sophisticated power control, NI recommends the TDK-Lambda Genesys (or similar) family of switching AC-DC power supplies. They are fully programmable via several methods, and offer a variety of safety and protection features. One model that is well-suited for the DCM, is the GEN 30-50.

Connecting Power with the NI PDU-2300 and Starter Harness Accessories

NI recommends the use of the NI PDU-2300 and Starter Harness accessories to connect power to the DCM, especially for quickly getting started with the DCM for the first time. These accessories are specially designed for optimized power distribution and fusing to the DCM and associated external devices. With these two accessories, no specialty wire-tooling is required to power the DCM for the first time and interact with the DSI. The NI DCM Getting Started Guide lists the simple steps to connect the

DCM to power using these accessories. The DCM and accessories are shown in Figure 12 below. Please note the PDU-2300 fuse configuration for 12 V and 24 V (nominal) power supplies, shown in Figures 13 and 14. The fuse configuration optimizes the internal relay coils for 12 V or 24 V operation. If the PDU-2300 is used with a 24 V power supply, while configured for 12 V, then the relays within the PDU-2300 will be damaged. Conversely, if the PDU-2300 is used with a 12 V power supply, while configured for 24 V, then the relays within the PDU-2300 may not switch on. When configured for 12 V, the operating range is 7 V to 16 V. When configured for 24 V, the operating range is 14 V to 32 V.

Figure 12 DCM Starter Harness and PDU-2300 Accessories



1. PDU-2300	5. Heavy-duty power supply cables
2. Light-duty power supply cables	6. Emergency stop (ESTOP)
3. Power supply	7. RS232
4. DCM	

Figure 13 PDU-2300 Voltage Configuration Fuses (Inside View)

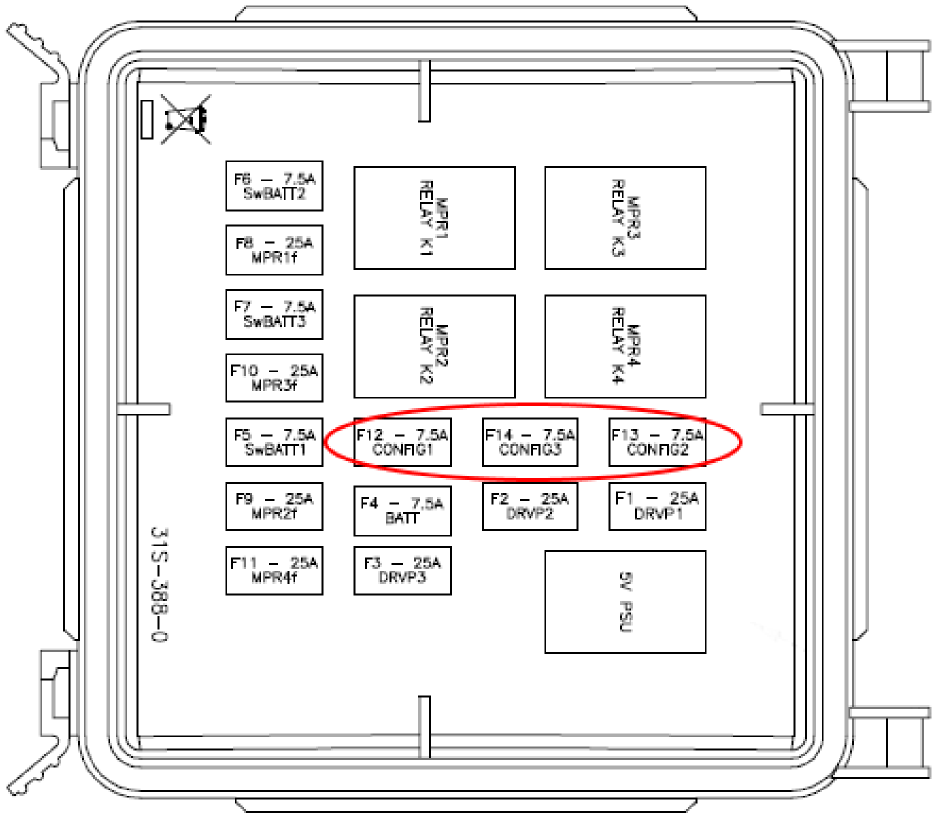


Figure 14 PDU-2300 12 V Configuration

Figure 15 PDU-2300 24 V Configuration

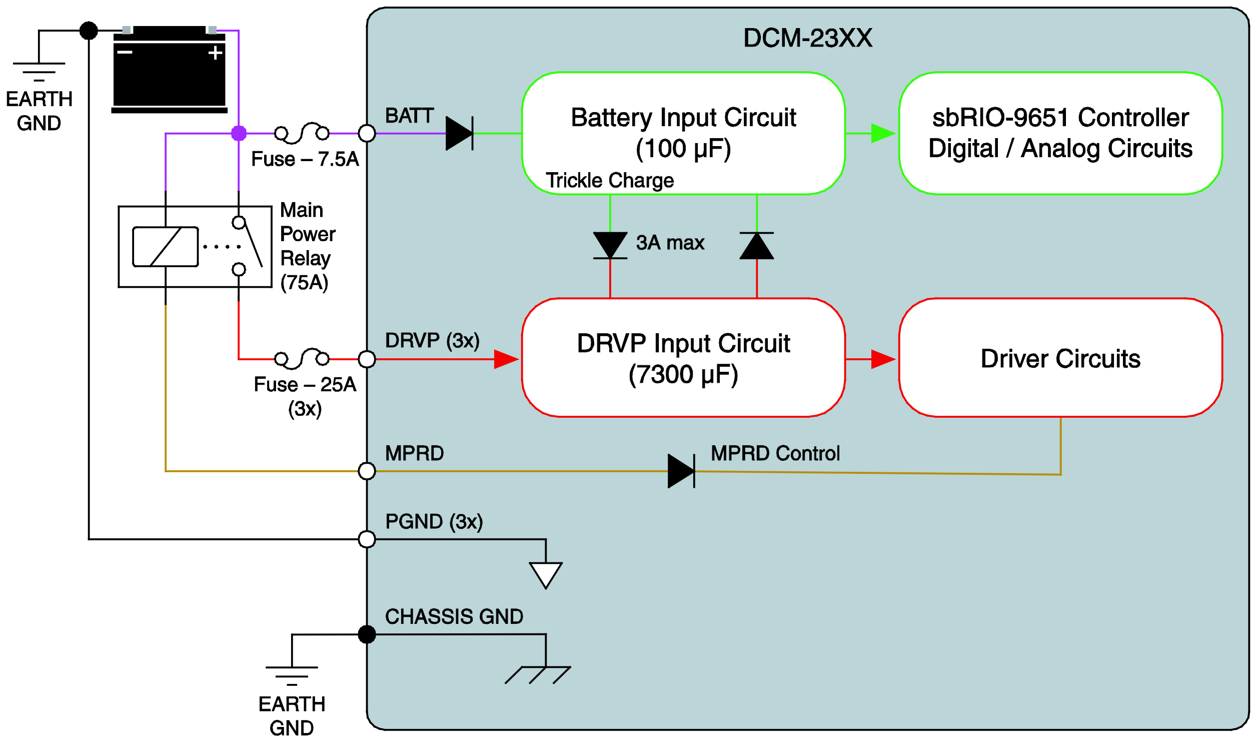
Table 9 PDU-2300 Voltage Configuration Fuse Guide

PDU Configuration	PDU Voltage Range	Populated Config Fuses	Depopulated Config Fuses	Wrong Configuration?
Nominal 12 V	7 V – 16 V	F12 & F13	F14	24 V Applied → Damaged Relays
Nominal 24 V	14 V – 32 V	F14	F12 & F13	12 V Applied → Relays May Not Turn On

Connecting Power without the NI PDU-2300 and Starter Harness Accessories

For installations that require custom power wiring, please follow the guidelines illustrated in Figure 16 below. Please note that all PGND (3x) and DRVP (3x) pins of the DCM should be utilized and wired with 12 AWG wire.

Figure 16 DCM Custom Power Wiring



Configuring the DCM

The following topics are related to configuring the behavior of the internal NI 9651 SOM controller via a host computer.

Connecting the DCM to a Host Computer

The front RJ-45 connector is a Gigabit Ethernet port with direct access to the internal NI 9651 controller. A standard Category 5 (CAT-5) or better cable should be used. Connect the Ethernet cable directly to your computer, or to an Ethernet switch that forms a local network between the DCM and your computer. It is not necessary to use a crossover cable for direct connections to your computer.

As a factory default setting, the DCM attempts to initiate a DHCP network connection when powered, which means that it expects to be served an IP address by a DHCP server. If the DCM is unable to initiate a DHCP connection, then a link-local IP address with the form 169.254.x.x is used. Typically, your host computer will not be configured to act as a DHCP server. Therefore, if you are making a point-to-point Ethernet connection with the DCM for the first time, you should modify your computer Ethernet TCPIP settings to a static IP address of 169.254.1.1, and a netmask of 255.255.0.0. These basic host computer

IP settings should allow you to interact with the DCM over Ethernet after the DCM DHCP initiation fails and times out. Then you can modify the DCM IP settings via NI Measurement and Automation Explorer (MAX) for the planned network usage. Don't forget to also change your computer IP settings for the planned network usage to connect to the DCM again.

If the DCM Ethernet port is connected to an existing network infrastructure with a DHCP server, then the DCM should be served an IP address automatically. If your host computer is also connected to that same network, then you should be able to discover the DCM IP address via NI MAX. However, it is not guaranteed that the DCM will be served the same IP address each time the DCM is powered up. Therefore, if possible, it would be beneficial to establish a network-compatible static IP address for the DCM.

If a MAX connection cannot be established with the DCM, make sure that any anti-virus or firewall software is disabled that would prevent Ethernet data traffic over UDP 44525 port.

Configuring the DCM in Measurement and Automation Explorer (MAX)

Once a network connection is established between the DCM and your host computer, then a variety of settings and utilities are available via NI MAX. All the settings provided within MAX are related to the internal NI 9651 controller. They are not related to the DCM IO circuitry. The DCM can be found within MAX by expanding the Remote Systems icon in the left pane. When the Default Software Image (DSI) is installed to the DCM (i.e. from the factory), MAX lists the system as the DCM model number, followed by the serial number, such as **NI-DCM-2316-XXXXXXX**. If the DCM is formatted without DSI, MAX lists the system as the internal controller model number, followed by the serial number, such as **NI-sbRIO-9651-XXXXXXX**.

Setting a System Password

The default username for the DCM is admin, and no password is assigned. Until changed, the password should be left blank for any prompts for login credentials. The system password can be changed by right-clicking on the system and selecting **Web Configuration**. This will open a utility within your default browser. Click the **Security Configuration** icon to change security settings.

Installing Software on the DCM

The DCM ships with the DSI pre-installed. If you want to use the DSI, then no software changes should be made to the DCM via MAX. If the DSI needs to be updated to the latest version, or simply reinstalled, use the Software Calibration Management (SCM) toolkit. Refer to the *NI DCM-23XX DSI User's Manual* for more information.

To run non-DSI personalities, the DCM must be formatted and the proper device drivers installed for the intended use. The stepwise instructions for this are provided in the DCM Getting Started Guide.

Controller Startup Options

You can configure controller startup options in MAX. Select the controller under **Remote Systems** in the MAX configuration tree, then select the **System Settings** tab. You can configure the following options under **Startup Settings**.

Safe Mode

When you reboot the controller with this setting on, the controller starts without launching LabVIEW RT or any startup applications. In safe mode, the controller launches only the services necessary for updating configuration and installing software (via MAX).

Console Out

When you reboot the controller with this setting on, the controller enables output to the RS-232 serial lines on Connector 1. You can use a serial-port terminal program to read debug information such as the IP address and firmware version of the controller. A null-modem cable must be used to connect to a computer. Make sure that the serial-port terminal program is configured to the following settings:

- 115,200 bits per second
- Eight data bits
- No parity
- One stop bit
- No flow control

Disable RT Startup App

Rebooting the controller with this setting on prevents any LabVIEW startup applications from running. If the DSI is installed, this setting will prevent DSI from starting. The controller will simply boot and enter an idle state.

Enable Secure Shell (SSH) Logins

Rebooting the controller with this setting on starts sshd on the controller. Starting sshd enables logins over SSH, an encrypted communication protocol. For information about SSH, go to ni.com/info and enter the Info Code openssh.

Disable FPGA Startup App

Rebooting the controller with this setting on prevents any FPGA application from being auto-loaded. The DSI does not depend on an auto-loaded FPGA application. The DSI loads the FPGA application after the RT portion starts. Therefore, this setting will not affect the DSI. However, it may affect custom applications.

Safe Mode and IP Reset

The DCM can be powered up to enter Safe Mode or reset its network configuration to DHCP by following the instructions below using Connector 1 pins AI11 and AI12. This may be necessary if any of the following occur:

- A custom application is deployed as a startup executable and it immediately crashes at startup.
- The static IP address is forgotten or not compatible with a new network.
- A connection cannot be established via MAX.

Simply booting into Safe Mode or resetting the IP address does not change any other settings, data files, or deployed software on the controller. Therefore, if a buggy startup executable is deployed, it should be removed or disabled while in Safe Mode.

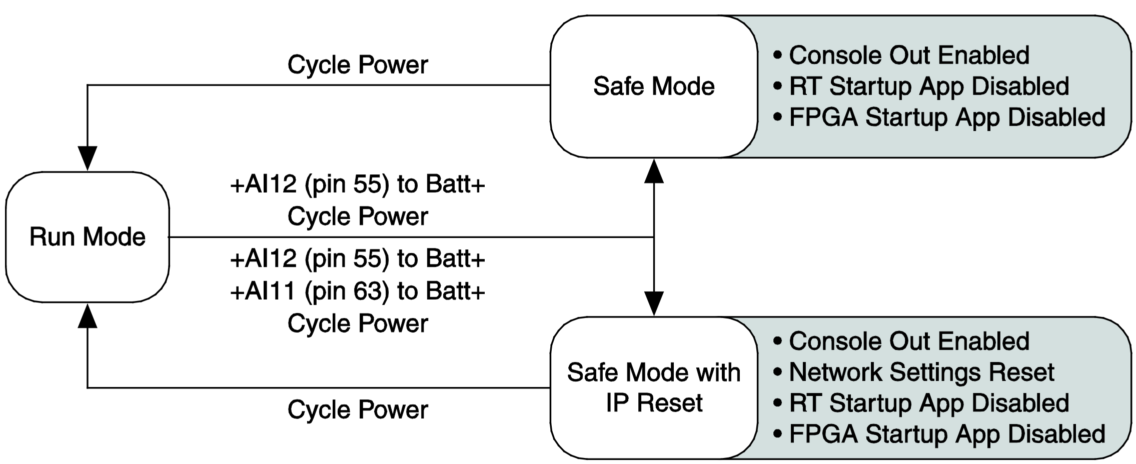
Booting into Safe Mode

Booting into Safe Mode may be performed by powering on the DCM with Connector 1 pin **AI12** shorted to battery voltage for at least one second after power up. After approximately 30 seconds, the Status LED will periodically flash three consecutive times, indicating the controller is in Safe Mode.

Booting into Safe Mode with IP Reset

Booting into Safe Mode with IP Reset may be performed by powering on the DCM with Connector 1 pins **AI11** and **AI12** shorted to battery voltage for at least one second after power up. After approximately 45 seconds, the Status LED will periodically flash three consecutive times, indicating the controller is in Safe Mode. The IP settings will be reset to DHCP. Figure 17 shows the reset behavior described above.

Figure 17 Reset Behavior



Launching the DCM Default Software Image (DSI)

At the factory, the DCM is loaded with a Default Software Image (DSI), which is a feature-rich application developed by the NI Powertrain Controls Group. The DSI is built using the latest version of LabVIEW RT and SCM, and is configured as a startup executable. When the DCM is powered, the DSI executable automatically begins running and becomes fully functional in about 60 seconds. This is indicated by a steady flashing USER 1 green LED. The USER 2 amber LED may flash a variety of sequences to indicate fault or warning conditions. You can interact with the DSI via SCM installed on a host computer. Please refer to the *Default Software Image User Guide* for details of connecting-to and interacting-with the DSI. Throughout this user guide, DCM IO functions are explained from the perspective of the DSI and its user interface.

IO Lock

The DCM driver circuits are enabled at various levels of software, depending on the command function desired. However, at the hardware level there is an IO Lock circuit which enables and disables DI and general purpose half-H-bridge driver channels. The Connector 1 IO_LOCK+ and IO_LOCK- pins are used for this purpose. The IO Lock pins are internally connected to an isolated RS232 transceiver channel. IO_LOCK+ is the transmit pin (TX) and IO_LOCK- is the receive pin (RX). At the hardware level, a 1 kHz, 50% duty cycle PWM is output on IO_LOCK+. IO_LOCK- must receive this signal for at least 25 ms to "unlock" and enable the driver circuits. If the signal is removed from IO_LOCK- for more than 25 ms, then the driver circuits will be "locked" and disabled. The IO_LOCK+ PWM signal is typically -6 V to +6 V. The IO Lock function should be controlled by a passive emergency stop switch between IO_LOCK+ and IO_LOCK-, with no more than 15 m of cable.

DCM Internal Power Supplies, Sequencing, and Policies

The DCM contains a variety of internal DC-DC power supplies and circuits related to managing Driver Power (DRVP) and driver channels. *This section incomplete*.

Operating Direct Injectors and Engine-Synchronous Pumps

The direct injector and pump driver circuits are the primary focus of the DCM architecture. The goal of the DCM design was to enable a single device to operate as many known types of injector technologies as possible. This section of the manual will describe the various load types supported by the DCM, load connectivity, and the various software and hardware controls in place to operate those loads.

Direct Injector Load Types

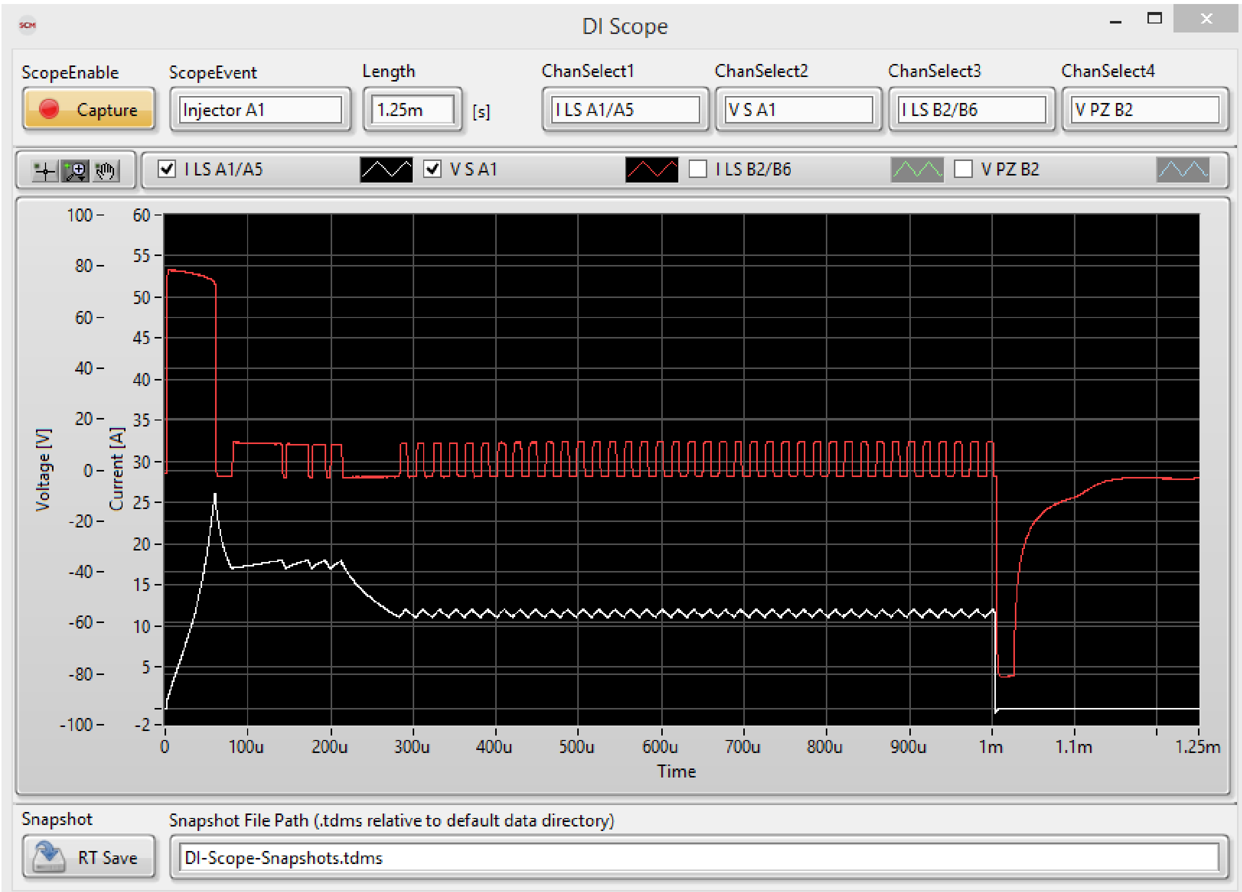
In some discussions about fuel injectors, there may be distinctions between injector types based on fuel type, or where the injector is situated in relation to the combustion chamber. For example, there are injectors designed for CNG, gasoline, diesel, etc. There are injectors designed for injecting into the intake before the throttle body (TBI), into the intake port before the intake valve (PFI), or directly into the combustion chamber (DI). This section has “Direct Injector” in the title because the DI driver channels are most often used to drive direct injectors. Generally, direct injectors require boosted voltage levels and higher current drive, as compared to non-direct injectors. However, there are a variety of other injector designs that require the drive capabilities of the DCM DI drivers, even though they are not direct injectors. If an injector requires only battery voltage (DRVP) as a drive source, and requires less than 8 A peak current, then the general purpose Half-H-Bridge driver channels should be used.

The DCM DI driver channels do not care about fuel types or injector mechanical design. Therefore, we will focus now on the *electrical-load* types, which narrows the discussion down to two main categories: solenoid (i.e. inductive) and piezo (i.e. capacitive).

Solenoid injectors

The electrical load of a solenoid injector is often characterized by an inductance, in henrys (H), and resistance in ohms (Ω). The solenoid of an injector is a specially designed coil of wire to act as an electromagnet while flowing current. Magnetic energy acts on a mechanical valve-body which controls fuel flow at the injector nozzle. While there are an abundant number of solenoid injector designs in the market, the DCM DI driver channel is only concerned with driving the proper voltage and current profile to any solenoid in a precisely timed sequence. Most automotive electronics and actuators operate from a nominal 12 VDC battery. But a solenoid direct injector may require 50 V to 120 V to drive the current levels required to generate a magnetic force strong enough to actuate the fuel valve. For example, a popular common-rail diesel injector requires a peak current of 25 A to open the valve. Furthermore, the peak current must be achieved in as little as 60 µs, with the aid of a 75 V boost supply. The DCM includes internal boost power supplies and specialized drive circuitry to drive with boost voltages up to 220 V and peak currents up to 40 A. Once the injector valve is opened, the current level required to hold the valve open is lower than the peak current. Thus, solenoid fuel injectors require a complex profile of drive-voltage and current within each injection event. At the end of a solenoid injection event, the current must be brought down to 0 A as quickly as possible to collapse the magnetic field and shut off the fuel flow. Otherwise, unknown quantities of fuel will dribble from the nozzle if the current is simply allowed to decay based on the solenoid properties. Again, the DCM implements specialized circuitry to quickly bring the current flow to 0 A. Figure 18 shows a typical solenoid diesel direct injector current and voltage waveform.

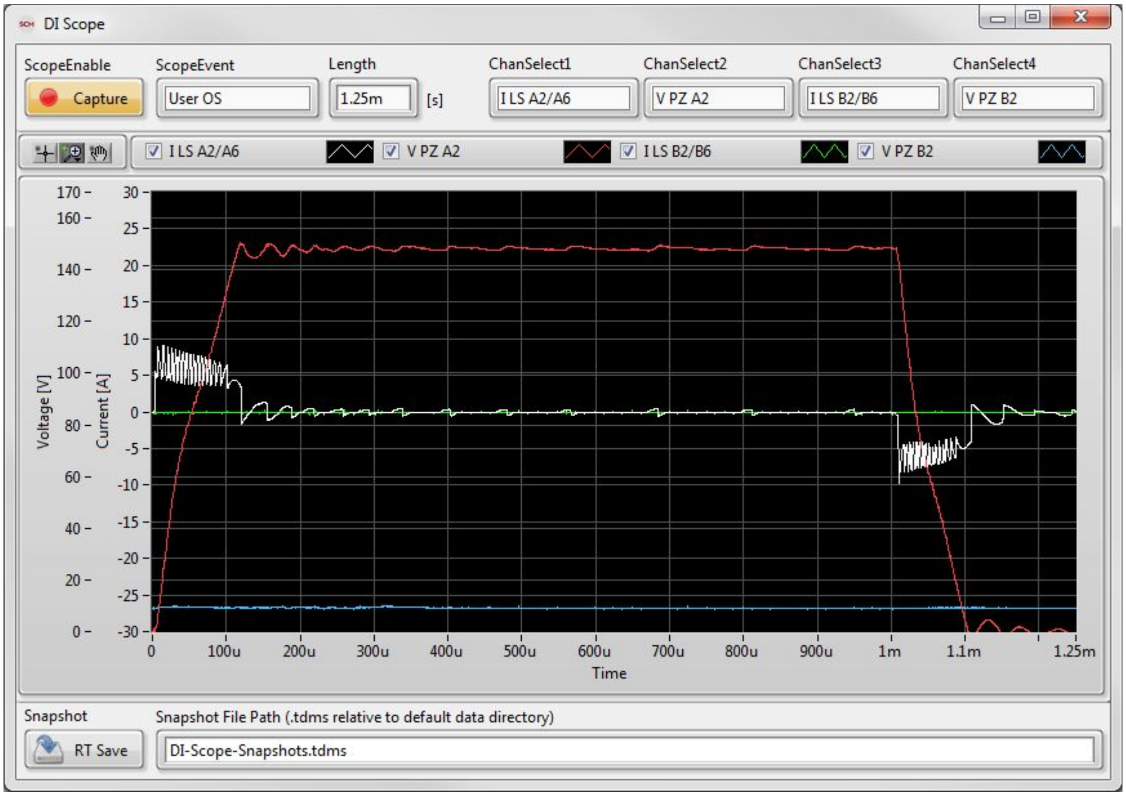
Figure 18 Typical Solenoid Diesel Direct Injector Current and Voltage Waveform



Piezo injectors

The electrical load of a piezoelectric (piezo) injector is often characterized by a capacitance in farads (F). The internal piezoelectric actuator is referred to as the piezo “stack” because it is made from a layering of piezo crystal wafers, with interleaving electrodes connected in parallel. Two wires are internally connected to the positive and negative poles of the stack. Electrically, the piezo stack acts like a capacitor. As the stack is charged, it physically expands along its axis, on the order of 10 µm. As the stack is discharged, it returns to its original length. This expansion and contraction drives the internal fuel valve body to open and close. The charge rate to the piezo stack is controlled by the DCM DI driver channel, acting as a dithering current source. The stack is typically charged to 100 V to 220 V, depending on fuel rail pressure behind the valve. The charge and discharge rate is a critical design parameter for the injector performance and durability. Higher charge and discharge rates are desirable for faster valve opening and closing. However, if the rates are too high, then the piezo stack can be damaged. The DCM software provides a variety of features related to piezo injector charge, discharge, and current-waveform configuration. Figure 19 shows a typical piezo diesel direct injector current and voltage waveform.

Figure 19 Typical Piezo Diesel Direct Injector Current and Voltage Waveform



The past benefits of piezo injector technology, over solenoid, have been shorter injector open and close times leading to more precise fuel control, electrical efficiency improvements, and quieter injector operation. However, solenoid injector technology continues to make significant improvements in these areas also, while costing less to manufacture. Both solenoid and piezo injector technologies have their strengths and weaknesses, depending on the application.

Side-Note About Dual Solenoid Injectors

While dual solenoid injectors obviously fit in the solenoid category, it is worth mentioning them separately as a side-note. These injectors are found in the sphere of Hydraulic-Electronic Unit Injectors (HEUI). HEUI technology was developed by Caterpillar and used primarily on Navistar Powerstroke diesel engines for Ford heavy duty trucks. The original HEUI design uses a single solenoid to gate pressurized engine oil flow to a fuel-pressure-intensifier within the injector. The solenoid is controlled similarly to any common-rail diesel solenoid injector.

Some subsequent HEUI designs utilize a spool valve to control the oil flow to the intensifier. The spool valve is pulled at each end by a separate solenoid. Therefore, two DI driver channels are required to operate the “open” and “close” solenoids of a single injector. The open-solenoid is pulsed to open the spool valve and start injection at a desired engine position. The close-solenoid is pulsed to close the spool valve and end injection after a desired time duration. While the DCM DSI does not have a built-in feature to directly support dual-solenoid spool valve injectors, this mode of operation can be implemented using the flexible RIO architecture with custom programming.

High-Pressure Fuel Pump Types

As with fuel injectors, there is a wide variety of high-pressure fuel pump designs. At the time of writing, all known high pressure fuel pumps utilize a solenoid actuator to regulate the fuel pressure within the fuel-rail behind the common-rail injectors. Most of these pumps fit into two distinct categories related to how the solenoid is energized: non-engine-synchronous and engine-synchronous.

Non-Engine-Synchronous Pumps

Non-engine-synchronous pumps require simple PWM-style energizing of the solenoid to meter the fuel flow at the inlet of the pump. The PWM is not required to be synchronous with engine operation in the angle domain. The solenoid is energized using a lowside switch to PGND using a constant-frequency PWM with a dynamic duty-cycle to control rail pressure. The highside of the solenoid is connected to external DRVP. Current to the solenoid is dithered per the PWM function and typically requires no more than an average of 3 A. Therefore, the general purpose half-h-bridge driver channels of the DCM are suitable for this purpose.

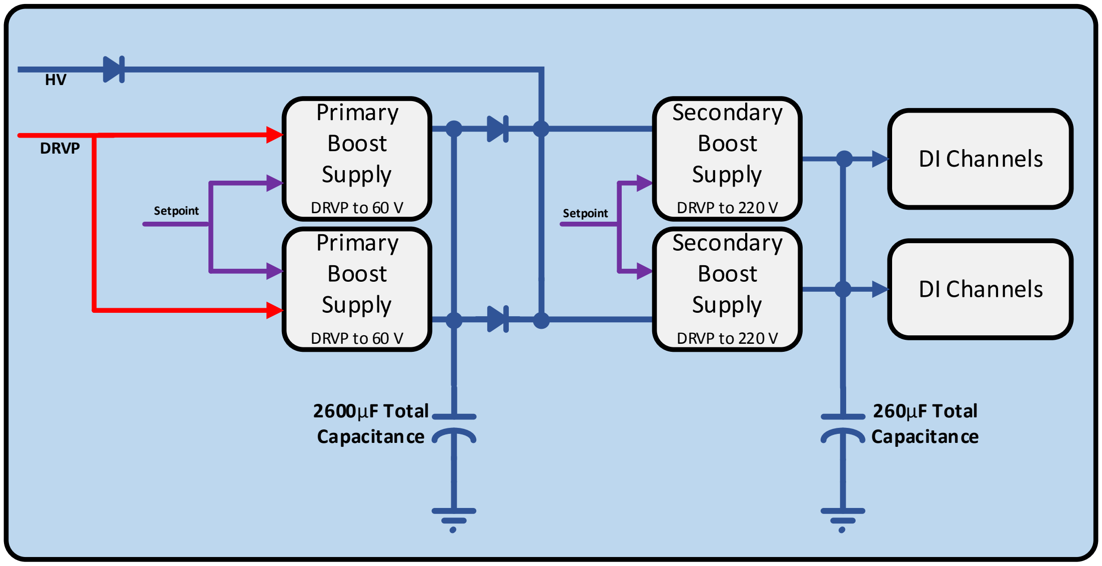
Engine-Synchronous Pumps

Engine-Synchronous pumps require some number of solenoid pulses throughout the engine cycle. Each pulse is timed, in the angle domain, to align with cam-driven lobes or pistons within the pump. The duration of each pulse determines the amount of fuel to be forced into the fuel rail, or spilled back to the low-pressure fuel circuit. The peak current required during each solenoid pulse is typically greater than 8 A, and sometimes requires a boosted voltage to drive this current. Therefore, the DI driver channels are suitable for this purpose (as opposed to the general purpose half-h-bridge drivers). If the current-drive does not require boosted voltages, then one of the dedicated lowside pump channels provided within each DCM DI driver bank can be used. Using the dedicated lowside pump channel frees up the DI Driver channels for injectors.

DI Bank Architecture

The DCM DI driver channels and boost power supplies are implemented within two identical, independent banks: Bank A and Bank B. A simplified block diagram of a single bank is shown in Figure 20.

Figure 20 Simplified Circuit Diagram of the DI Bank Architecture



Dual Primary Stage Boost Supply

The purpose of the primary stage boost supply is to increase the efficiency of the secondary stage, which must provide final boost voltages up to 220 V. The dual primary stage boost supply consist of two boost controllers operating from DRVP and charging into 1300 µF output capacitors. The dual primary output capacitors are connected in parallel for a total of 2600 µF capacitance for the complete primary stage. Therefore, the dual controllers cannot charge to independent voltages. The controllers are enabled automatically by device driver software whenever MPRD is turned on. The controllers are commanded to a charge set point automatically by device driver software, in the range of DRVP to 60 V. If the secondary boost supply is enabled, then the primary set point is commanded to 10 V below the secondary set point, up to 60 V. If the secondary boost supply is disabled, then the primary set point is commanded to equal the secondary set point, up to 60 V. The primary stage output is routed to the input of the secondary stage boost supplies and is also routed to the secondary stage output capacitance via a diode. Therefore, if the secondary charge falls below the primary, then the primary charge will supplement the secondary. Furthermore, if the high voltage drive requirement of an injector is less than 60 V, then the secondary can be disabled while the primary stage maintains the boost voltage.

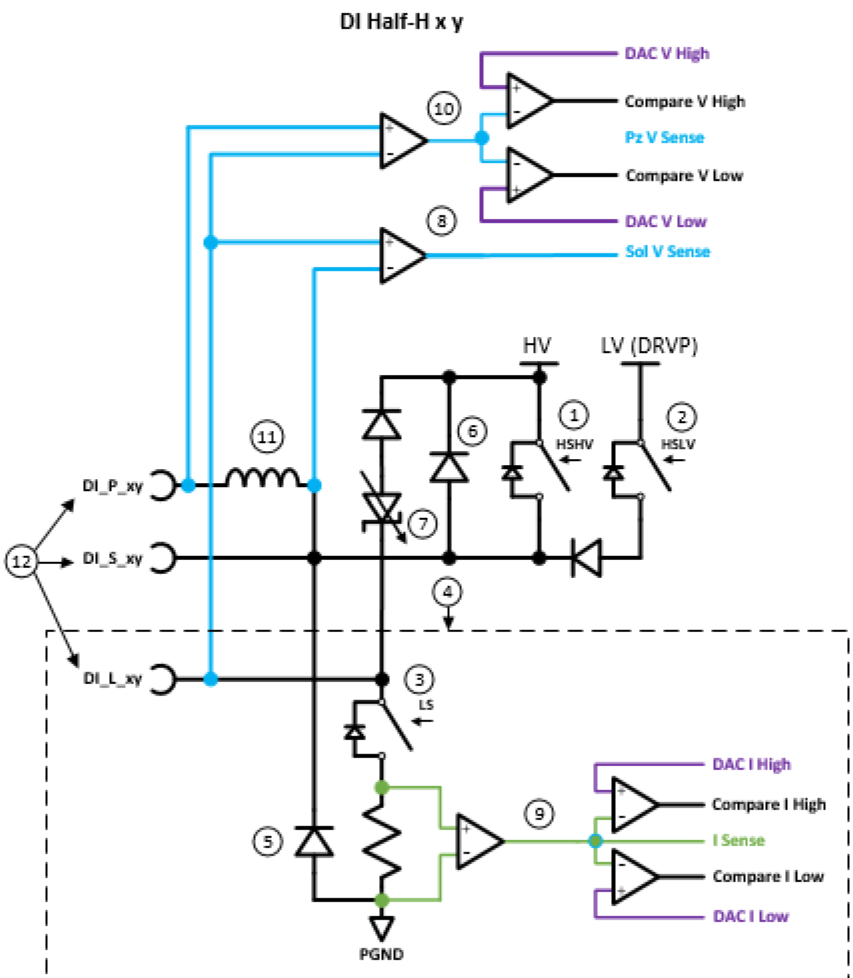
Dual Secondary Stage Boost Supply

The purpose of the secondary stage boost supply is to provide boost voltage directly to the DI driver channels. The dual secondary stage boost supply consist of two boost controllers operating from the primary stage output and charging into 130 µF output capacitors. The dual secondary output capacitors are connected in parallel for a total of 260 µF capacitance for the complete secondary stage. Therefore, the dual controllers cannot charge to independent voltages. The secondary stage voltage is user-specified.

DI Driver Channels

There are four identical, independent DI driver channels within a bank. Each channel is a specialized half-H driver configuration with two sources of highside drive voltage: DRVP or secondary HV. There is an additional lowside driver channel within each bank that can be used as a dedicated engine-synchronous fuel pump driver or assist with multiplexed injector modes. Figure 21 shows a simplified circuit diagram of a single DI driver half-H driver channel and a pump driver channel. The sections below describe the numbered circuit features from Figure 21.

Figure 21 Simplified Circuit Diagram of a Single DI Half-H Driver Channel and Pump Driver Channel



Highside HV Drive (1)

The Highside High Voltage (HSHV) FET is an N-channel FET controlled by a floating, high voltage MOSFET driver circuit. The MOSFET driver is commanded by a digital output from the controller FPGA. The HSHV FET is automatically cycled on and off per the user-specified injector current profile during HV boost phases. From this FET, HV is delivered directly to an external solenoid load via the DI_S_xy pin, and directly to a piezo load via the DI_P_xy pin (with series inductor).

Highside DRVP Drive (2)

The Highside Low Voltage (HSLV) FET is an N-channel FET controlled by a floating, MOSFET driver circuit. The MOSFET driver is commanded by a digital output from the controller FPGA. The HSLV FET is automatically cycled on and off per the user-specified injector current profile during DRVP phases (non-boosted). From this FET, DRVP is delivered directly to an external solenoid load via the DI_S_xy pin. HSLV is not used in piezo modes.

Lowside Drive (3)

The Lowside (LS) FET is an N-channel FET controlled by a MOSFET driver circuit. The MOSFET driver is commanded by a digital output from the controller FPGA. The LS FET provides a controlled path to PGND via a current-sense resistor.

For solenoid loads, the LS FET is turned ON continuously during all current-control phases, and turned OFF during back-boost phases to direct solenoid energy back into the boost supply.

For piezo loads, the LS FET is turned ON continuously during piezo charging, and cycled ON and OFF per the user-specified injector current profile during piezo discharging – dumping the piezo charge to ground.

The LS FET is turned ON during idle injector conditions while MPRD is ON and IO is UNLOCKED. The LS FET is turned OFF while MPRD is OFF or IO is LOCKED.

Dedicated Lowside Pump Drive (4)

There is an additional lowside driver channel utilized for multiplexed injector modes or dedicated high pressure pump driver. The circuitry is identical to the lowside circuitry of a DI driver channel.

Recirc Path (5)

The recirc diode allows current to circulate through the load and LS FET while highside FETs are OFF during current-control phases.

Backboost Path

For solenoid injection events, it is important for load-current to drop sharply to 0 A at the end of the event. This ensures that the injector valve is closed as quickly as possible to prevent unknown amounts of fuel from dribbling out of the nozzle. At the end of an injection event, the LS FET will turn off for a user-defined amount of backboost time. The solenoid load has inductance, and energy is stored in the inductive load during injection. When the LS FET turns OFF, the voltage at the lowside pin will rise sharply, attempting to dump the energy somewhere. This is the purpose of the backboost path, which routes the energy back to the secondary boost supply to absorb it. The rate at which the injector current drops to 0 A depends on the voltage of the secondary boost supply and the amount of energy stored in the solenoid before the end of injection. There will be a small rise in voltage on the secondary supply. The amount of voltage rise depends on the secondary boost voltage level and the amount of energy stored in the solenoid before the end of injection. This recaptured energy can be used for the next injection event.

Default Backboost Mode (6)

The default backboost mode is implemented as a simple diode pointing to the secondary boost supply. For the default backboost path to flow current, the lowside voltage must rise above the secondary boost voltage. When this happens, the stored energy will dump into the capacitance of the secondary boost supply.

Programmable Zener Backboost Mode (7)

For some solenoid injector applications, the required boost voltage level for opening the injector is lower than the voltage level required for backboost. For example, an injector may require no more than 50 V boost to open the injector. But it may be desired to bring the injector current to 0 A faster than the default backboost path (to 50 V) can achieve. Therefore, a more sophisticated backboost circuit, called a Programmable Zener, is implemented in series with the simple diode. In Programmable Zener mode, a Zener voltage can be set higher than the secondary boost voltage. For the Programmable Zener backboost circuit to flow current, the lowside voltage must rise above the Programmable Zener voltage. When this happens, the stored energy will dump into the capacitance of the secondary boost supply. If the default backboost mode is used, then the Programmable Zener circuit is bypassed. There is only one Programmable Zener voltage level for each bank. When Programmable Zener mode is enabled for a bank, then every channel within the bank will operate using its Programmable Zener.

Solenoid Voltage Sense (8)

Each DI driver channel provides a differential voltage measurement across the DI_S_xy pin and the DI_L_xy pin for solenoid injector modes. The measurement range is -250 V to +250 V. This signal is one of 55 software-selectable signals that can be selected for measurement by the four DI Scope channels. Each DI Scope channel contains 5 MS/s, 15-bit A/D converter.

Lowside Current Sense and Compare (9)

Each DI driver channel provides a current sense measurement between the LS FET and PGND, utilizing a 2 mΩ sense resistor. The measurement range is -12 A to +50 A. This signal is one of 55 software-selectable signals that can be selected for measurement by the four DI Scope channels. Each DI Scope channel contains 5 MS/s, 15-bit A/D converter.

The current sense measurement is also routed to a dual comparator and compared against DAC voltages for the upper and lower current-dithering set points. The DAC voltages are automatically commanded by the controller FPGA device-driver based on the user-specified injector current profile. The comparator outputs are fed back to the controller FPGA to control the highside and lowside FETs during current control phases. Generally, when the upper comparator is triggered (i.e. current rises above the upper current threshold), the highside FET is turned OFF. When the lower comparator is triggered (i.e. current falls below the lower current threshold), the highside FET is turned ON.

Piezo Voltage Sense and Compare (10)

Each DI driver channel provides a differential voltage measurement across the DI_P_xy pin and the DI_L_xy pin for piezo injector modes. The measurement range is -250 A to +250 V. This signal is one of 55 software-selectable signals that can be selected for measurement by the four DI Scope channels. Each DI Scope channel contains 5 MS/s, 15-bit A/D converter.

The voltage measurement is also routed to a dual comparator and compared against DAC voltages for the upper and lower piezo charge set points. The DAC voltages are automatically commanded by the controller FPGA device-driver based on the user-specified piezo charge profile. The comparator outputs are fed back to the controller FPGA to control the highside and lowside FETs during piezo voltage control phases. During piezo injector control, there is a combination of current control (using lowside current sense) and voltage control. Generally, when the upper comparator is triggered (i.e. voltage rises above the upper charge threshold), current control to the piezo load is turned OFF. When the lower comparator is triggered (i.e. voltage falls below the lower charge threshold), current control to the piezo load is turned ON.

Piezo Inductor (11)

The purpose of the piezo inductor requires some background discussion. As described above, DCM DI driver current control to any type of injector load is performed by switching highside and lowside FETs fully ON and OFF (i.e. the FETs do not operate in their linear region) at a rate fast enough to achieve a desired average current during a phase. Therefore, a phase of current control is specified by upper and lower dithering set points. The dithering performance of the driver circuit greatly depends on the propagation delay of control and feedback signals, and load inductance. The signal propagation delay of the control and feedback signals is fixed. In the DCM DI driver circuits, it happens to be on the order of a few hundred nanoseconds. However, the inductance of a solenoid injector can vary greatly, from a few hundred µH to several mH. Tighter current dithering can be achieved to a relatively larger inductance solenoid injector. At the extreme, a short circuit across the highside and lowside driver pins would have virtually 0 inductance, and current control from a switching driver circuit would be impossible because current would shoot up to high levels in a few nanoseconds before the control could respond. The DCM DI driver channels have additional active-shutdown circuitry in place to protect against this very condition.

As stated above, in the discussion about piezo injectors, a piezo stack, electrically, is very much like that of a capacitor. When a capacitor is fully discharged, it acts like a short circuit immediately after voltage is applied. That is why it is important to insert some amount of series inductance along the path to the piezo injector. If the inductance is too small, then current control performance will suffer. If the inductance is too large, then piezo voltage control performance will suffer. The DCM developers find that a 47 µH inductor is a reasonable compromise between piezo current control and voltage control performance.

Channel Pins (12)

Each DI driver channel utilizes three external pins. The DI_P_xy pin is the highside driver pin for piezo injector loads. The DI_S_xy pin is the highside driver pin for solenoid injector loads. The DI_L_xy pin is the lowside driver pin for all injector load types. The section below that discusses Modes of Injector Operation shows all possible ways to connect solenoid and piezo injectors supported by the hardware and software.

The simplest connection method for solenoid injectors is in non-multiplexed, unipolar mode. In this case, each solenoid injector connects between DI_S_xy and DI_L_xy.

The simplest connection method for piezo injectors is in non-multiplexed, unipolar mode. In this case, each piezo injector connects between DI_P_xy and DI_L_xy, and there is an additional jumper wire between DI_S_xy and the adjacent channel lowside pin. This jumper provides a piezo discharge path at the end of the injection event.

The multiplexed and bipolar injector modes require more complex connections between adjacent channels.

Unipolar and Bipolar Injector Modes

The DCM supports both unipolar and bipolar injector drive modes.

Unipolar Drive

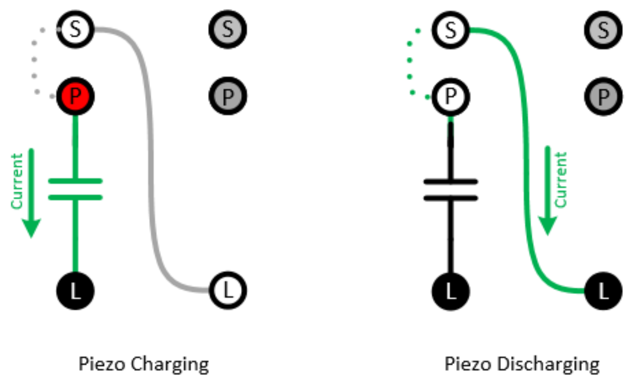
Unipolar injectors are by far the most common injectors in the industry. This means that only one highside FET from a single DI driver channel is required to drive current in the forward direction to open the valve.

For unipolar solenoid injectors, this means that a DI_S_xy pin is used to drive current forward through the solenoid and into the DI_L_xy pin, as shown in Figure 22.

Figure 22 Unipolar Solenoid Operation

For unipolar piezo injectors, this means that a DI_P_xy pin is used to drive current forward through the capacitive piezo stack and into the DI_L_xy pin to charge the piezo stack and open the valve. Once the piezo stack is charged and the valve is open, the highside drive only needs to maintain the required charge throughout the injection event. However, the piezo stack must be discharged at the end of the injection event. This is accomplished by using a jumper wire between the DI_S_xy pin and the adjacent channel lowside pin. The DI_S_xy pin is not used to drive current to the piezo stack, but simply provide an easy wiring connection to create the discharge path from the top of the piezo stack to another lowside FET.

Figure 23 Unipolar Piezo Operation

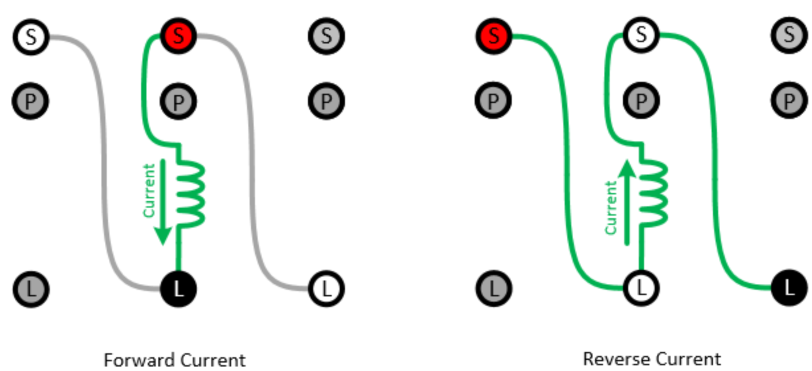


Bipolar Drive

Fuel injectors requiring bipolar drive are not as common as unipolar. Bipolar drive means that two highside FETs from two adjacent DI driver channels are required to drive current in the forward or reverse direction to achieve the desired current and voltage profile to the load.

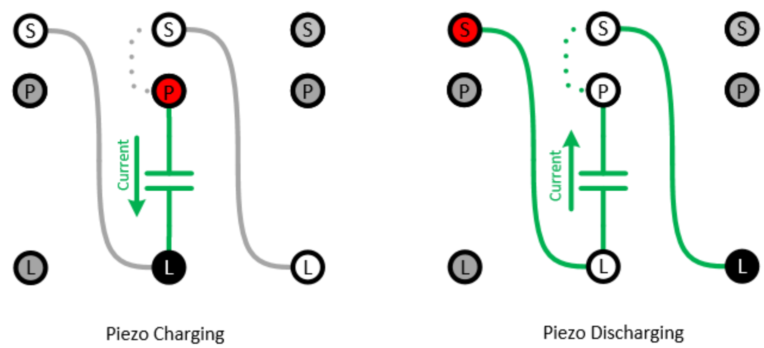
For bipolar solenoid injectors, this means that two adjacent DI_S_xy pins are used to drive current forward or reverse through the solenoid via additional jumper wires with the adjacent channels, as shown in Figure 24.

Figure 24. Bipolar Solenoid Operation



For bipolar piezo injectors, a single DI_P pin is used to drive current in the forward direction, using the internal inductor. The DI_P pin of the same channel is used as a discharge path to the adjacent channel DI_L pin. The DI_P pin of an adjacent channel is used to drive current in the reverse direction. Note that a DI_S pin is not used for reverse current because the internal inductor is already present on the opposite side of the piezo load.

Figure 25. Bipolar Piezo Operation



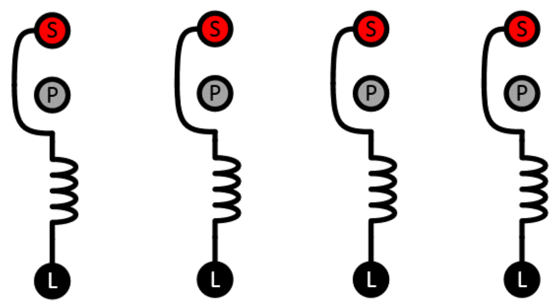
Non-Multiplexed and Multiplexed Injector Modes

The DCM supports both non-multiplexed and multiplexed injector drive modes.

Non-Multiplexed Drive

Non-multiplexed injection means that DI driver circuit resources are not shared among injectors. Therefore, injection events among injectors are completely independent and can occur simultaneously if necessary. It is recommended to use non-multiplexed injector configurations when possible to simplify wiring and diagnostic tasks. Figure 26 shows an example of four non-multiplexed, unipolar, solenoid injectors within a bank.

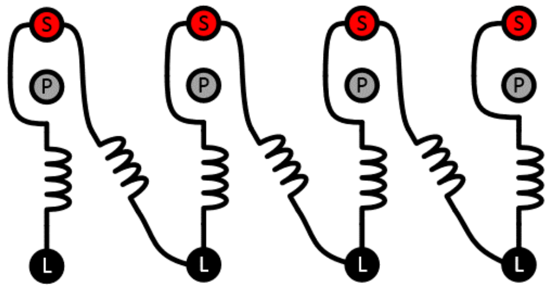
Figure 26. Four Non-Multiplexed, Unipolar, Solenoid Injectors Connected to a Single Bank



Multiplexed Drive

If the number of injectors required for a system is more than the number accommodated by non-multiplexed modes, then a multiplexed configuration is required. However, multiplexed modes share DI driver circuit resources among two injectors. This means that injection events among any two injectors within the same bank are not allowed to overlap. The low-level software device driver will not allow it. All injection events within a bank must be sequential. Figure 27 shows an example of six multiplexed, unipolar, solenoid injectors within a bank. Notice that each utilized DI_S pin is responsible for highside drive to two adjacent injectors. Also, each utilized DI_L pin is responsible for lowside drive to two adjacent injectors.

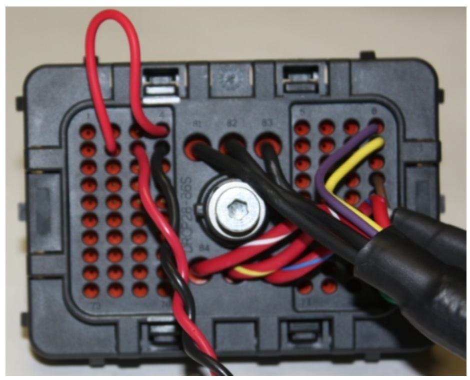
Figure 27. Six Multiplexed, Unipolar, Solenoid Injectors Connected to a Single Bank



Jumpers Wires

As seen in Figure 28, some injector configurations require jumper wires across DI driver pins. When this is necessary, it is recommended that the jumper be no longer than 10 centimeters. The jumper wire should use similar wire size (16 awg) and contacts (size 20) as wires that lead to the injectors.

Figure 28. Example of a Jumper Wire Used for a Unipolar Piezo Injector



Splitter-Junctions

As seen in Figure 29, several injector configurations require two wires attached to the same DI driver pin. While the diagrams show two wires terminating at the actual driver pin, this is not recommended in actual wiring practice. It is not possible to fit two 16 awg wires into the back of a single contact, and it is not recommended to use smaller wires for the sake of doing so. A special type of connector body, made by Deutsch is designed to act as a robust wiring junction for automotive use. The connector body contains 12 cavities for female contacts. The cavities are arranged in four groups of three. Each group is internally connected. Therefore, three wires can each be terminated with the proper contacts and inserted into the connector body for a secure junction. We recommend this splitter-junction system be used for any necessary driver-pin wire split. Four independent splitter-junctions can be achieved in a single connector. NI offers part number 785223-01 called "DCM-23XX Injector Multiplexing Junctions" for this purpose. More detail about each DCM accessory can be found in the "DCM Accessories" section, including manufacturer part numbers within each accessory kit.

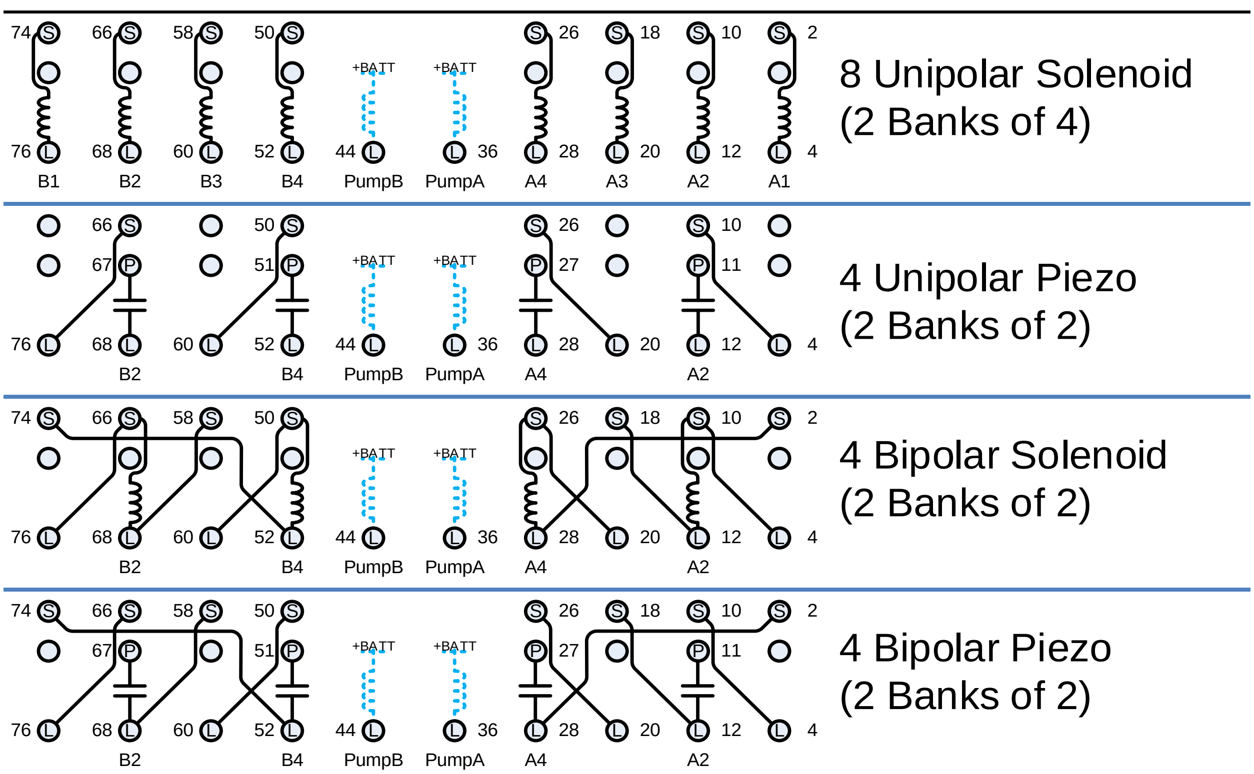
Figure 29. Splitter Junction

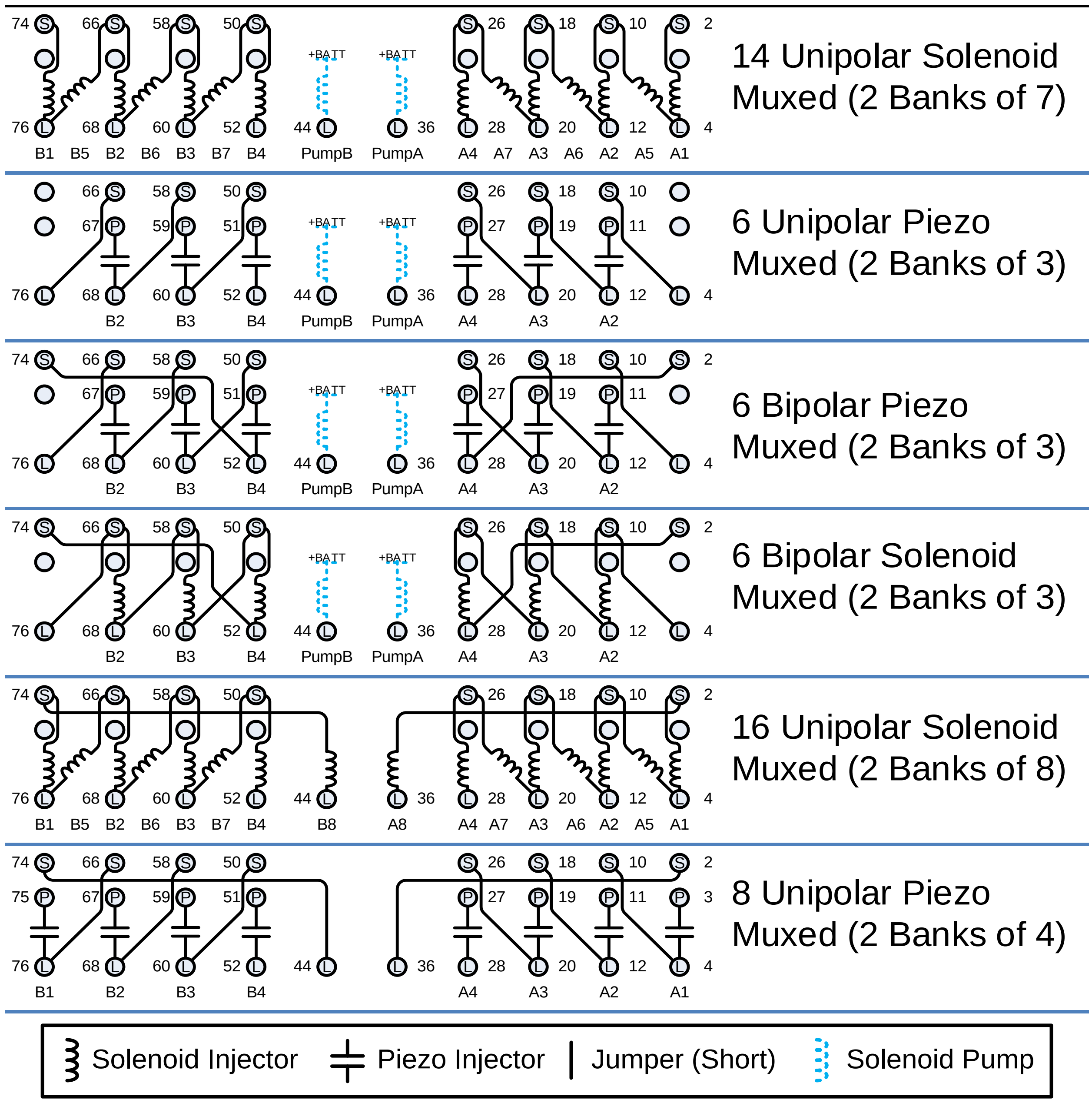
Modes of Direct Injector Operation

The DCM DI driver pins used for injectors varies depending on the Injection Mode configured in software. There are 10 different modes. Figure 30 shows the pins used, and connection diagrams for all injection modes. Each mode diagram shows the maximum number of injectors that can be connected for that mode, assuming both banks are configured (in software) for the same mode. Please note that each bank is independent from the other. Therefore, each bank can be configured for different injector modes.

Two of the multiplexed modes utilize the additional lowside pump driver channel to support injector operation. Therefore, an engine synchronous pump requiring high current drive cannot be used in those modes, for that bank.

Figure 30. DCM-23XX Injector Configurations





Solenoid Injector Current and Voltage Control

This section utilizes a popular Gasoline-Direct-Injector (GDI) to demonstrate several driver circuit and software features related to solenoid injector control. The electrical characteristics of the GDI solenoid are 2 mH (@1 kHz) and 1.5 Ω (DCR). The waveform screen shots are taken from the DI Scope feature within the DSI. The DSI documentation provides greater detail about the various controls within the user interface to configure these demonstrations. However, each demo below will specify the values of those relevant parameters. The use of bold text throughout this section calls attention to a parameter name or selection within the DSI user interface. This demo utilizes the manual one-shot trigger to command the DI driver channel for a single event at a specified duration. There are a variety of other methods to trigger channel events, including external digital input and engine position tracking. Those features are discussed in the section titled Channel Command Modes.

This demo assumes the following preparatory tasks have been completed, in the order listed:

- A single GDI is connected to channel A1 (Bank A) and configured for 4 Unipolar Solenoid mode.
- The DCM is properly powered at the BATT pin with a nominal 12 V (13.8 V is used for this demo).
- The DCM is running DSI, connected to a host PC, and the host is displaying the DSI user-interface using SCM.
- The injector mode for Bank A is configured for Unipolar Solenoid.
- The MPRD control is switched ON to energize the external Main Power Relay, allowing power to the DRVP pins.
- IO_LOCK+ and IO_LOCK- pins are connected, preferably via an external ESTOP switch. This places the DCM IO in an "Unlocked" state, allowing DI driver channels to operate.
- The secondary boost voltage set point is set to 65 V and the secondary boost is enabled.
- Channel A2 command source is configured for User One Shot, so that pressing the One-Shot button will trigger a single injection event of the specified duration. The event duration may vary throughout these demonstrations, but will generally be in the range of 1 to 5 milliseconds.

Basic Current and Voltage Profile

To demonstrate a basic GDI current and voltage profile we will start by configuring a three-phase profile as captured from DSI in Figure 32. Any injection event must operate in accordance to a specified **Phase Array**. Each element of the array contains a cluster of parameters that specify how the load should be driven during the phase. A **Phase Array** can contain up to 16 phases. For now, the Current Control method for each phase will be configured as **Closed Loop**, which utilizes both **Current High** and **Current Low**.

Figure 31. Basic GDI Phase Array Without Backboost

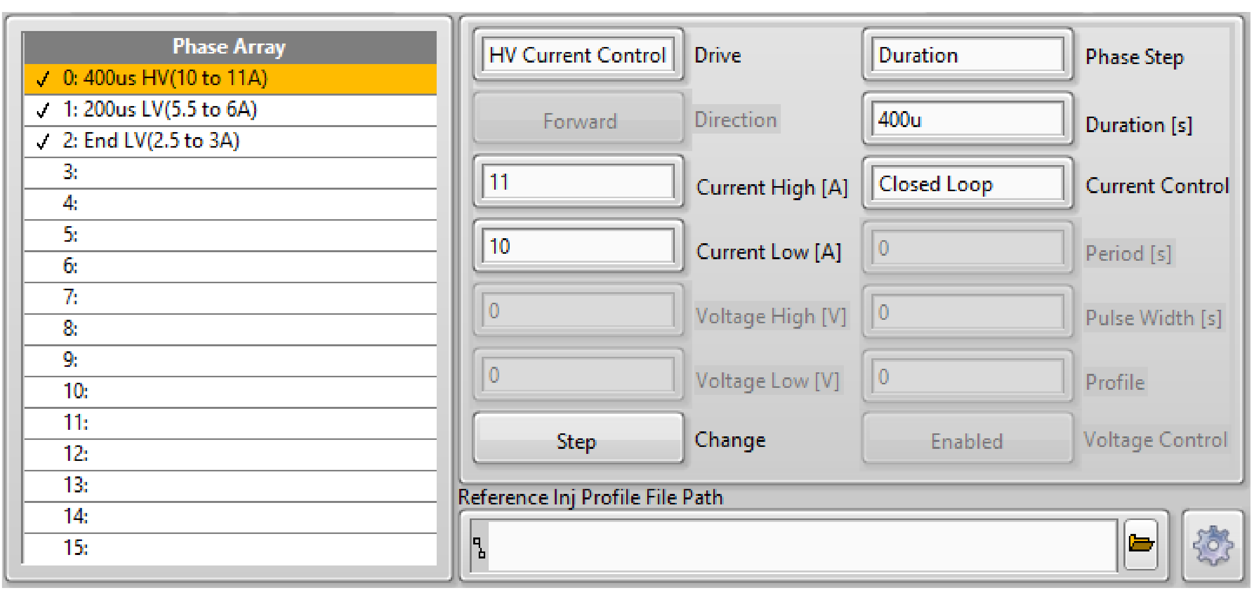


Figure 32. Basic GDI Operation Without Backboost

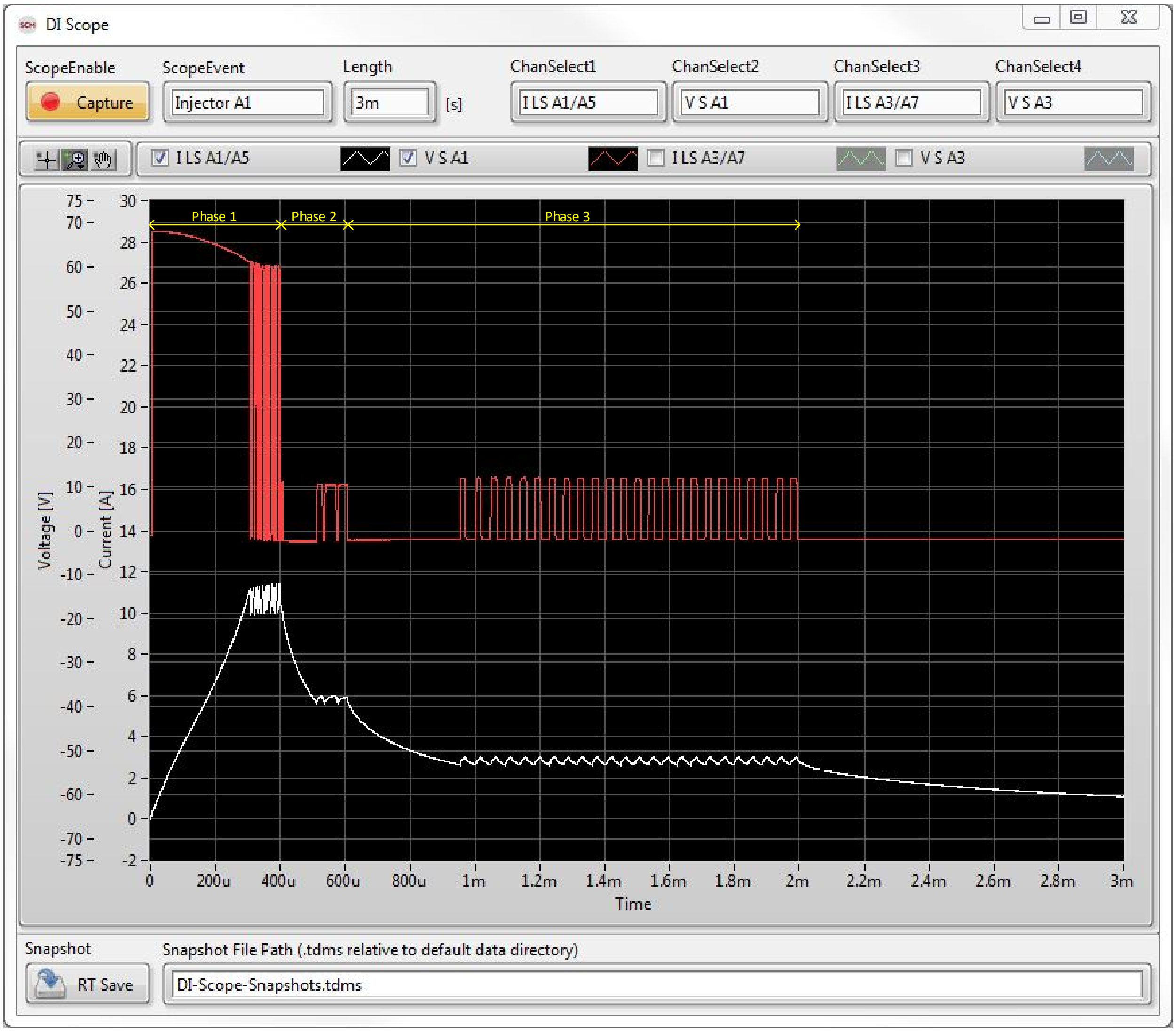


Figure 32 is annotated to show the phases according to the Phase Array. Phase 1 uses **HV** (i.e. Boost) to drive current to 11 A and dither between 10 A and 11 A for 400 µs. Phase 2 uses **LV** (i.e. DRVP) to drive current between 5.5 A and 6 A for 200 µs. Notice there is no LV drive until the current decays down to 5.5 A. Phase 3 starts after 600 µs with LV driving current between 2.5 A and 3 A, until the **End of Command**. After all specified phases are executed, the channel enters the **Idle** state, with both highside FETs OFF and the lowside FET ON.

Standard Backboost

Notice the current, after the end of command, decays gradually to 0 A in the Idle state. This is not desired behavior at the end of an injection event. An unknown quantity of fuel will dribble out of the injector while waiting for the current to decay enough for the valve to close. However, it is important to observe the dramatic difference between recirculation current and backboost. If we insert a 500 µs standard backboost phase before Idle, then the lowside FET will be turned OFF for 500 µs, upon the end of command. This blocks the recirculation path and the current falls sharply, as the lowside voltage spikes up. Once the lowside voltage rises above the boost supply, the solenoid energy dumps into the boost supply capacitance. Figure 34 shows a similar GDI waveform, but with a standard backboost phase added before Idle. Note that the voltage waveform is a differential measurement of highside – lowside. Therefore, the backboost voltage spike is negative.

Figure 33. Basic GDI Phase Array with Backboost

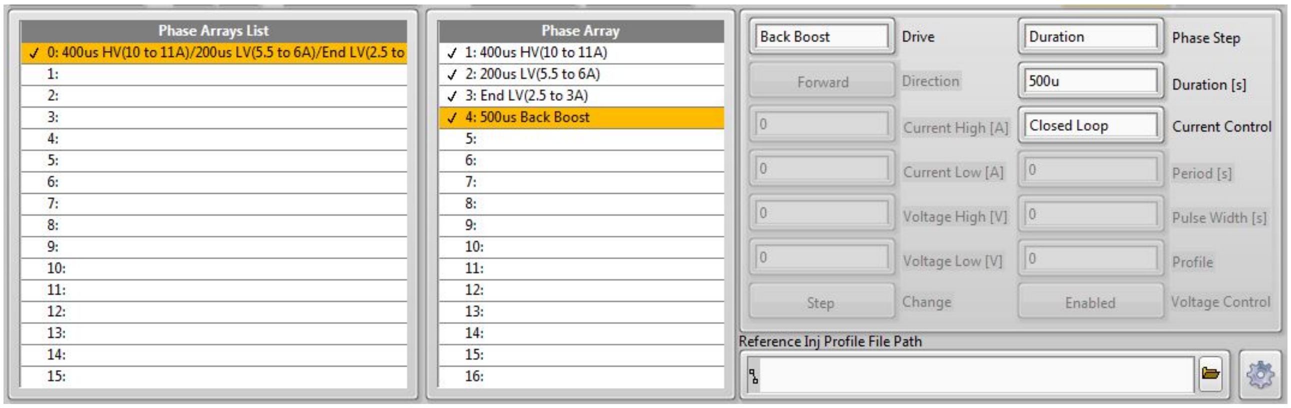


Figure 34. Basic GDI Operation with Backboost

First Peak

Now we will modify Phase 1 with a parameter **First Peak.** This causes the channel to automatically advance to the next phase after the upper current level is reached for the first time, or the duration expires, whichever occurs first. The phase duration should be set to a time longer than the time required to reach the first peak. The purpose of this feature is to facilitate more consistent application of drive energy from pulse to pulse. The injector manufacturer's datasheet should be consulted to know if the First Peak feature is critical to injector performance.

Figure 35. GDI Phase Array with Phase 1 First Peak

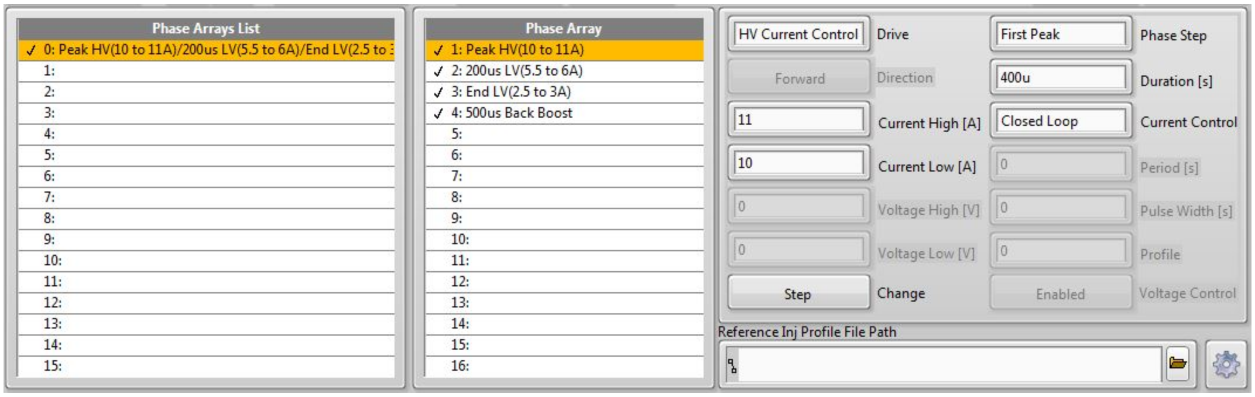


Figure 36. GDI Operation with Phase 1 First Peak

2-Phase Duration

After modifying Phase 1 to enable First Peak, the duration of Phase 1 may be uncertain from pulse to pulse. However, you can specify a total duration for Phase 1 and Phase 2, combined, by using the 2-Phase Duration option for Phase 2. Then the third phase will consistently start at the same time from pulse to pulse. Figure 37 demonstrates the 2-Phase Duration feature enabled for Phase 2, so that the total time for Phase 2 plus the previous phase is 600 µs.

Figure 37. GDI Phase Array With 2-Phase Duration Configured for Phase 2

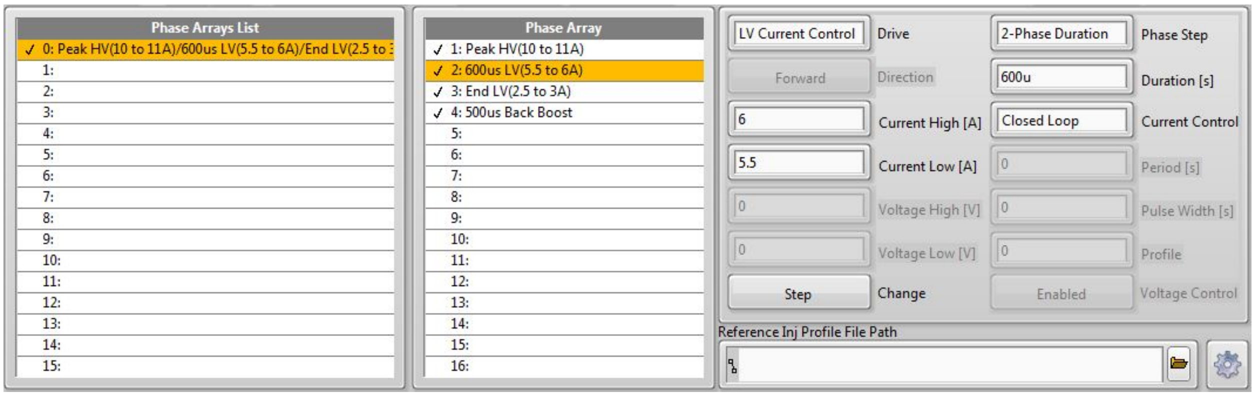


Figure 38. GDI Operation with 2-Phase Duration Configured for Phase 2

Programmable Zener Backboost

If a faster current drop is desired at the end of command, then the **Backboost** mode can be changed from **Standard** to **Zener**, and a Zener **Voltage** level can be specified. The Zener voltage, plus 5 V, is added to the boost voltage, to get the total backboost voltage. Figure 40 demonstrates a total backboost voltage of 120 V, by setting the Zener voltage to 50 V (i.e. 50V + 5V + 65V = 120V).

Figure 39. GDI Phase Array with Zener Backboost

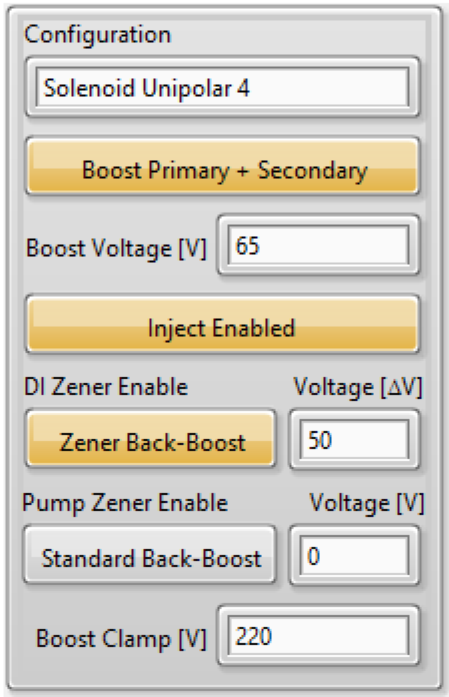
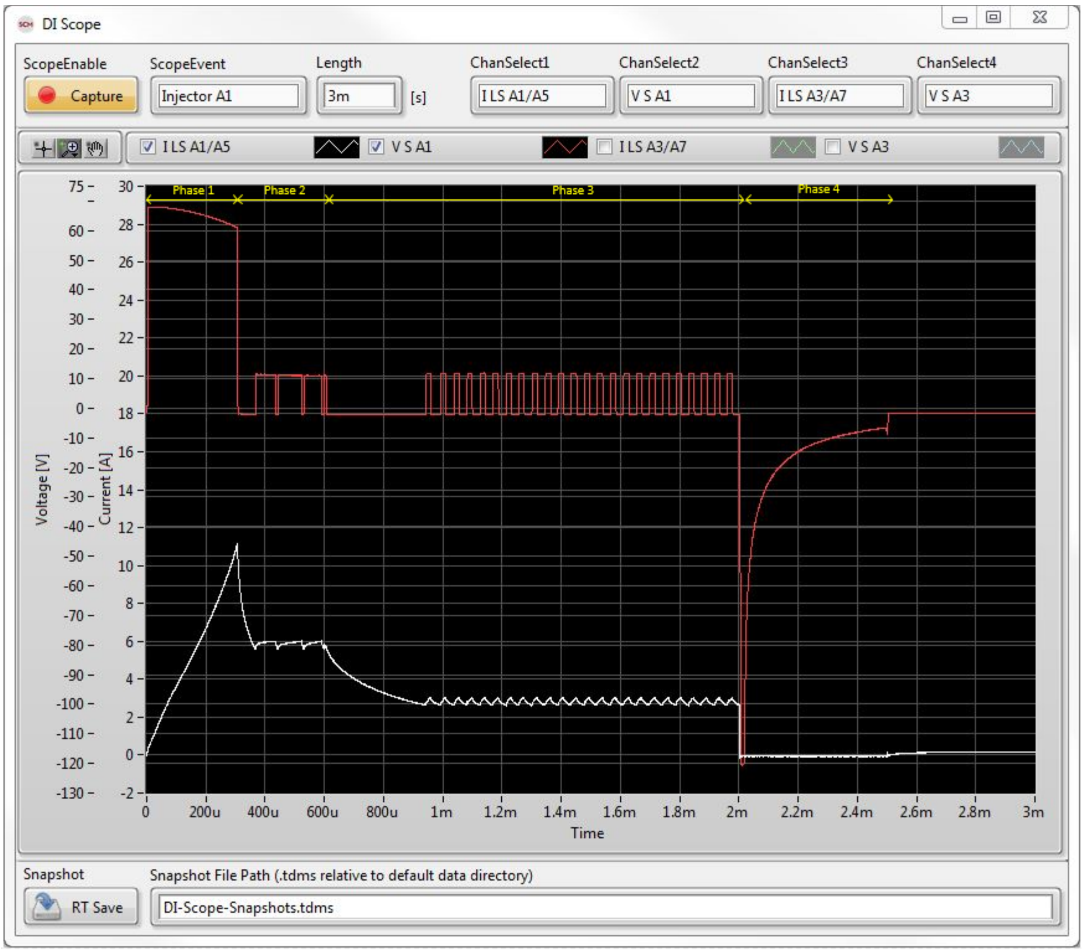


Figure 40. GDI Operation with Zener Backboost



It is also possible to insert a backboost phase during the injection event. Figure 42 demonstrates a **Back Boost** phase inserted between the second and third current-control phases. Thus, the Phase 2 current is brought down quicker than simply leaving it to recirculate and decay. Notice that the current measurement during the backboost phase drops to 0 A. This is because the DI driver channel is not able to measure lowside current while the lowside FET is OFF. However, the current dropped to approximately 3.2 A at the start of Phase 4.

Figure 41. GDI Phase Array with Inter-Phase Backboost

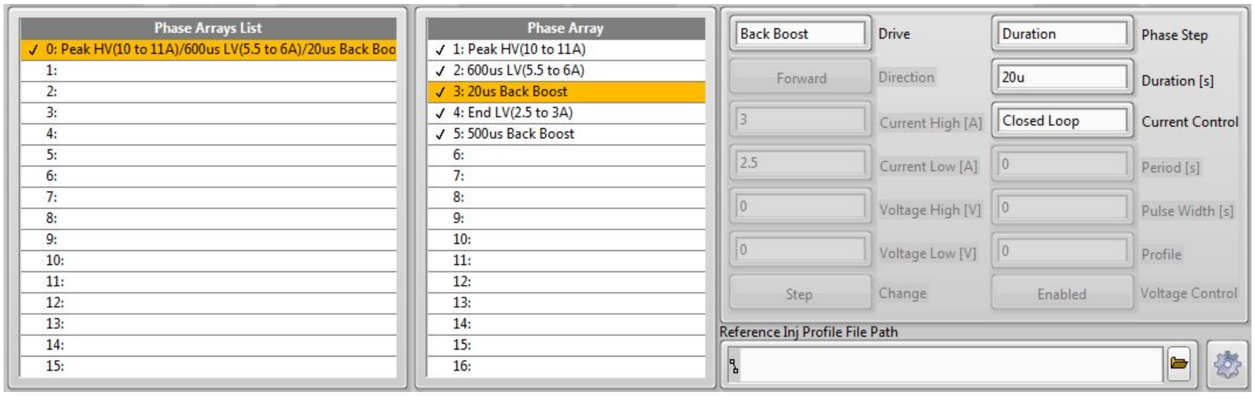
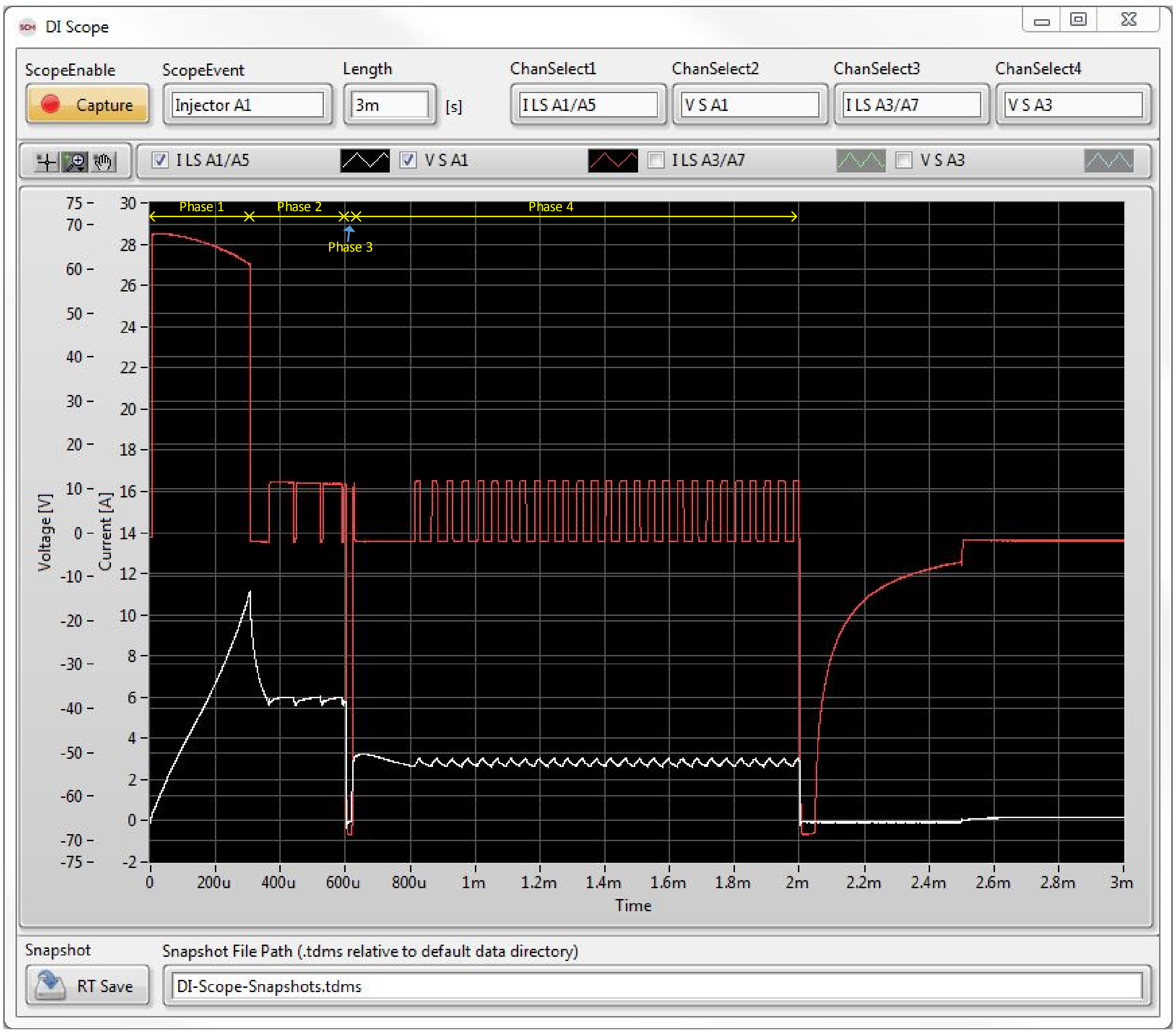


Figure 42 GDI Operation with Inter-Phase Backboost



Other Current Control Modes

So far, we have demonstrated a solenoid Phase Array that implements Closed Loop Current Control. There are five other current control methods available. Fixed Period, Fixed ON Pulse, and Fixed OFF Pulse are a combination of closed-loop and open loop control, because they use current feedback to automatically switch FETs at one current boundary while using a time parameter to switch again. Open Loop and Profile methods do not use current feedback.

Fixed Period

The **Fixed Period** method automatically switches the highside FET OFF at the **Current High** set point, and switches the highside FET ON at the end of the specified **Period**.

Fixed ON Pulse

The **Fixed ON Pulse** method switches the highside FET OFF until the **Current Low** set point is reached, and switches the highside FET ON for a specified **Pulse Width**.

Fixed OFF Pulse

The **Fixed OFF Pulse** method switches the highside FET ON until the **Current High** set point is reached, and switches the highside FET OFF for a specified **Pulse Width**.

Open Loop

The **Open Loop** method switches the highside FET ON for a specified **Pulse Width**, then switches OFF. The highside FET stays OFF for the remainder of the specified **Period**.

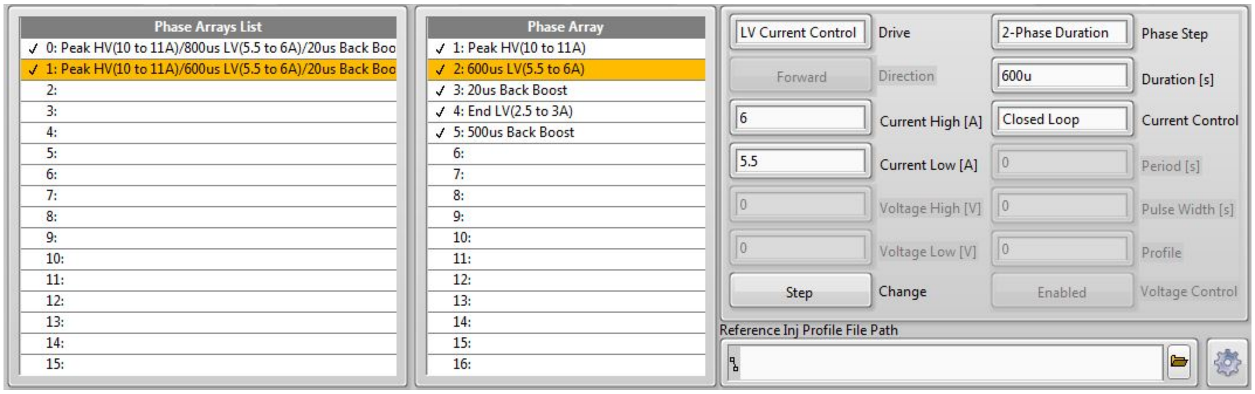
Profile

The **Profile** method allows the user to specify a complete pulse width profile for each FET pulse throughout the phase. Each pulse is executed per the specified fixed **Period**. This feature is most useful for piezo injector modes while using the **DI Phase Learn** feature in DSI.

Using Multiple Phase Arrays Among Multiple Injection Events

Figures 43 and 44 show two Phase Arrays specified for a GDI. The second Phase Array in the list is selected and therefore shown in detail in the Phase Array. Notice the second phase of each Phase Array uses different durations of 800 µs and 600 µs, respectively. Each Phase Array is identified by its index, 0 through 15. A multi-pulse injection cycle can be configured, either in Triggered Multi-Pulse (TMP) or Engine Position Tracking (EPT) command modes. The Phase Array indexes can be specified for each individual injection event, as shown in Figure 43. Figure 44 shows the DI Scope plot of two injection events from a TMP trigger. Each injection event uses a different Phase Array.

Figure 43. Two Phase Arrays Configured for Two Injection Events



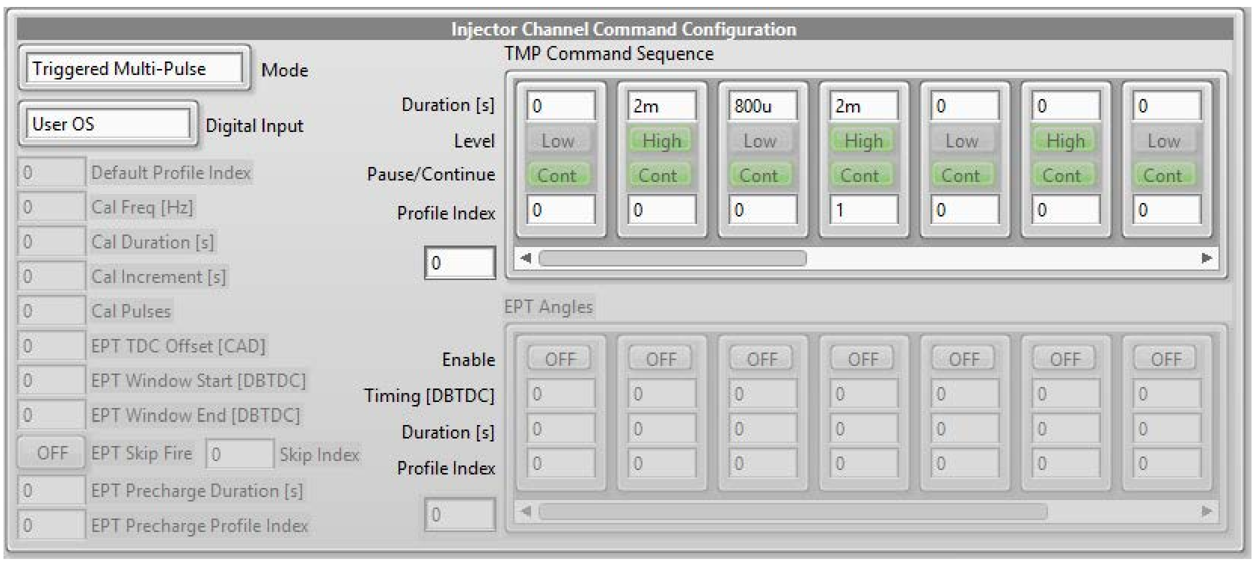


Figure 44. GDI Operation Using Multiple Phase Arrays

Using Multiple Phase Arrays for Injector Precharge

Figure 45 shows two **Phase Arrays** specified for a GDI. The first Phase Array consists of a single phase with LV drive to 1 A. The **Phase Step** is configured for **Branch**, and a timeout **Duration** of 1 ms. This Branch method is designed to work in conjunction with the Precharge feature of EPT channel command configuration, as shown in Figure 46. In the plot of Figure 47, the EPT function generates a Precharge trigger to Phase Array 0, 500 µs prior to the main injection command. The injection command specifies Phase Array 1. Phase Array 0 branches to Phase Array 1 upon the angle of the main injection command. The **Branch Duration** is a timeout value that should be longer than the actual **Precharge Duration**.

Figure 45 Two Phase Arrays Configured for Injector Precharge

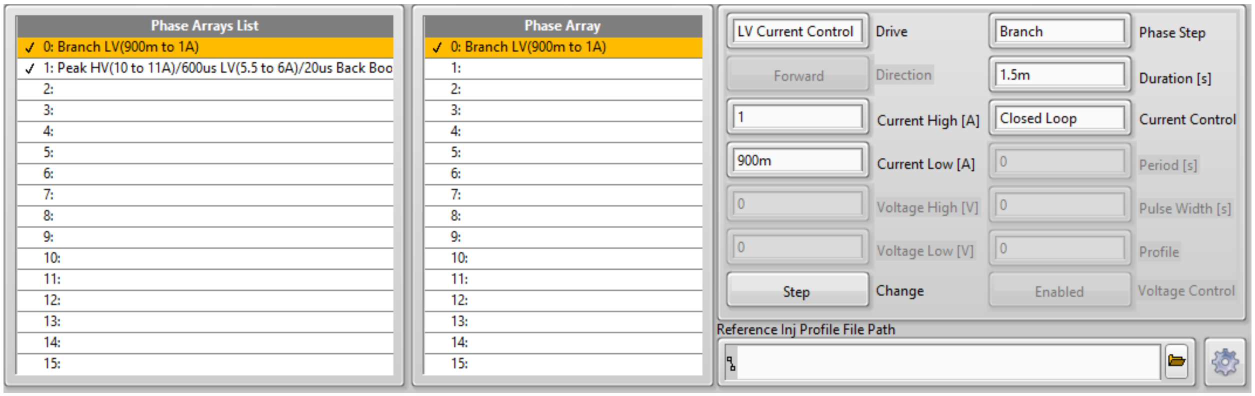


Figure 46 Injector Channel Command Configuration for EPT Precharge

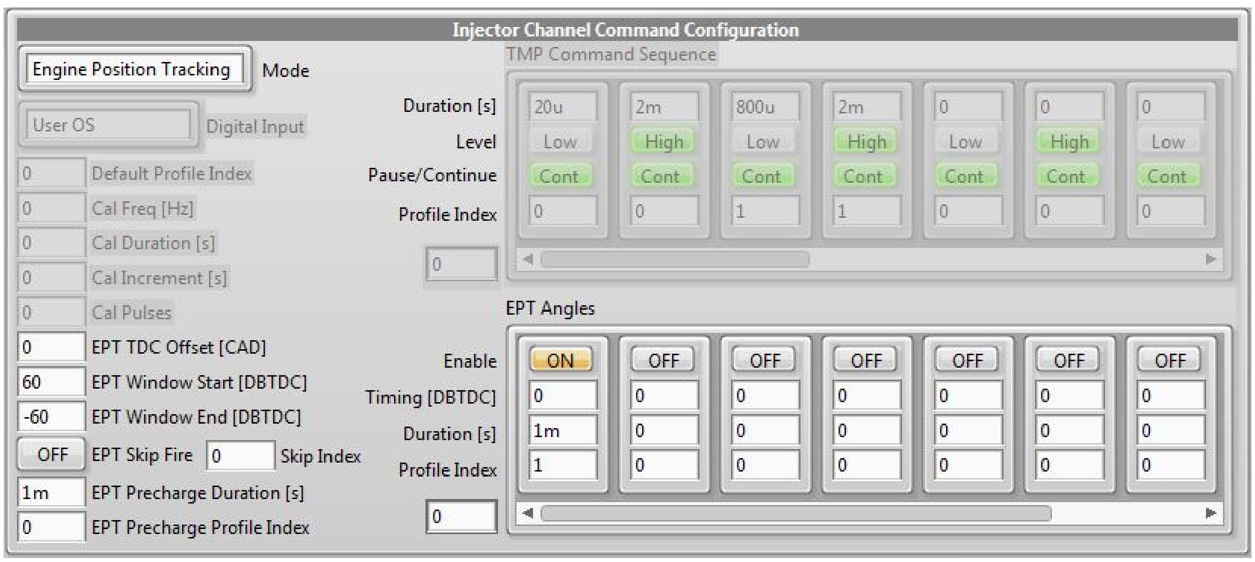


Figure 47 Plot of GDI Precharge Current and Voltage

Piezo Injector Current and Voltage Control

This section utilizes a popular common-rail diesel piezo injector to demonstrate several driver circuit and software features related to piezo injector control. The electrical characteristics of the piezo injector load are 2.2 µF (@10 kHz) and 0.3 Ω (ESR @10 kHz). The waveform screen shots are taken from the DI Scope feature within the DSI. The DSI documentation provides greater detail about the various controls within the user interface to configure these demonstrations. However, each demo below will specify the values of those relevant parameters. The use of **bold** text throughout this section calls attention to a parameter name or selection within the DSI user interface. This demo utilizes the manual one-shot trigger to command the DI driver channel for a single event at a specified duration. There are a variety of other methods to trigger channel events, including external digital input and engine position tracking. Those features are discussed in the section titled *Channel Command Modes*.

This demo assumes the following preparatory tasks have been completed, in the order listed:

- A single piezo injector is connected to channel A2 (Bank A) and configured for 4 Unipolar Piezo mode.
- The DCM is properly powered at the BATT pin with a nominal 12 V (13.8 V is used for this demo).
- The DCM is running DSI, connected to a host PC, and the host is displaying the DSI user-interface using SCM.
- The injector mode for Bank A is configured for Unipolar Piezo.
- The MPRD control is switched ON to energize the external Main Power Relay, allowing power to the DRVP pins.
- IO_LOCK+ and IO_LOCK- pins are connected, preferably via an external ESTOP switch. This places the DCM IO in an “Unlocked” state, allowing DI driver channels to operate.
- The secondary boost voltage set point is set to 170 V and the secondary boost is enabled.
- Channel A2 command source is configured for User One Shot, so that pressing the One Shot button will trigger a single injection event of the specified duration. The event duration may vary throughout these demonstrations, but will generally be in the range of 1 to 5 milliseconds.

Basic Current and Voltage Profile

To demonstrate a basic piezo injector current and voltage profile we will start by configuring a two-phase profile as captured from DSI in Figure 48. Any injection event must operate per a specified **Phase Array**. Each element of the array contains a cluster of parameters that specify how the load should be driven during the phase. A Phase Array can contain up to 16 phases. For now, the **Current Control** method for each phase will be configured as **Closed Loop**, which utilizes both **Current High** and **Current Low.**

Figure 48 Basic Piezo Injector Phase Array

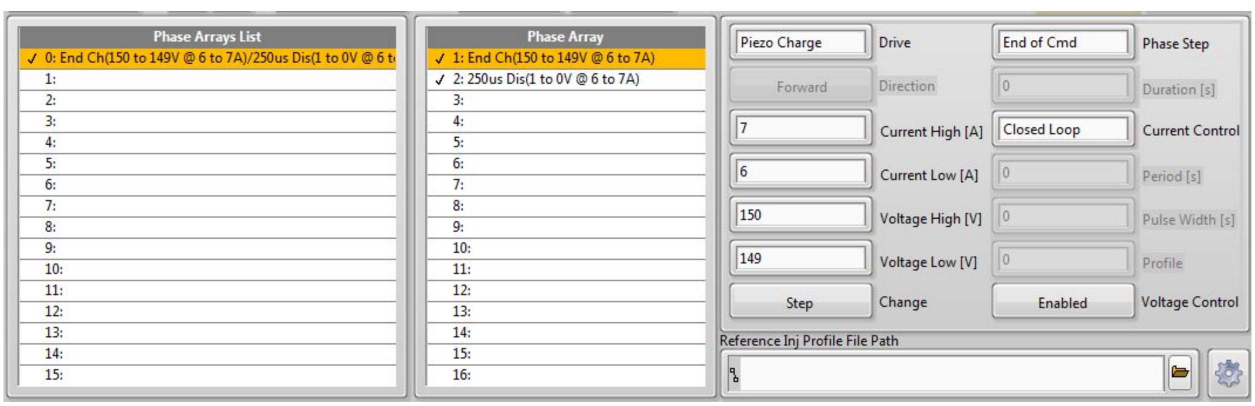
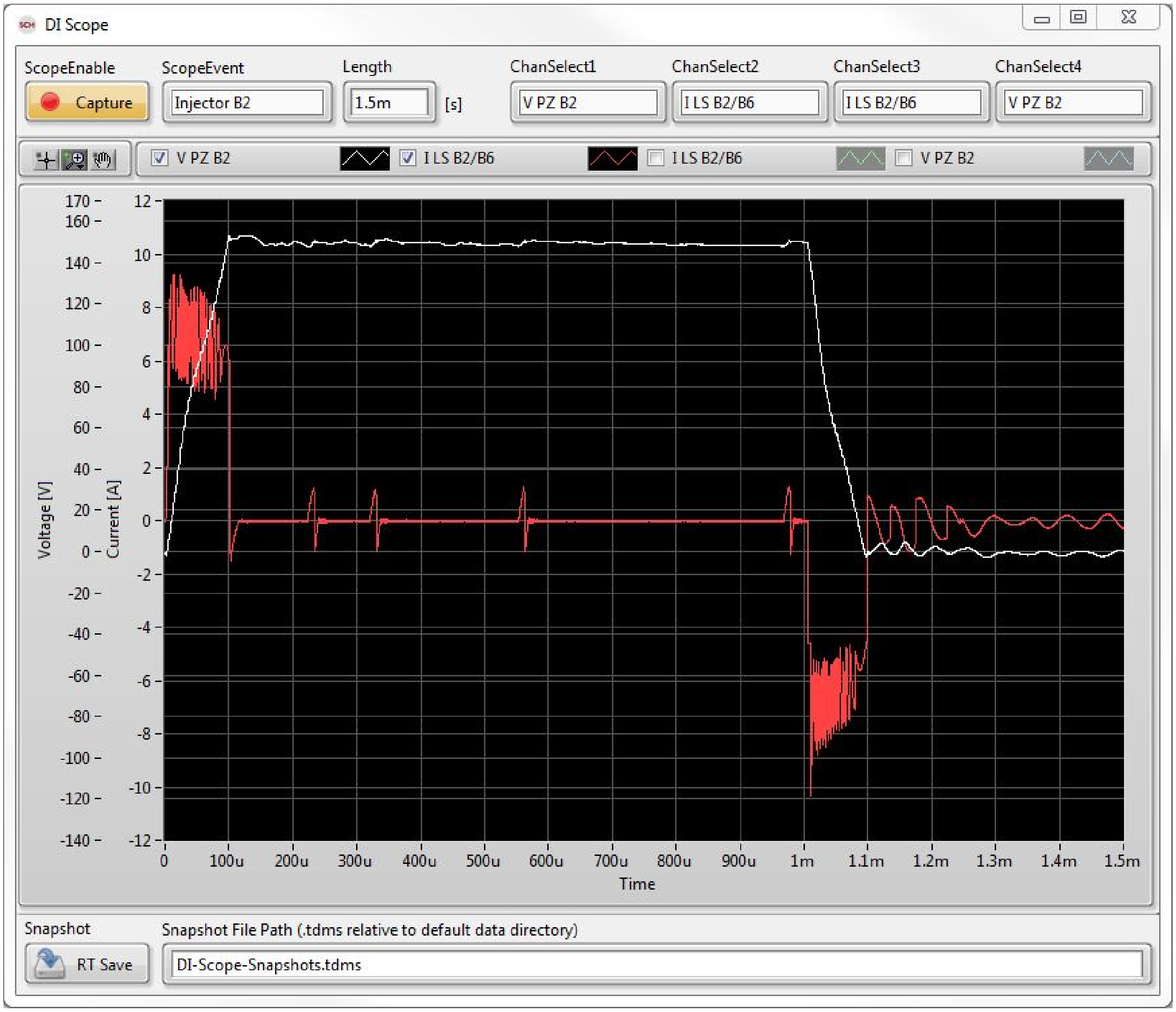


Figure 49 Basic Piezo Injector Operation



Phase 1 uses HV (i.e. Boost) to drive current to dither between 6 A and 7 A until the End of Command. This charges the capacitive load at a desired rate. However, it will only attempt to drive current while the piezo voltage is outside the voltage range specified by **Voltage Low** and **Voltage High**. Notice, after about 100 µs, the driver stops driving because the piezo voltage is within the target range of 149 V and 150 V. After this point, if the piezo voltage decays below 149 V then the driver attempts to drive current until the piezo voltage is back within range. This can be seen as small current spikes and coinciding piezo voltage bumps. Notice that in this simple example, Phase 1 is handling injector control from beginning to the **End of Command**. The injector valve will remain open as long as there is sufficient charge to the piezo stack. Therefore, we need to begin discharging the piezo stack immediately at the End of Command, to close the valve. Phase 2 takes over, triggered by the End of Command. As discussed above, the discharge is accomplished by an adjacent lowside FET connected to the highside of the piezo load via a jumper wire. The adjacent lowside FET will begin cycling to dither discharge current at the specified Phase 2 settings, until the piezo voltage reaches the target range of 0 V to 1 V. A duration of 250 µs is specified for this phase that will allow enough time for complete discharging. After all phases are executed, the channel enters the **Idle** state, with highside FETs OFF and the lowside FET ON. Notice that the secondary boost voltage set point is about 10 V higher than the piezo charge voltage in the Phase Array. This head-room allows the piezo charge voltage to be more consistent throughout the injection event, and from pulse to pulse, even though the boost voltage fluctuates.

Multiple Piezo Voltage Levels Within Injection Events

Figure 51 shows a Phase Array configured for multiple voltage levels within a single injection event. Starting with the two-phase array above, two additional phases are inserted at the beginning, specifying two different voltage levels. Each phase also specifies different current levels to demonstrate different charge rates within the voltage profile. The profile being demonstrated is not necessarily a useful profile, but demonstrates the current and voltage control features of piezo injector mode.

Figure 50 Piezo Injector Phase Array with Multiple Voltage Phases 120, 135, 150

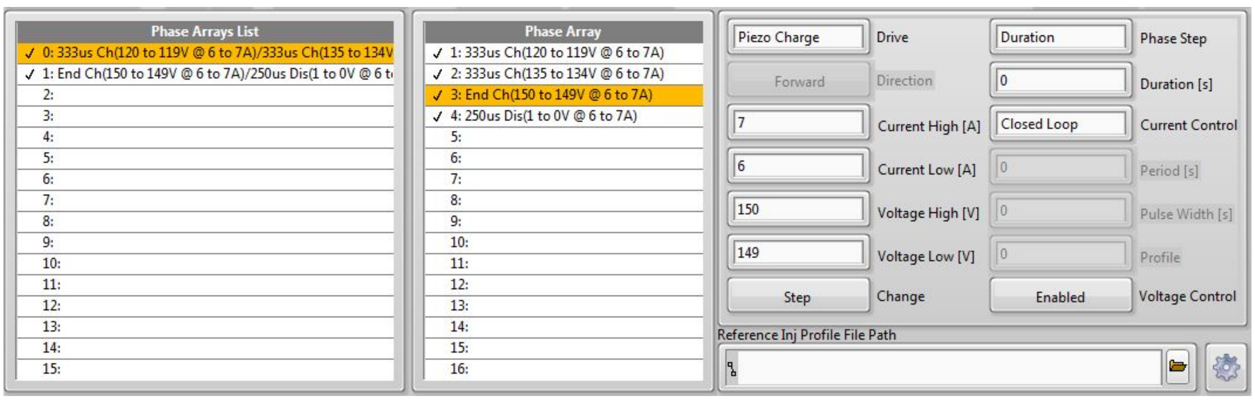


Figure 51 Piezo Injector Operation with Multiple Voltage Phases

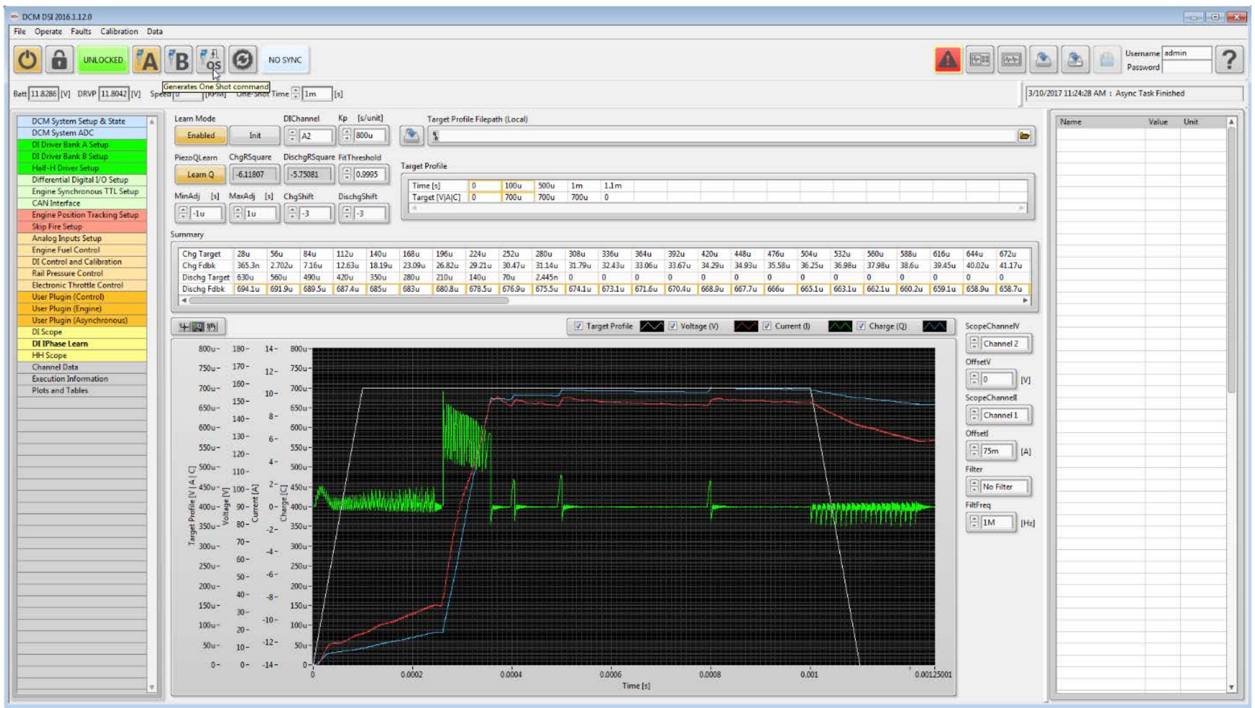
Learning Piezo Profiles

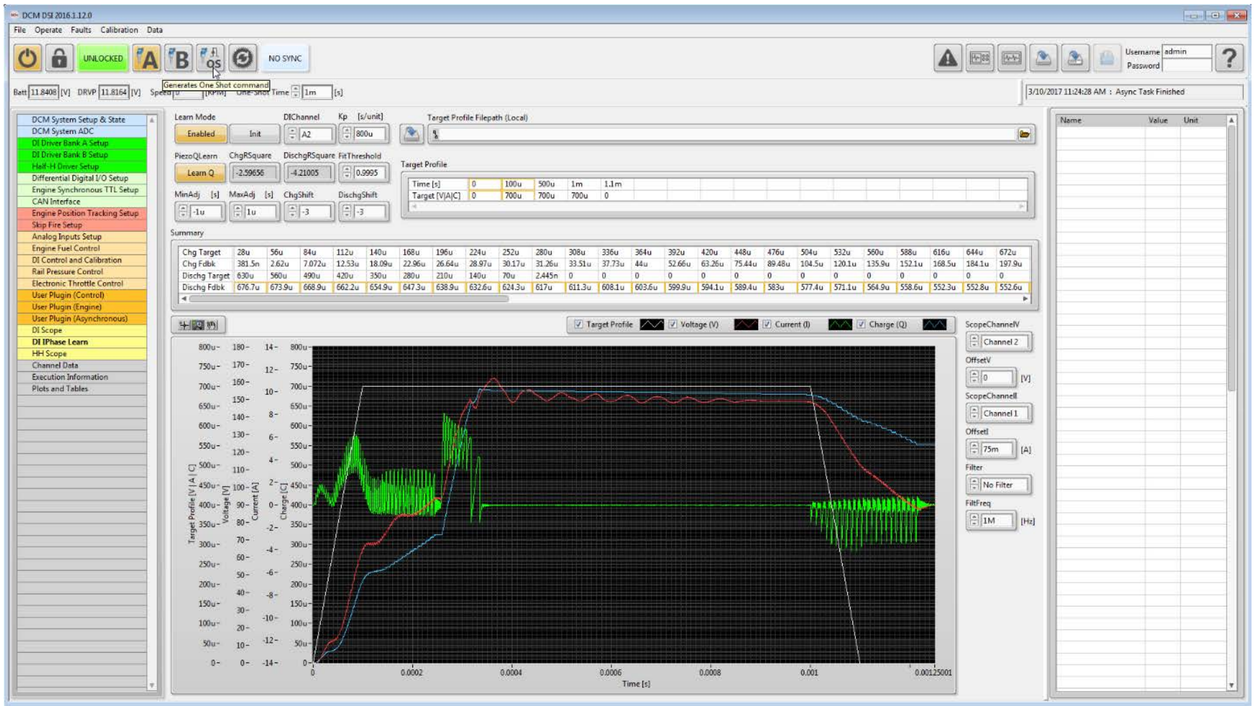
The DSI also includes a piezo profile-learn feature that can quickly build an open-loop pulse-width profile to match a target voltage profile. The open loop pulse-width profile was discussed briefly in the section above about operating a solenoid GDI. One or more of those profile arrays can be used with the piezo learn feature. Via the DSI user-interface, the user must import a CSV or tab-delimited waveform that specifies the target voltage throughout the injection event. Using DI Scope, the learn function monitors each injection command and compares the actual waveform to the target. Then the function applies a simple feedback/adjust algorithm to the profile using a few tunable parameters. Each profile element is adjusted, per the algorithm parameters, to minimize the waveform error on the next injection event. After about 100 injection events, the algorithm typically converges on an open loop profile with minimal error. Note that the learn function does not work in bipolar piezo modes and only works for monotonically increasing charge waveforms, or monotonically decreasing discharge waveforms. The default values for the tunable parameters have been calibrated by NI PCG engineers and provide a good starting point. The parameters may need adjustment for your specific application. The tunable parameters are associated with feedback filtering, pulse-width adjustment gain, and phase shift. The phase shift controls the alignment of the profile elements with the feedback waveform, which considers the round-trip feedback-to-command propagation delays.

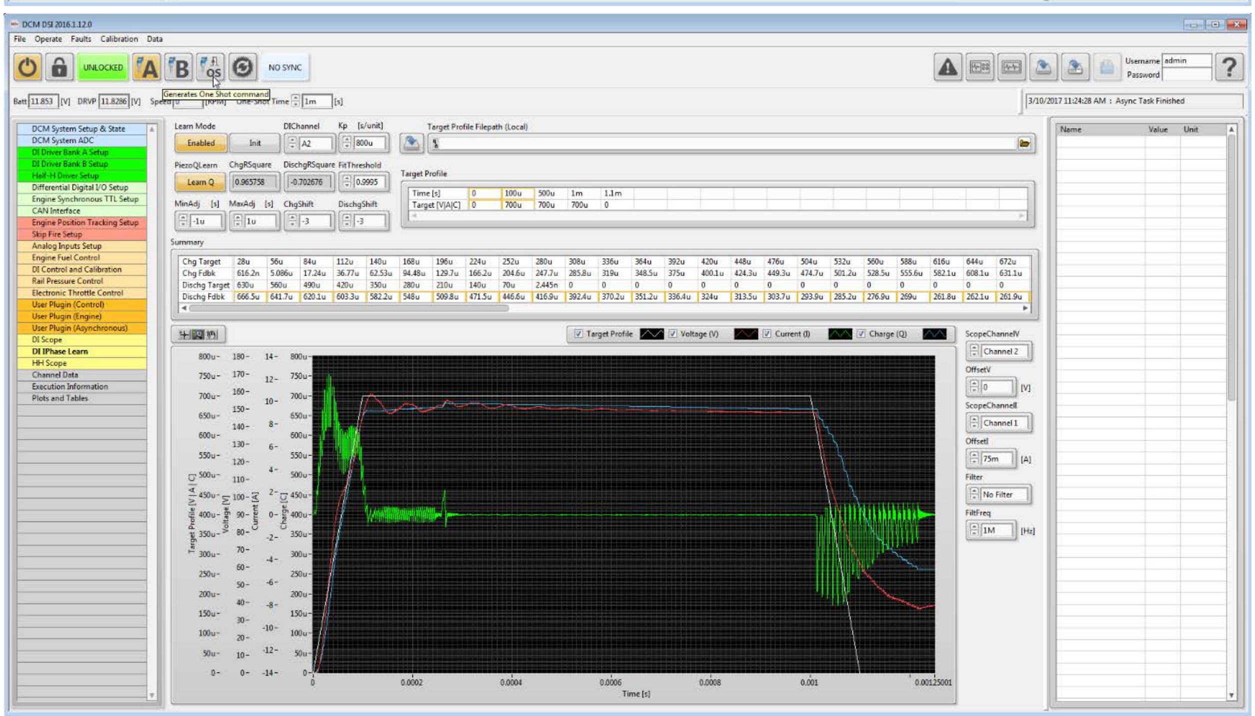
After the learning process develops a profile that is satisfactory to the user, then learning can be disabled, while continuing to use the fixed learned profile. Multiple phases can be utilized during an injection event using multiple learned profiles. The final target voltage can be adjusted within each phase.

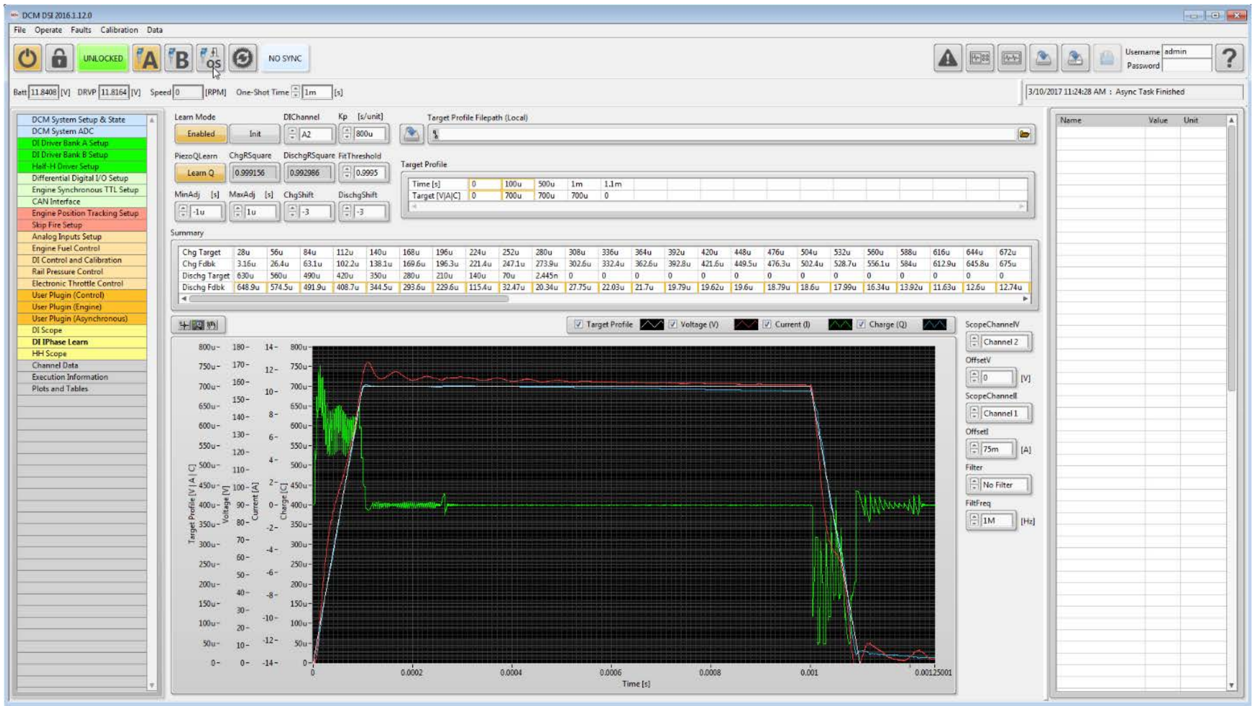
Figure 51a Shows a series of DI Scope waveforms of the piezo voltage during the learn process. For this demonstration, 50 injection events were used at 250 ms intervals, to converge on a final learned profile.

Figure 51a. Piezo Injector Profile Learning









Engine-Synchronous Fuel Pump Current and Voltage Control

This section utilizes a popular engine-synchronous GDI high pressure pump to demonstrate the dedicated pump driver circuit and software features related to pump solenoid control. The electrical characteristics of the GDI pump solenoid are 1 mH (@1 kHz) and 0.5 Ω (DCR). The waveform screen shots are taken from the DI Scope feature within the DSI. The DSI documentation provides greater detail about the various controls within the user interface to configure these demonstrations. However, each demo below will specify the values of those relevant parameters. The use of **bold** text throughout this section calls attention to a parameter name or selection within the DSI user interface. This demo utilizes the manual one-shot trigger to command the DI driver channel for a single event at a specified duration. There are a variety of other methods to trigger channel events, including external digital input and engine position tracking. Those features are discussed in the section titled Channel Command Modes.

This demo assumes the following preparatory tasks have been completed, in the order listed:

- The lowside of a GDI pump solenoid is connected to channel PumpA (Bank A). The highside of the pump solenoid is connected externally to DRVP.
- The DCM is properly powered at the BATT pin with a nominal 12 V (13.8 V is used for this demo).
- The DCM is running DSI, connected to a host PC, and the host is displaying the DSI user-interface using SCM.
- The injector mode for Bank A is configured for Unipolar Solenoid. This is one of several modes that does not utilize the PumpA channel for multiplexed injector operation.
- The MPRD control is switched ON to energize the external Main Power Relay, allowing power to the DRVP pins.

- IO_LOCK+ and IO_LOCK- pins are connected, preferably via an external ESTOP switch. This places the DCM IO in an "Unlocked" state, allowing DI driver channels to operate.
- It is not necessary to enable the secondary boost supply for this demonstration because the dedicated pump channel does not have an associated highside FET.
- Channel PumpA command source is configured for User One Shot, so that pressing the One-Shot button will trigger a single injection event of the specified duration. The event duration may vary throughout these demonstrations, but will generally be in the range of 1 to 5 milliseconds.

Basic Current and Voltage Profile

To demonstrate a basic GDI pump current and voltage profile we will start by configuring a two-phase profile as captured from DSI in Figure 52. Any pump event must operate per a specified **Phase Array**. Each element of the array contains a cluster of parameters that specify how the load should be driven during the phase. A Phase Array can contain up to 16 phases. For this demonstration, the Current Control method for each phase will be configured as **Fixed OFF Pulse**, which utilizes the **Current High** set point only. It is not possible to use **Closed Loop** current control mode with the lowside Pump channel because the internal current sense measurement is below the lowside FET. It is only possible to measure current while the lowside FET is ON (closed), allowing current to flow through the sense resistor. In the **Fixed OFF Pulse** mode, the FET is turned on until the current reaches the **Current High** set point. Then the FET is turned OFF for a fixed amount of time.

Figure 52 Basic GDI Pump Phase Array Without Backboost

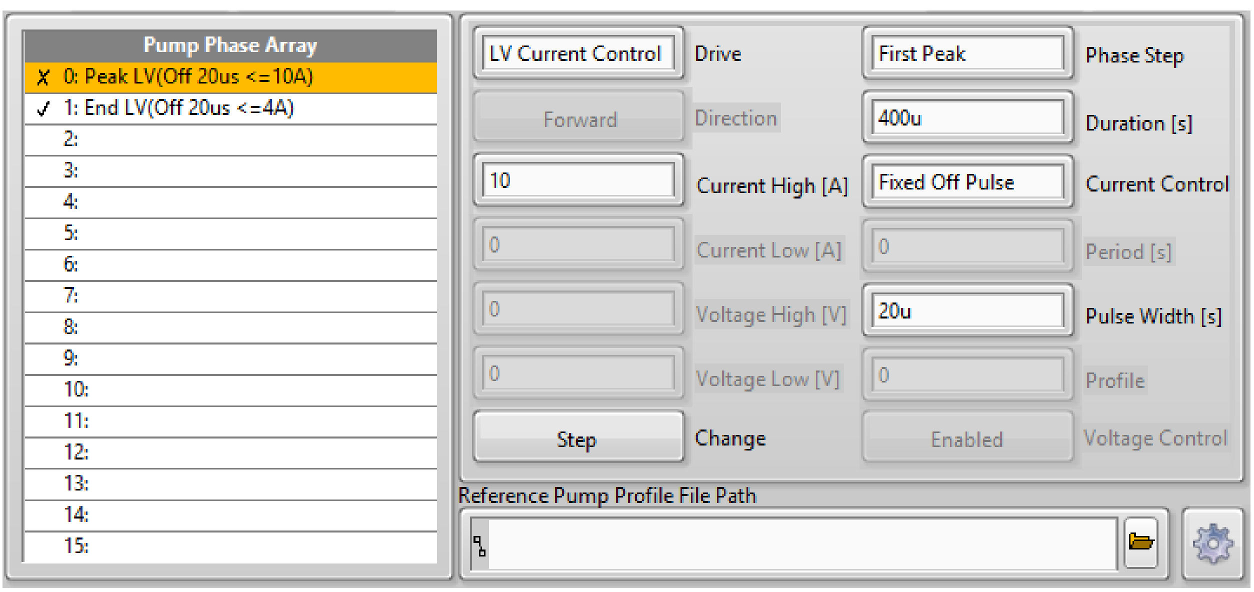
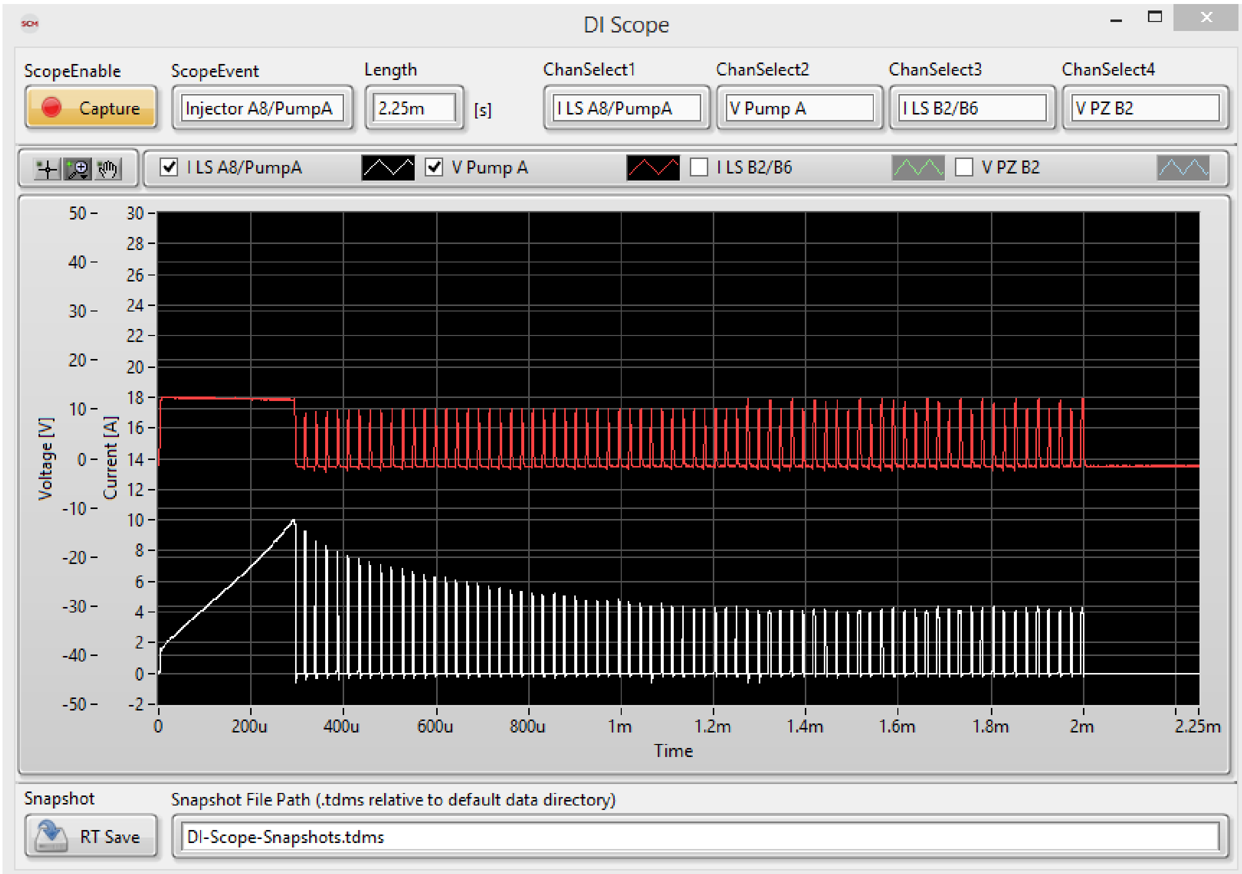


Figure 53 Basic GDI Pump Operation Without Backboost



Phase 1 uses external DRVP to drive current to 10 A until the first peak is reached. The Phase 1 duration is set to 400 µs, but for this particular solenoid, the actual Phase 1 time to reach the first peak is 300 µs. Phase 2 uses external DRVP to dither current around 4 A, until the End of Command. After all specified phases are executed, the channel enters the Idle state, with the lowside FET OFF.

Standard Backboost

Without a backboost phase, the valve behavior is unknown during this current recirculation period. If we insert a 250 µs standard backboost phase before Idle. This blocks the recirculation path and the current falls sharply, as the lowside voltage spikes up. Once the lowside voltage rises above the boost supply, the solenoid energy dumps into the boost supply capacitance. Figure 55 shows a similar GDI pump waveform, but with a standard backboost phase added before Idle. Note that the voltage waveform is a differential measurement of highside – lowside. Therefore, the backboost voltage spike is negative.

Figure 54 Basic GDI Pump Phase Array with Backboost

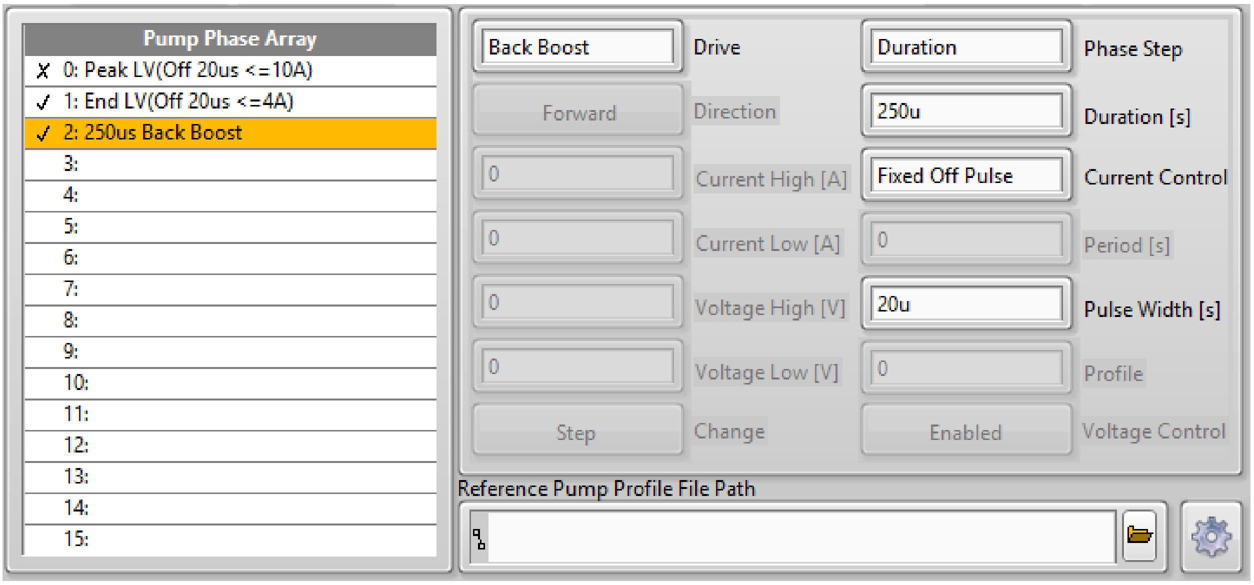
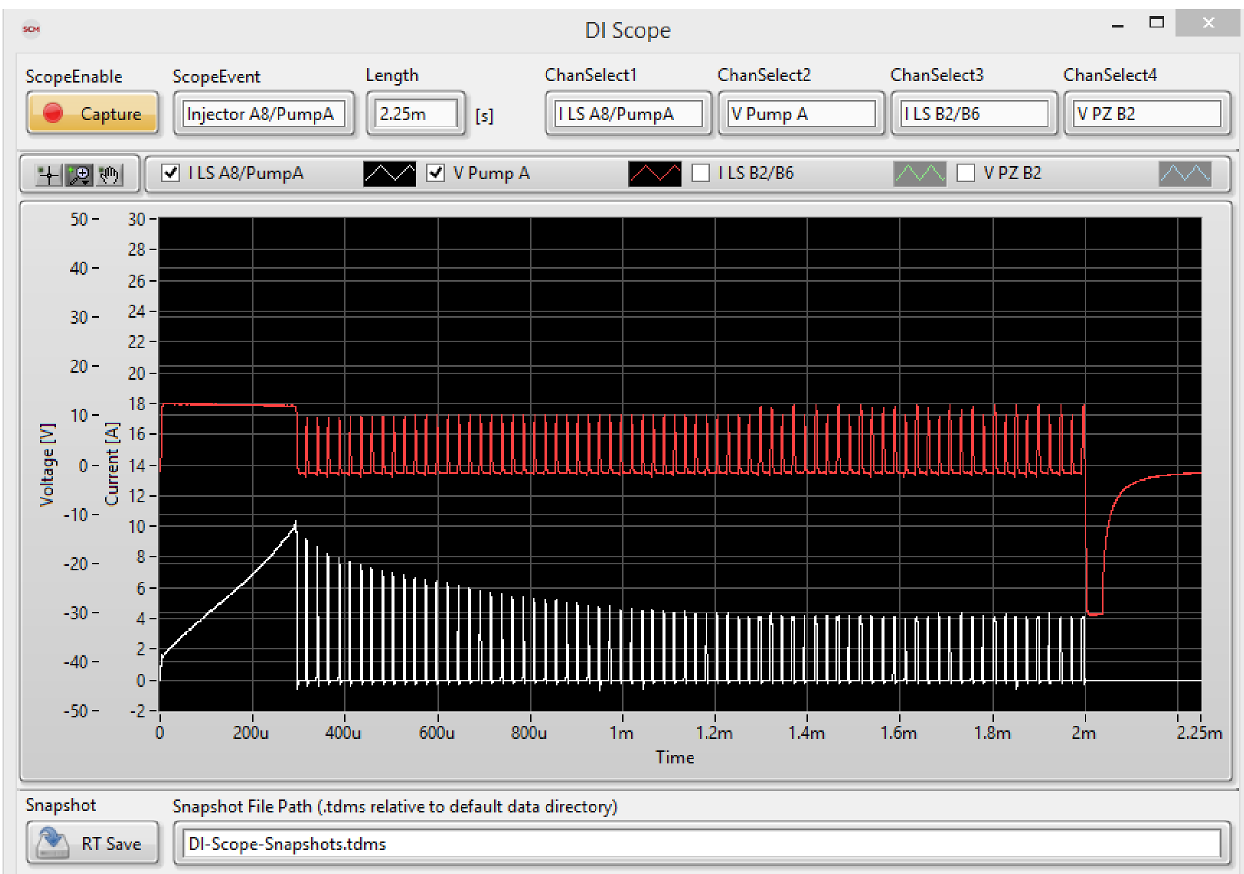


Figure 55 Basic GDI Pump Operation with Backboost



General Purpose Half-H-Bridge Drivers

Load Types Supported

The general purpose Half-H-Bridge (HH) drivers can drive inductive or resistive loads. Each HH channel can be configured to operate as a highside or lowside driver with currents up to 8 A peak and 4 A continuous. Under these specifications, a wide variety of actuator and load types are supported. This section will describe the most common actuator types encountered in automotive systems that can be operated by the general purpose HH driver channels.

Port Fuel Injectors

Port Fuel Injectors (PFI) are commonly operated using a lowside driver, such that the high side of the load is connected to external DRVP. Most PFIs are further specified as having a low-impedance or high-impedance solenoid. The high-impedance PFI solenoid has about 12 Ω DCR, while the low-impedance type has about 2 Ω DCR. The high impedance type requires less sophisticated drive electronics because the lowside FET simply needs to turn ON continuously throughout the injection command while the current through the solenoid saturates at approximately 1 A (assuming a nominal battery voltage of 12 V). The low-impedance type requires current control logic to drive two phases of current during the command. The first phase is 4 A to properly open the injector valve. The second phase is 1 A to hold the valve open until the end of command. If a low impedance injector is operated by a driver channel designed for high impedance injectors only, then it is likely the driver channel or injector will soon fail because the current will saturate at 4 A throughout the command. The DCM HH driver channels can perform multiple phases of current control during commands. It is important that current to a PFI can recirculated during current control within the command, but not recirculate at the end of command. The HH driver channel supports this mode of operation.

Proportional Solenoid Valves

Proportional solenoid valves are very common powertrain control actuators. They utilize a solenoid, operated via a PWM driver, to drive an average current which proportionally opens or closes a valve. The valve controls flow of air, oil, fuel or coolant to control some aspect of the engine. Most proportional solenoid valves are operated with a simple lowside driver FET, such that the highside of the solenoid is connected to DRVP, while the lowside is connected to the driver circuit. The lowside driver circuit must operate in PWM-fashion to dither current to the solenoid. It is important that the driver circuit allow current to recirculate through the solenoid during the OFF-portion of the PWM. The DCM HH driver channels can operate proportional solenoid valves in this manner, and operate as a highside driver.

Electronic Throttle Bodies

Electronic throttle bodies typically implement a brushed DC motor to actuate a butterfly valve. The Throttle bodies have built-in analog position sensors to provide valve position feedback. Most electronic throttle bodies require current to be driven bi-directionally to achieve the desired position control performance, and to fully close the valve. Therefore, a full-H-bridge driver circuit is required. Adjacent DCM HH driver channels can be coupled together in software to act as a full-H-bridge driver. In this mode, the two HH channels work together to drive current in either direction while implementing shoot-through protection to protect the driver channels. The DCM DSI also includes higher-level throttle body position control functions and handle throttle control challenges such as stiction, limp-home position, and range calibration.

Relays

Relays utilize a solenoid to actuate a switch to carry larger currents, or accommodate higher voltages than the driver channel can support. Relay solenoids typically require currents less than 1 A. Some relays have built-in recirculation diodes; however, recirculation is part of the DCM HH driver circuit in lowside or highside operating mode.

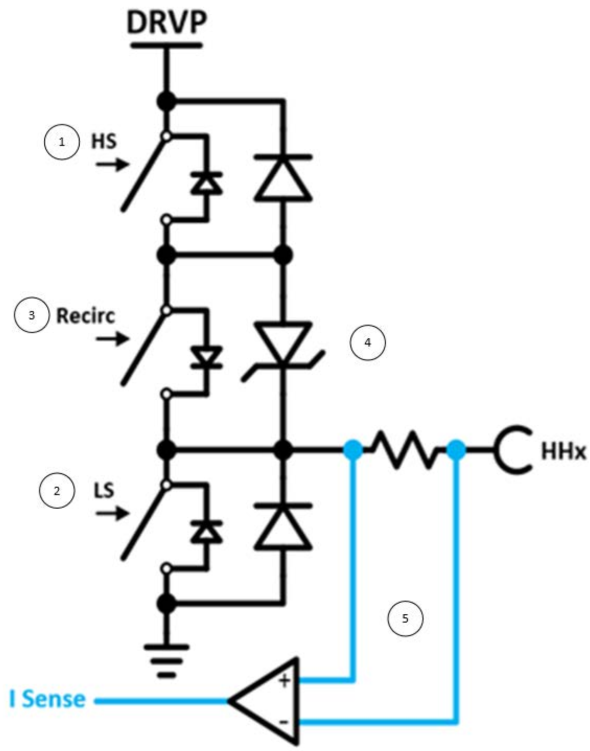
Resistive Loads

Pure resistive loads can be supported by the DCM HH drivers so long as the continuous current does not exceed 4 A. The heating element within a narrow-band exhaust oxygen sensor is an example of a resistive load supported by the DCM HH drivers. Sometimes it is useful to utilize the DCM HH driver channels to generate a 0 V – 5 V (or 0 V to DRVP) digital command to an external device. This can be supported by the HH drivers in either lowside or highside operating mode. If lowside mode is used, then an external pullup resistor would be connected between an external 5 V supply and the HH driver pin. If highside mode is used, then an external pulldown resistor would be connected between PGND and the HH driver pin.

Half-H Driver Channel Architecture

There are 12 identical, independent HH driver channels within the DCM. A half-H driver provides a highside FET and lowside FET connected to the same pin. Internally the highside FET switches DRVP to the pin, and the lowside FET switches the pin to PGND. If both FETs are turned on at the same time, there would be an internal short circuit from DRVP to PGND. However, the circuit design and software prevent this from happening for the various modes of operation. Figure 56 shows a simplified circuit diagram of a single HH driver channel. The sections below describe the numbered circuit features.

Figure 56 Simplified Circuit Diagram of a Single General Purpose Half-H Driver Channel



Highside Drive (1)

The Highside (HS) FET is an N-channel FET controlled by a MOSFET driver circuit. The HS MOSFET driver is commanded by a digital output from the controller FPGA. When this FET is ON, internal DRVP is delivered to the highside of the load via the Recirc FET, current-sense resistor, and the HHx pin. The lowside of the load must be externally connected to PGND.

If the channel operating mode is highside drive, and a current drive profile is configured, then the HS FET is automatically controlled to dither the current between the specified upper and lower current setpoints throughout the channel command.

If the channel operating mode is highside drive, and the user wants to directly command the HS FET, then the current drive profile values should be set higher than the desired current range. This will allow the channel command to directly operate the HS FET. In this case, the current profile values only act as an upper safety limit.

Lowside Drive (2)

The Lowside (LS) FET is an N-channel FET controlled by a MOSFET driver circuit. The LS MOSFET driver is commanded by a digital output from the controller FPGA. When this FET is ON, the lowside of the load is connected to PGND via the HHx pin and current sense resistor. The highside of the load must be externally connected to DRVP.

If the channel operating mode is lowside drive, and a current drive profile is configured, then the LS FET is automatically controlled to dither the current between the specified upper and lower current setpoints throughout the channel command.

If the channel operating mode is lowside drive, and the user wants to directly command the LS FET, then the current drive profile values should be set higher than the desired current range. This will allow the channel command to directly operate the LS FET. In this case, the current profile values only act as an upper safety limit.

Recirculation FET (3)

The Recirculation (Recirc) FET is a P-channel FET controlled by a MOSFET driver circuit. The Recirc MOSFET driver is commanded by a digital output from the controller FPGA. When this FET is ON, and the HS and LS FETs are OFF, current is allowed to recirculate through the load.

In highside drive mode, the Recirc FET is always ON.

In lowside drive mode, the Recirc FET is always ON.

In full H-Bridge mode, the Recirc FETs of both HH channels are always ON.

In PFI drive mode, The Recirc FET is ON while the channel command is ON, and OFF while the channel command is OFF. When the channel command is OFF, any energy in the solenoid is forced through the PFI-Zener to DRVP. This feature brings the solenoid current to 0 A quickly so that the injector valve is closed quickly at the end of command.

PFI-Zener Clamp (4)

The PFI-Zener Clamp is only utilized in PFI mode. At the end of a PFI command, the Recirc FET is opened, which causes a voltage spike at the HHx pin. When the differential voltage across the injector solenoid spikes to 26 V, the energy is forced through the PFI-Zener clamp circuit to quickly dump the energy to DRVP through a diode pointing to DRVP. For a typical PFI solenoid, this energy dump takes approximately 100 µs.

Current Sense (5)

The current sense circuit is able to measure currents in the range of -9.17 A to +9.17 A with a resolution of 4.5 mA, at a rate of 500 kS/s. Each HH channel has its own current sense, and is used as feedback for current control with the HS or LS FET, depending on operating mode. The current sense measurements are available to higher level software for other data acquisition and control tasks. In highside mode, current flows out of the HHx pin (sourcing) and positive currents are measured. In lowside mode, current flows into the HHx pin (sinking) and negative currents are measured.

Connecting loads to General Purpose Half-H-Bridge channels

There are three ways to connect loads to the HH driver channels, shown below, supporting 4 software drive modes. Figure 58 is a screen shot from the DSI HH driver configuration window showing the configuration of five HH driver channels operating in the four software drive modes. Note that two channels, HH4 and HH5 are utilized for the Full-H drive mode.

Figure 57 General Purpose Half-H-Bridge Driver Wiring Connections

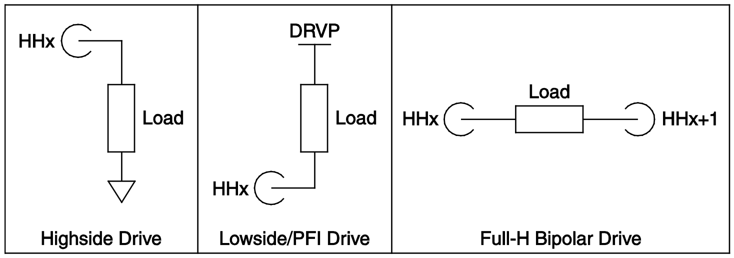
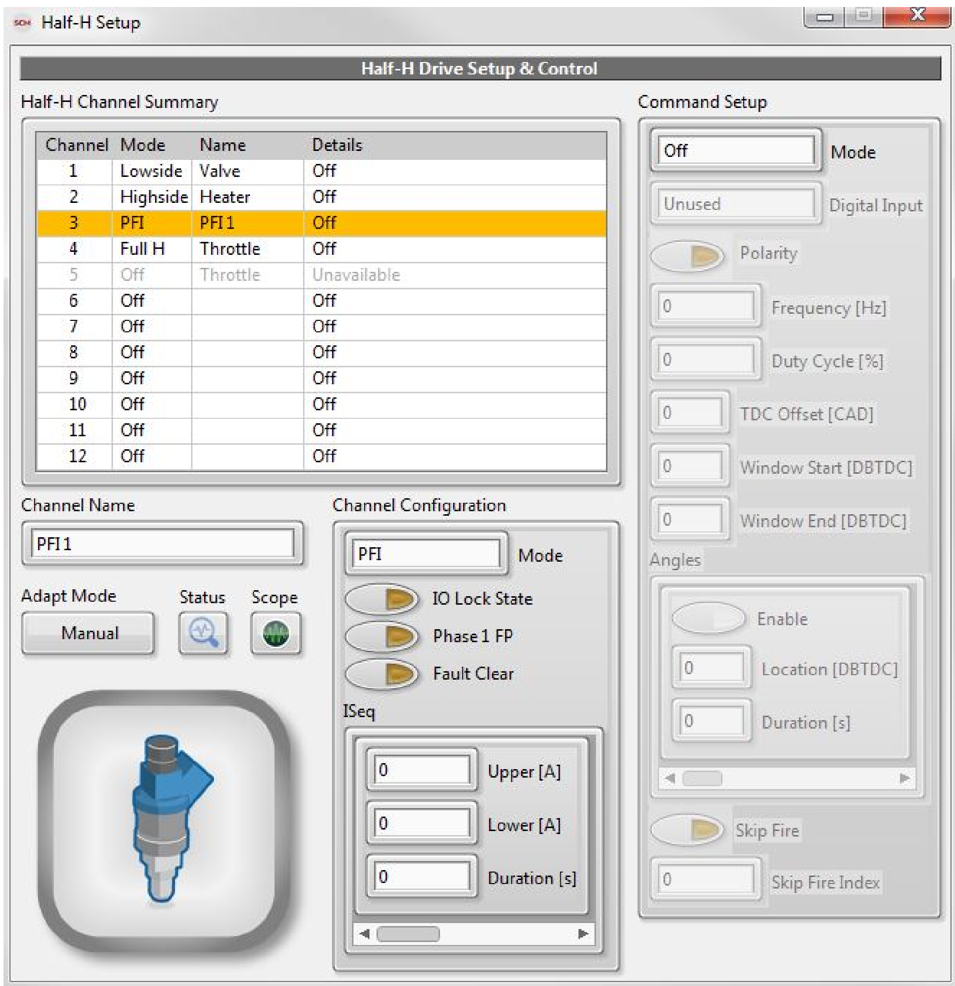


Figure 58 DSI HH Driver Configuration of Five Channels Demonstrating Each Drive Mode



Differential Digital I/O (Diff-IO)

Channel Architecture

The DCM provides eight independent differential digital IO (Diff-IO) channels that support the voltage range of 0 V – 5 V, and include over-voltage protection features. Each channel's final I/O stage consists of a RS485 transceiver. Refer to the DCM-23XX specifications guide for full electrical specifications of the DCM differential digital IO. Differential digital I/O offer greater immunity to electromagnetic interference because the receiving circuit responds to the electrical difference between the two signals, rather than the difference between a single signal and ground.

Digital Input Mode

When a Diff-IO channel is configured as an input, the transceiver monitors the voltage difference between the a-pin and b-pin. If the a-pin voltage is greater than the b-pin, then the transceiver sends a logic 1 to the controller FPGA. If the a-pin voltage is less than the b-pin, then the transceiver sends a logic 0 to the controller FPGA. The controller FPGA is monitoring this logic state at the rate of 40 MHz, but the transceivers are only rated for 10 MHz switching frequency. Internally, the a-pin and b-pin are weakly biased to approximately 1.6 V, with the a-pin biased 20 mV lower than the b-pin. Therefore, when disconnected, the channel will read logic 0.

The Diff-IO channels can also be used as single-ended digital inputs. Software configuration for single-ended digital input is not necessary. Simply leave the b-pin disconnected and use the a-pin as the digital input. Since the b-pin is biased to 1.6 V, the channel will report logic 1 when the a-pin voltage is higher than the biased b-pin, and report logic 0 when the a-pin voltage is lower than the biased b-pin. The digital input measurement is referenced to DGND.

A common misunderstanding about using differential digital input channels as single-ended inputs, is that the b pin should be grounded, or tied to DGND. However, this lowers the differential measurement threshold to 0 V and the channel will always read logic 1. Thus, for single-ended digital inputs, leave the b-pin disconnected. One exception to this is if you want a threshold other than the default 1.6 V. For example, if you want a b-pin threshold of 2.5 V, simply connect an external 2.5 V source to the b-pin. If the external source is capable of sourcing at least a few milliamps, this will override the weak internal bias.

Digital Output Mode

When a Diff-IO channel is configured as an output, the transceiver accepts a digital logic 1 or 0 from the controller FPGA and drives complimentary 0 V and 5 V to the a-pin and b-pin. Logic 1 maps to 5 V on the a-pin and 0 V on the b-pin. Logic 0 maps to 0 V on the a-pin and 5 V on the b-pin. The transceiver is tolerant of a variety of load conditions and capable of driving 13 mA continuous into a short-to-ground. The output can drive closer to 5 V when the external load is a higher resistance. Refer to the DCM-23XX Specifications Guide for example loads and drive voltages.

The Diff-IO channels can also be used as single-ended digital outputs. Software configuration for single-ended digital output is not necessary. Simply leave the b-pin disconnected and use the a-pin as the digital output. If you want the output signal to be inverted from the controller FPGA logic, then leave the a-pin disconnected and use the b-pin as the digital output. The digital output is referenced to DGND.

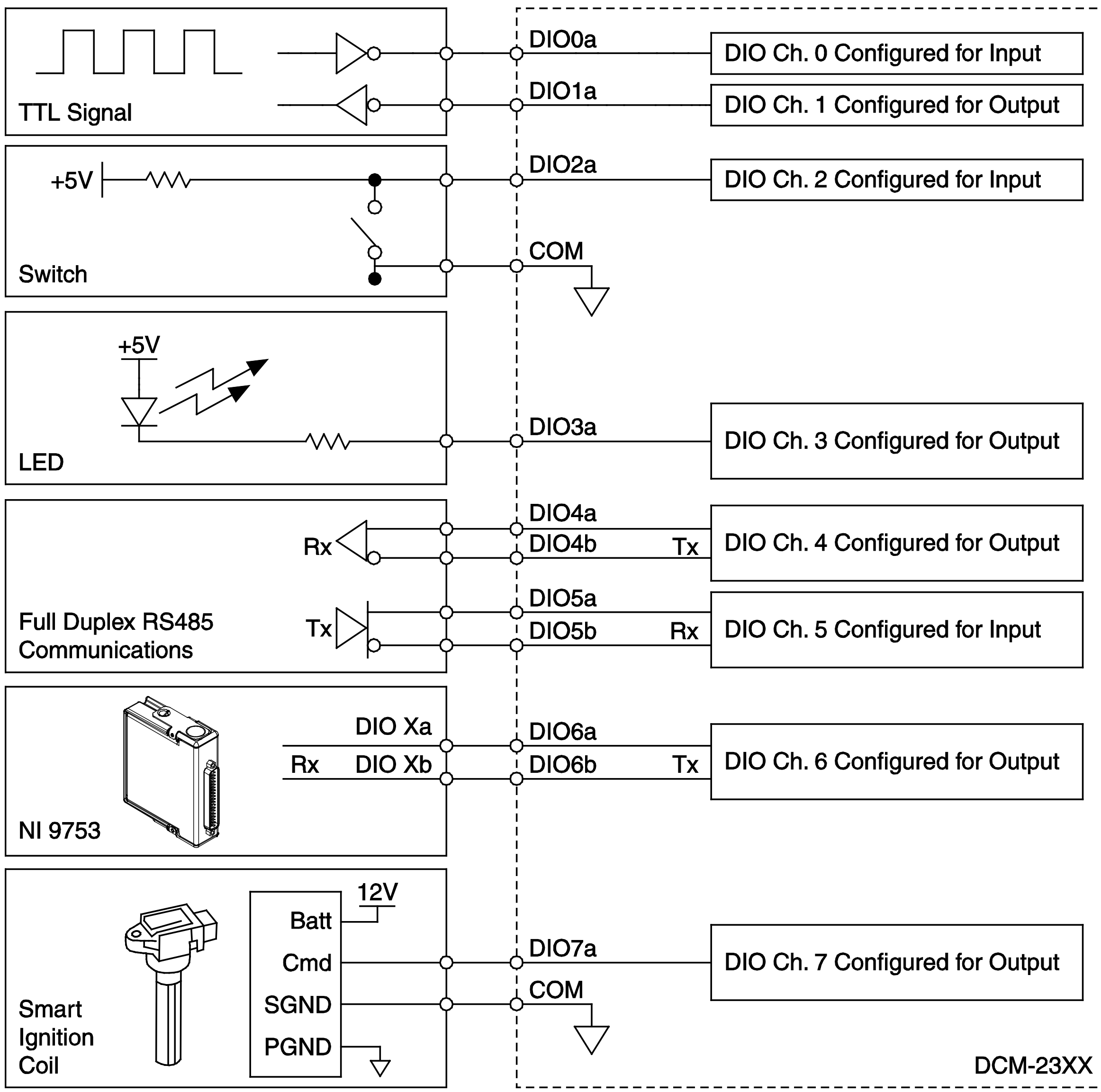
Changing I/O Direction

The DCM differential digital I/O channels are designed for steady state direction configuration. Direction changes can be made at any time, as fast as 1 kHz. However, the direction change cannot be synchronized with other events. Therefore, these channels should not be considered for half-duplex serial communications.

Use Cases and Device Connections

Figure 59 below shows Diff-IO channels connected to a variety of digital IO devices in differential and single-ended configurations.

Figure 59 Common Diff-IO Connections to External Devices



Channel Command Modes

There are a variety of modes to command the DI driver, HH driver and Diff-IO channels. This section will present the most common modes, demonstrating their configuration within the DSI. Bold text in this section refers to specific DSI windows, tabs, controls and list-selections.

Applicable Channel Types

The command modes below are applicable to DI driver, HH driver and Diff-IO channels. However, not all modes apply to all output channel types. Each mode will list the applicable channel types.

Direct

Applicable to: DI Driver, HH Driver

Direct commands are sourced from the Diff-IO channels or manual user one-shot. When direct commands are sourced from the Diff-IO channels, an external device is used to make command logic and timing decisions while the DCM is basically acting as a smart driver stage. An external device may have simple digital outputs that can be wired directly to the DCM Diff-IO channels. However, lowside or highside driver channels on the external device can be used with some simple external components, such as pullup or pulldown resistors.

If the external device has a lowside driver, then a pullup resistor (such as 1 kΩ) to 5 V can be used. Be aware that this configuration creates a signal which has inverted logic with respect to the external device lowside driver. The DCM Diff-IO channel can invert the signal logic.

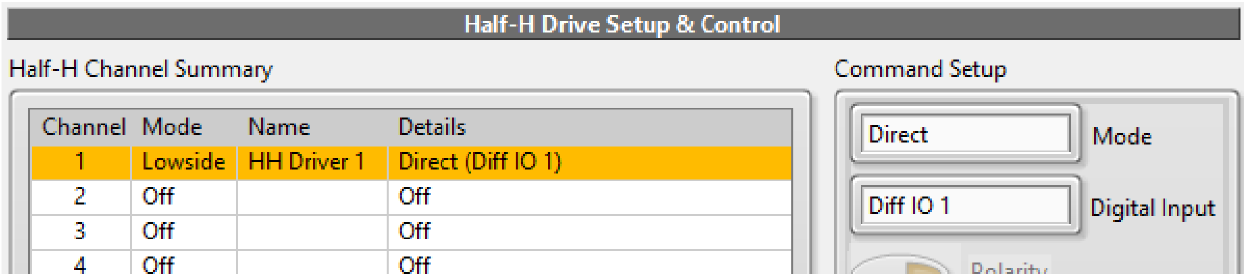
If the external device has a highside driver, then a pulldown resistor (such as 1 kΩ) can be used. This configuration creates a signal which has the same logic with respect to the external device highside driver.

One issue that may prevent using external device lowside or highside drivers for this purpose is that the drivers may be designed for driving only inductive loads with a minimum current level. Using an external pullup or pulldown resistor with small current flow may cause the external device to fault-out and turn the channel off. These issues must be sorted out with the external device hardware or software, and are beyond the scope of this discussion.

Direct Diff-IO Source

When a Diff-IO channel is configured as input, then the Diff-IO signal can be mapped to a DI driver or HH driver channel as a command by setting the HH **Command Setup Mode** to **Direct** and setting the **Digital Input** selection to one of the DCM Diff-IO channels. In this case, the driver channel will turn ON when the Diff-IO channel is logic 1 and turn OFF when the Diff-IO channel is logic 0.

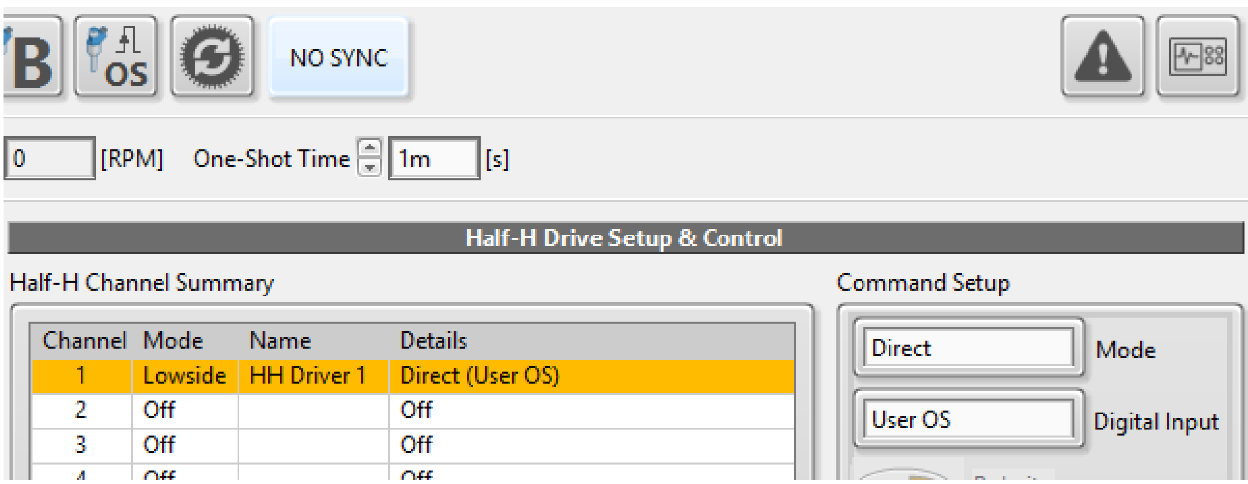
Figure 60 Configuring a HH driver channel for direct commands from Diff-IO Channel 1



Direct User One-Shot Source

Within Direct command mode, you can select **User OS** as a command source. In this case, you must specify the duration of the command in the **One-Shot Time** parameter and press the **OS** button. Each press of the OS button will trigger a single one-shot command to the driver channel with the specified duration.

Figure 61 Configuring a HH driver channel for direct commands from the User One-Shot



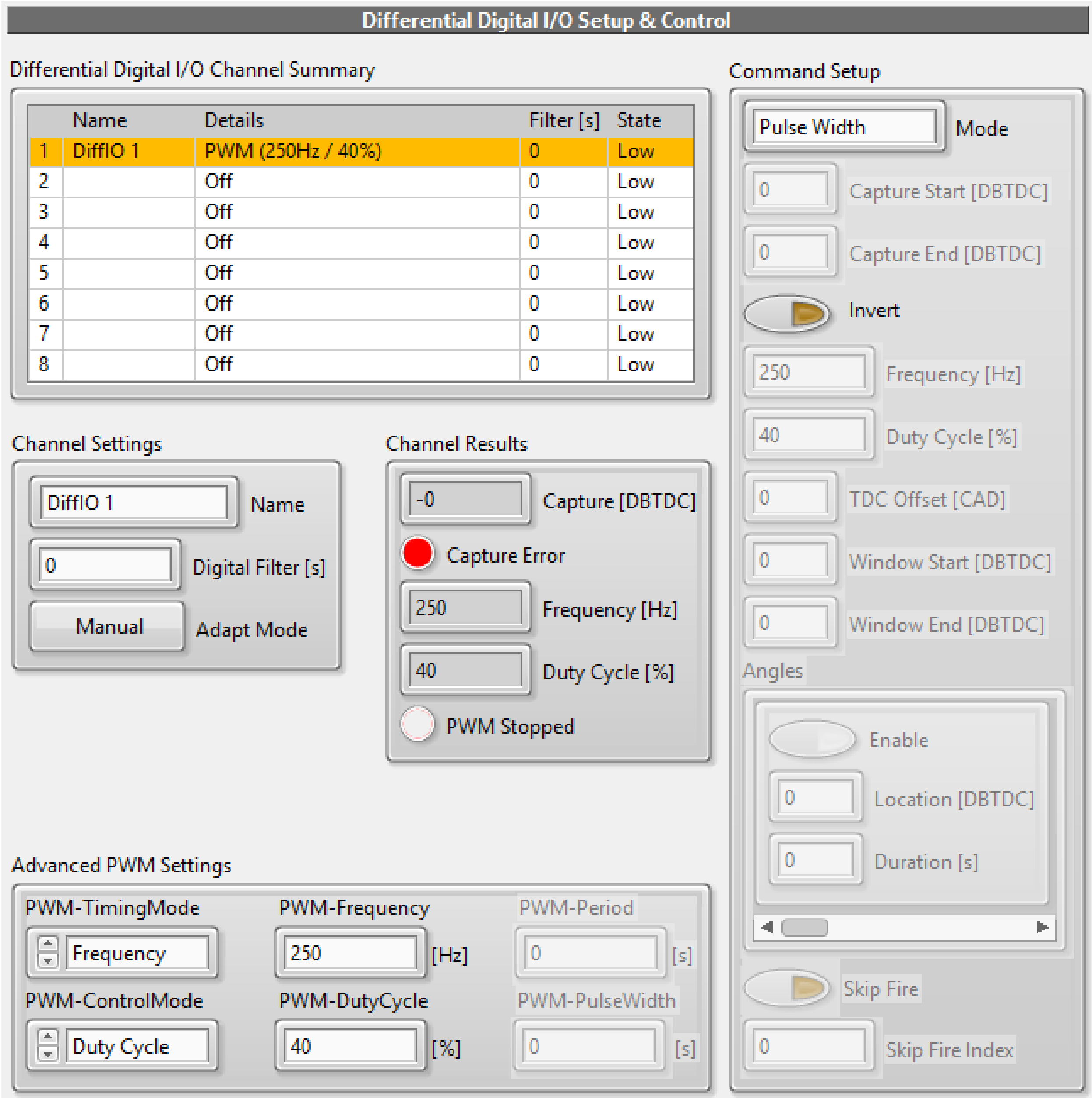
PWM

Applicable to: DI Driver, HH Driver, Diff-IO.

PWM Command to Diff-IO

Within the **Differential Digital I/O Setup** window, the **Command Setup Mode** of a Diff-IO channel can be configured to output a **Pulse Width Modulation** (PWM) signal as shown in Figure 62.

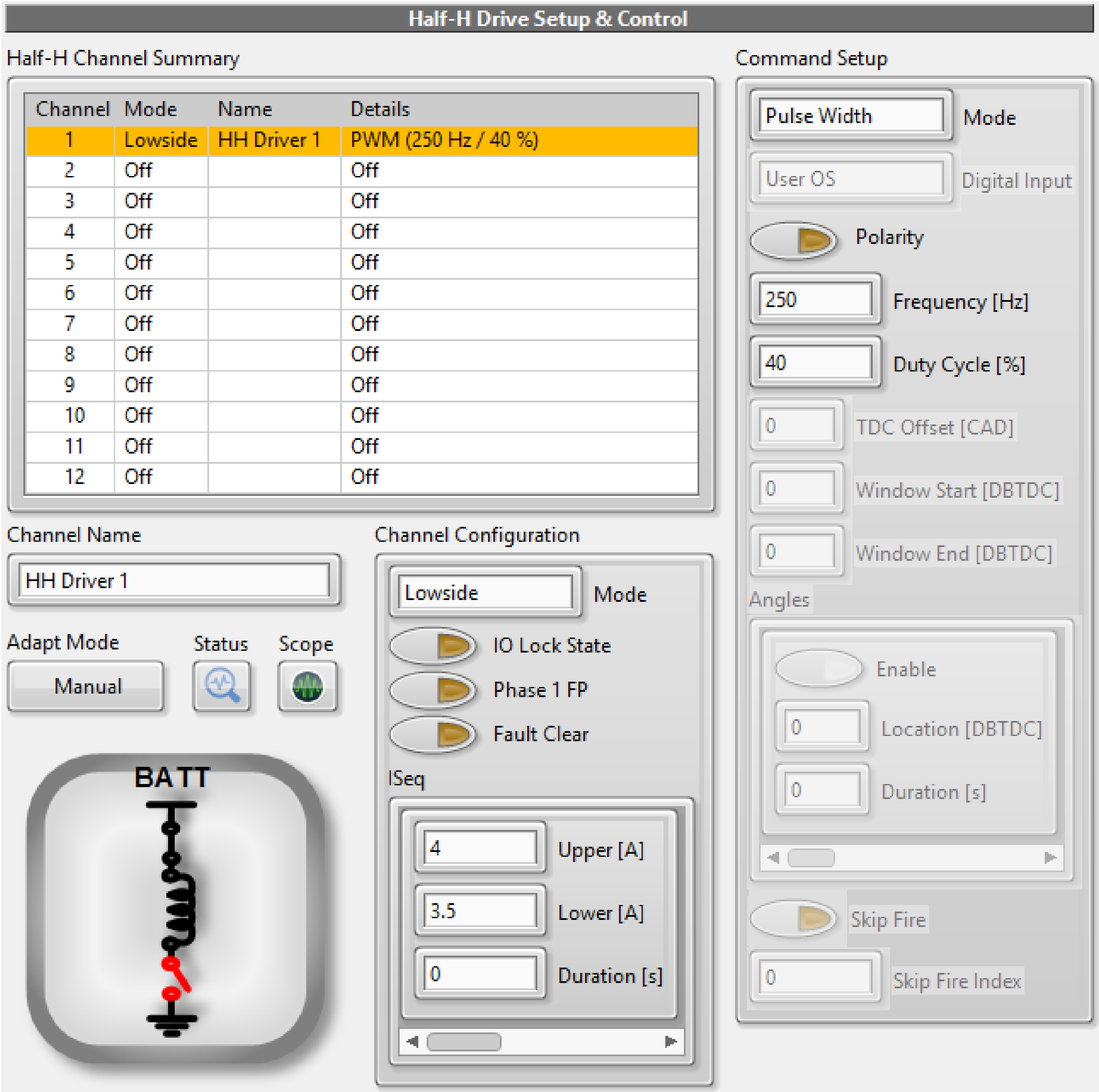
Figure 62 Configuring a Diff-IO channel for PWM Output



PWM Command to HH Driver

Within the Half-H Driver Setup page, the HH channel **Command Setup Mode** can be configured to drive according to a **Pulse Width Modulation** signal as shown in Figure 63.

Figure 63 Configuring a HH Channel for PWM



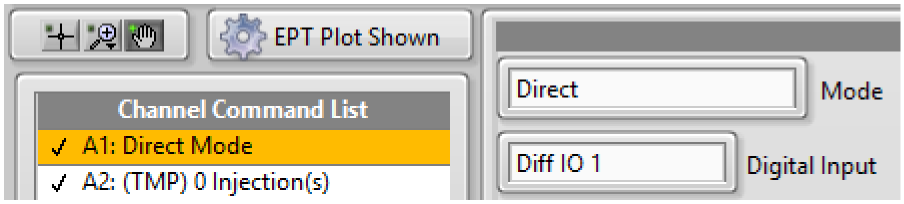
Diff-IO PWM Command to HH Driver

Another way to achieve a PWM command to a HH driver is to configure the HH **Command Setup** as **Direct** and select a Diff-IO channel as the source, as shown in Figure 63 above. The Diff-IO channel can be configured for PWM output as shown in Figure 62 above.

PWM Command to DI Driver

To achieve a PWM command to a DI driver, configure the DI Command **Mode** as **Direct** and set the **Digital Input** selection to a Diff-IO channel as the source, as shown in Figure 64. The Diff-IO channel can be configured for PWM output as shown in Figure 62 above.

Figure 64 Configuring a DI Driver Channel for Command from Diff-IO PWM

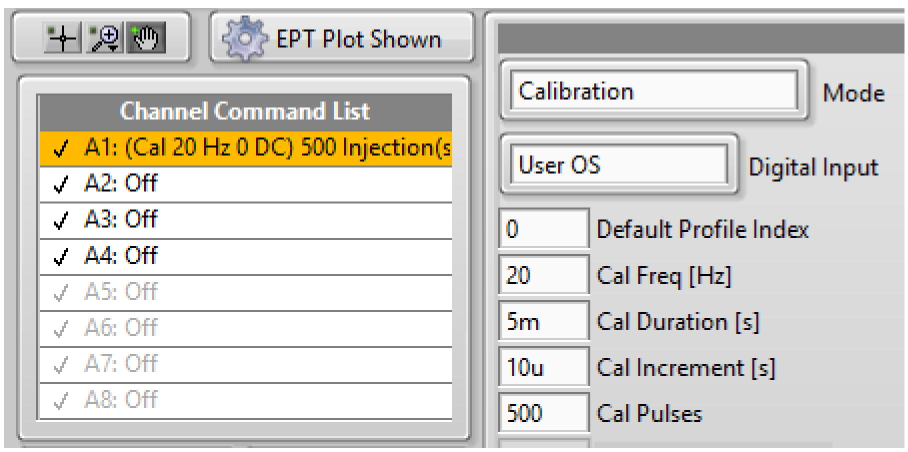


Calibration

Applicable to: DI Driver

The purpose of the Calibration command mode is to operate a direct injector on a flow measurement bench. You specify a fixed frequency and a fixed or sweeping duration for several pulses up to 500. The start trigger can be sourced from a Diff-IO input or a user one-shot. Figure 65 shows an example configuration of the calibration command mode.

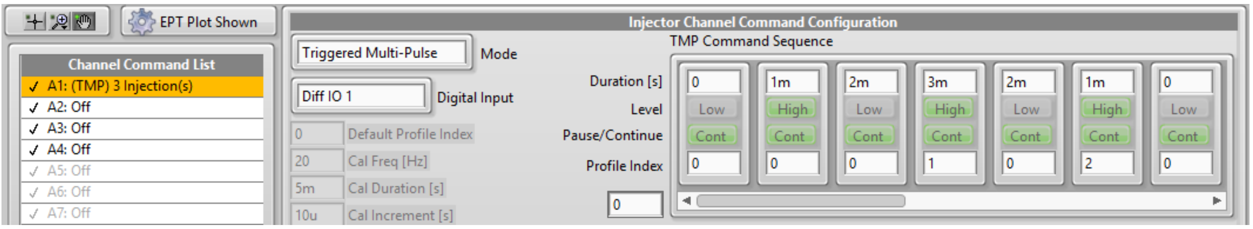
Figure 65 Configuring the DI Driver Calibration Command Mode



Triggered Multi-Pulse (TMP)

The Triggered Multi-Pulse (TMP) command mode is a way to send a sequence of logic-level commands to DI Driver channels. The TMP Command Sequence is an array of 16 cluster elements. Each cluster contains parameters for the duration and profile, while the logic level of each command cluster alternates from Low to High, for a maximum of 8 pulses in the sequence. The start of the TMP sequence is triggered from a Diff-IO channel rising edge or User OS. The first cluster of the TMP sequence is a low level. This makes it possible to have a delay inserted between the start-trigger and the first command pulse. If a delay is not desired, then set the duration of the first cluster to 0. A different current and voltage profile can be specified for each element of the sequence. The TMP command mode is useful for operating injectors in multi-pulse modes on an engine when an external device is the main engine controller, and the DCM is a smart injector driver stage.

Figure 66 Configuring the DI Driver for Triggered Multi-Pulse Command



Engine Position Tracking

Applicable to: DI Driver, HH Driver

The Engine Position Tracking (EPT) command mode is the most sophisticated mode for generating commands to the DI Driver and HH Driver channels when controlling engines. This mode relies on the EPT software function which accepts crank and cam position signals and tracks the angular position of the crankshaft throughout the engine cycle. Engine-synchronous, angle-based commands can be configured for a variety of multi-pulse formats.

Figure 67 shows the **Engine Position Tracking Setup** window within the DSI. This window accepts and deploys an EPTx configuration file, and displays the status of position tracking.

Figure 68 shows the **DI Driver Bank A Setup** window with the **Injector Commands Setup** tab selected. **Engine Position Tracking** is the command mode. This enables the lower right group of controls for configuring up to 8 angle-based commands. The EPT Angles is an array of clusters similar to the TMP Command Sequence, but each cluster element specifies the start angle and duration of a command. In the figure, three pulses are configured. Other parameters for the injection commands are for setting the TDC offset of the channel with respect to EPT position 0, and the window which defines the angle range within which the commands must operate.

Figure 67 Engine Position Tracking Setup Window

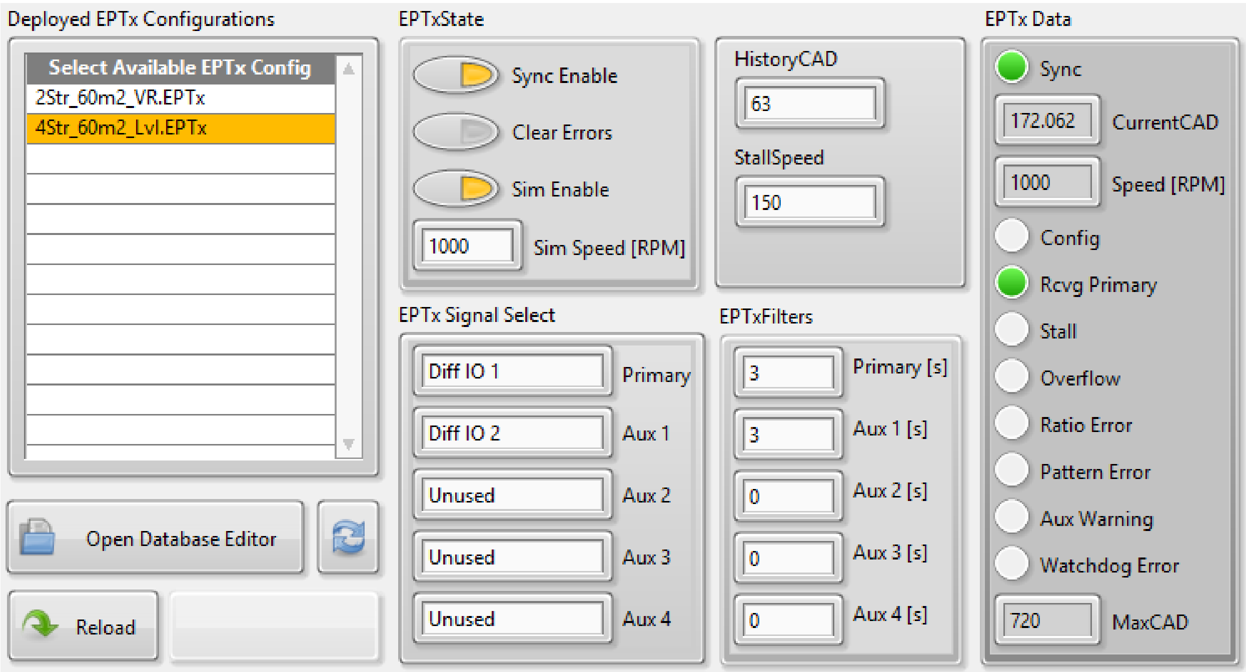
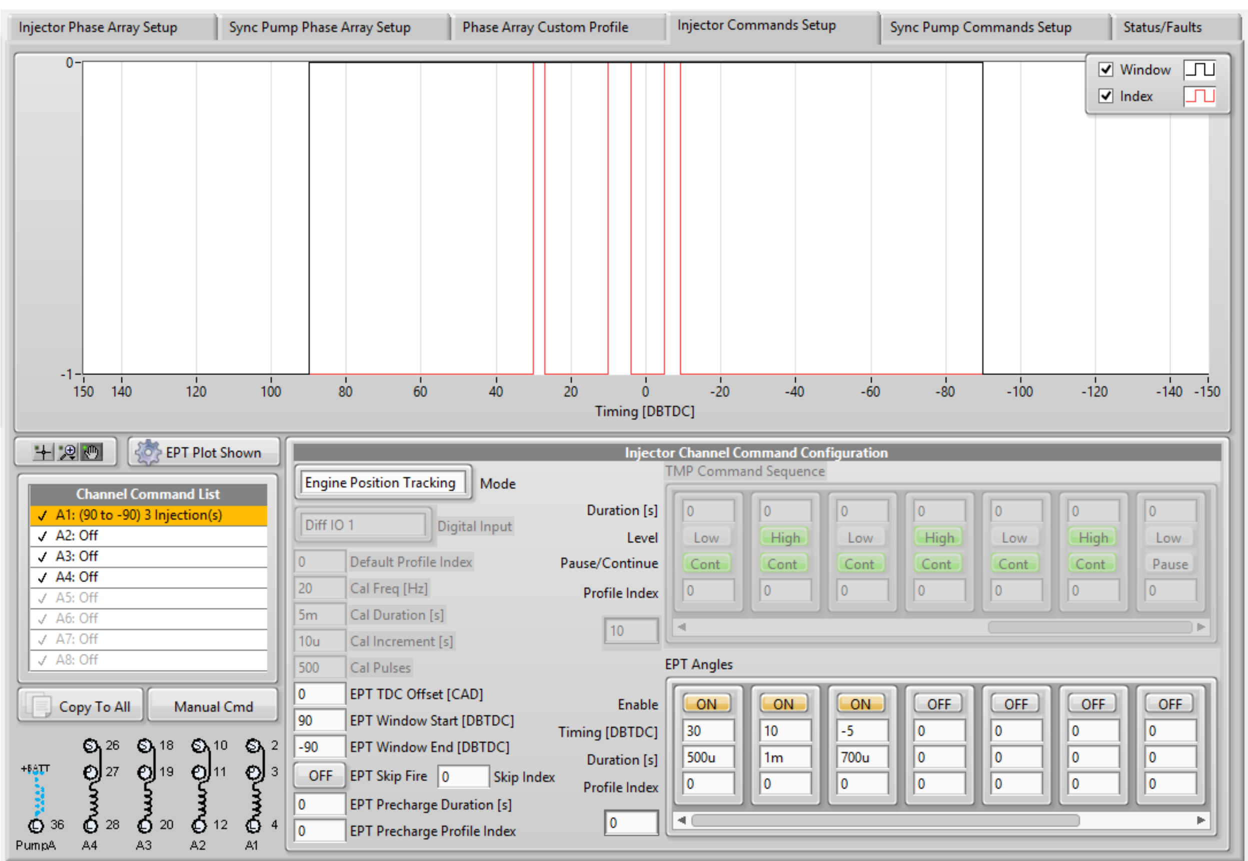


Figure 68 Configuring the DI Driver for Engine Position Tracking Commands

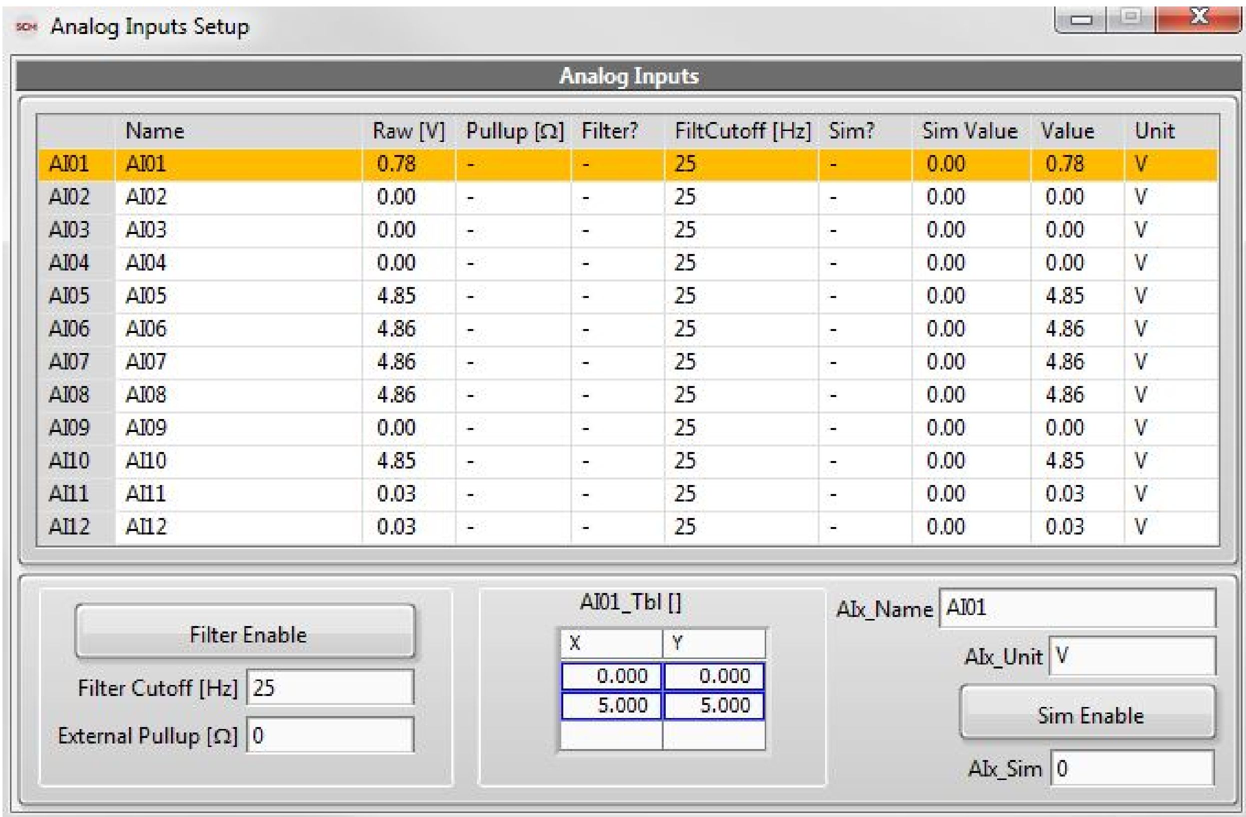


Analog Inputs

The DCM provides 12 channels of 12-bit analog input with an aggregate sample rate of 1 MS/s. The input voltage range is 0 V to 5 V, with overvoltage protection. Refer to the DCM-23XX Specifications Guide for detailed specifications. Within the DSI, the analog inputs can be monitored within the **DCM System ADC** window, along with other internal analog signals.

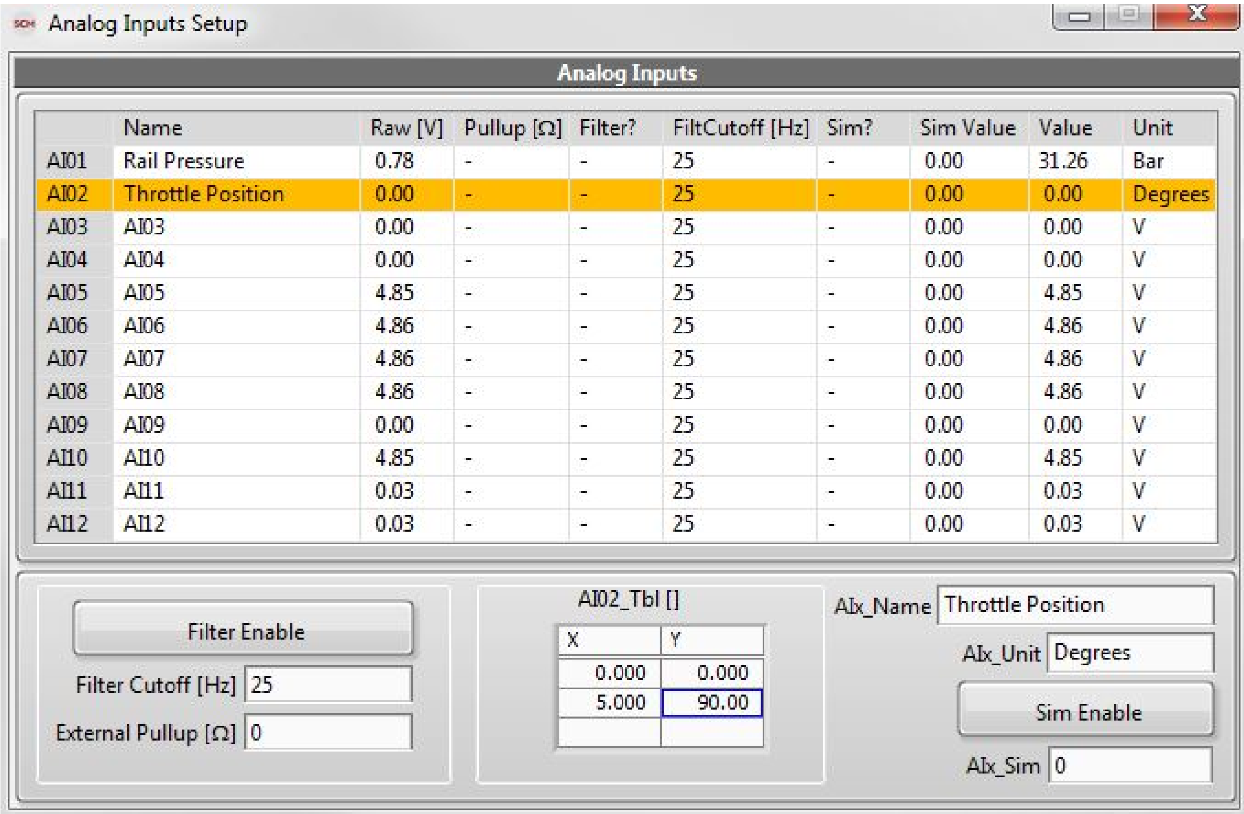
The **Analog Inputs Setup** window is used to apply filtering, table-based conversion, naming and units, as shown in Figure 69.

Figure 69 Analog Inputs Setup Window



Analog inputs can be utilized in standard control functions within the DSI, such as rail pressure feedback, and throttle position feedback. Figure 70 shows the analog input mapping to these functions.

Figure 70 Analog Input Mapping to Rail Pressure and Throttle Position Control



Analog inputs can also be utilized within the DSI **User Plugin** architecture. The plugin procedure is beyond the scope of this document; however, the open DSI LabVIEW project contains template VIs for creating DSI plugins to programmatically manipulate DSI controls. Tutorials will be provided on this topic via online documents and videos.

Internal System Analog Signals

There are 32 analog signals internal to the DCM for monitoring system voltages and temperatures. Refer to the DCM-23XX Specifications Guide for detailed specifications. Within the DSI, these signals can be monitored within the **DCM System ADC** window, along with external analog inputs.

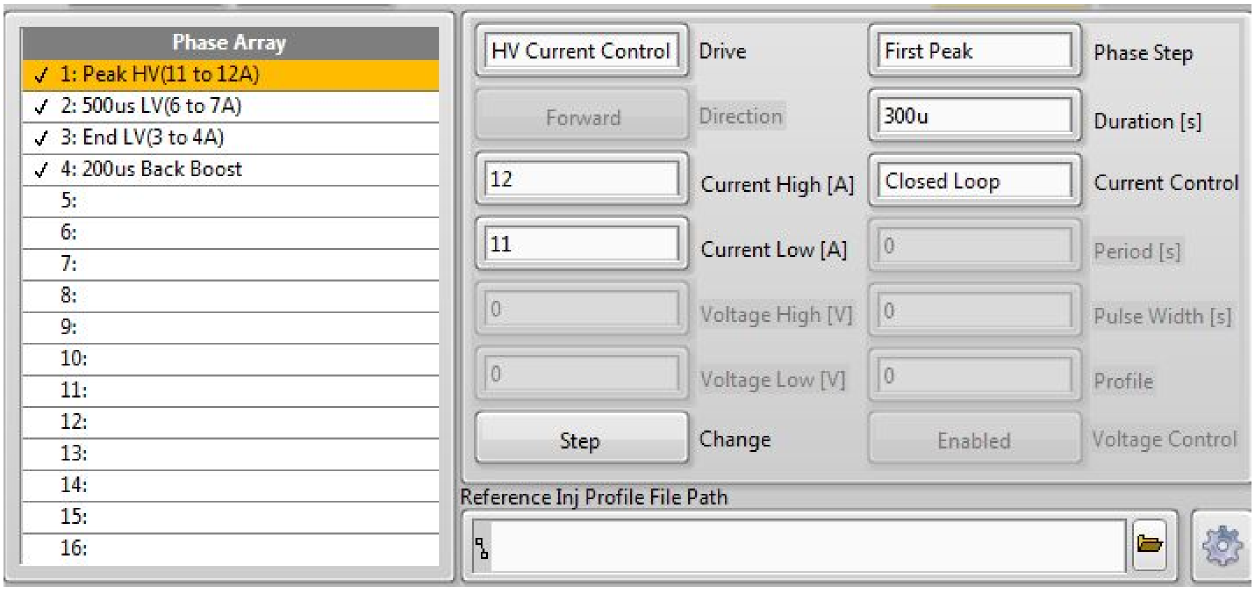
Within the **DCM System ADC** window, low and high fault thresholds can be established for these signals and faults can be monitored via the **Faults** window.

Internal system analog signals can be utilized within the DSI **User Plugin** architecture. The plugin procedure is beyond the scope of this document; however, the open DSI LabVIEW project contains template VIs for creating DSI plugins to programmatically manipulate DSI controls. Tutorials will be provided on this topic via online documents and videos.

DI Scope

The DCM hardware includes four independent, internal analog input channels called the DI Scope. Each DI Scope channel samples at 5 MS/s with 15-bit resolution. There are 55 internal signals related to DI Driver channels and boost power supplies that can be routed to each DI Scope channel. The 55 signals that can be routed to the DI Scope are documented in the DCM-23XX Specifications Guide. The DSI provides a window for viewing DI Scope data buffers triggered by DI Driver and Diff-IO channel events.

Figure 71 DSI DI Scope Window Showing Injector Current and Voltage



Communications

RS-232 Serial

The DCM provides an RS-232 transceiver channel available via Connector 1 and operated by the DCM controller UART named ASRL1. The sbRIO-9651 SOM has optional additional UARTS ASRL2 – ASRL6, but they are not implemented in the DCM. The ASRL1 port can be configured via NI Measurement and Automation Explorer to act as the Console Out, which outputs information about the controller boot process and operating system status. When acting as the Console Out, the serial port is not available for other user program functions, except for sending messages programmatically to the Console. The Console Out specifications are 115,200 bps, 8 data bits, no parity, 1 stop bit, and no flow control.

If the Console Out feature is disabled, the ASRL1 port can be used for other communications functions within the DCM user program. The serial port can also be used within a user plugin to the DSI. Otherwise, the serial port is not used for any other standard DSI function.

Refer to the DCM-23XX Specifications Guide for the RS-232 transceiver technical details.

Embedded CAN

The DCM provides a fully ISO 11898-2:2003 compliant, fault-protected, high-speed CAN transceiver channel available via Connector 1 and operated by the DCM controller dedicated CAN core within the FPGA. The DSI uses the CAN channel to send and receive DSI parameters via user-customized CAN frames.

The DCM CAN controller utilizes the NI Embedded CAN device driver and is not compatible with NI-XNET.

Refer to the DCM-23XX Specifications Guide for the CAN transceiver technical details.

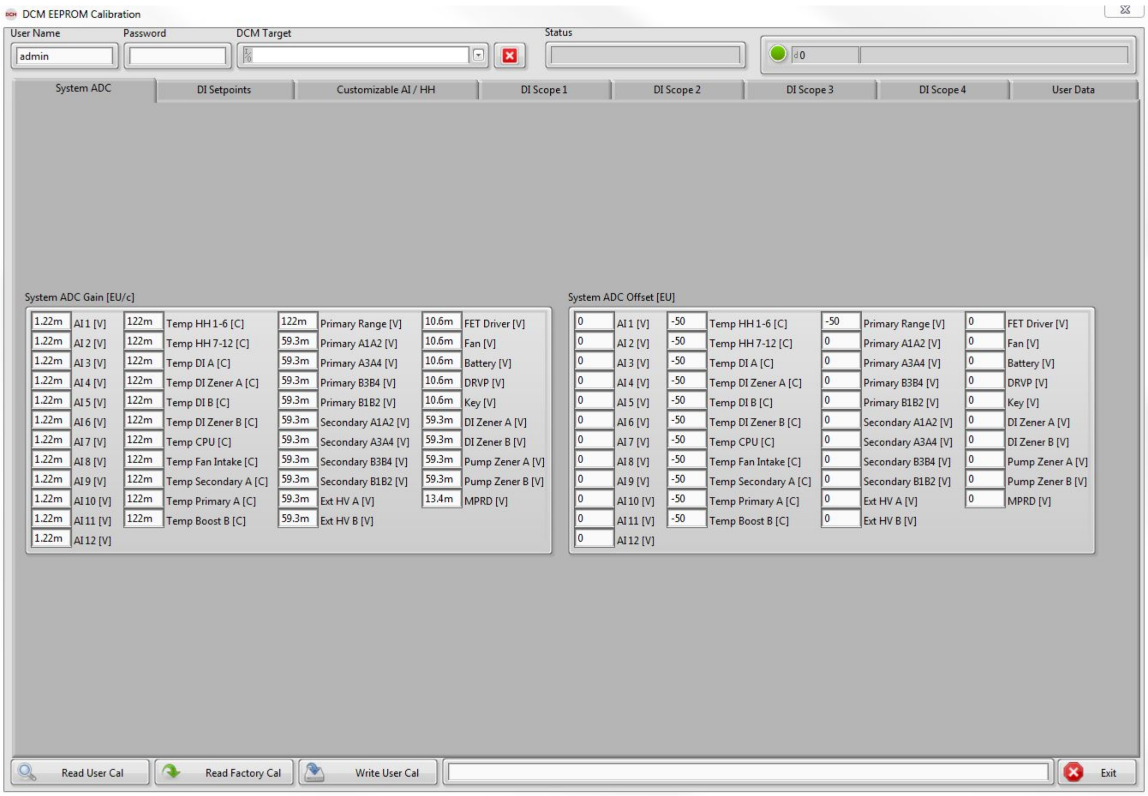
DCM Software Utilities

The DCM DSI and device drivers include executable utilities to assist with DCM configuration.

DCM Calibration

The DCM Calibration tool is an executable VI that is installed with the Powertrain Controls Device Drivers package. The tool can be started by selecting **Tools>>DCM>>Calibration**. The DCM Calibration tool should only be used with the support of NI PCG systems engineers. Figure 72 shows the DCM Calibration program.

Figure 72 DCM Calibration Program



DCM DI Simulation

The DCM DI Simulation tool is an executable VI that is installed with the Powertrain Controls Device Drivers package. The tool can be started by selecting **Tools>>DCM>>DI Simulation.** The DCM DI Simulation tool, shown in Figure 73, can be used to simulate the voltage and current response of the electrical load of an injector while experimenting with injector drive configurations. The tool can also be used to estimate the total power dissipation of the DCM during the most demanding injection sequences and engine speeds. The estimated power dissipation can be compared to the DCM's maximum power dissipation rating.

Portions of the DCM DI Simulation tool are implemented within DCM DSI. The parameters associated with injector load electrical characteristics are entered via the **DI Sim Settings** sub window, opened via the **Settings** button within the **DI Driver Bank Setup** windows, as shown in Figure 74.

Figure 73 DCM DI Simulation Tool PC Executable

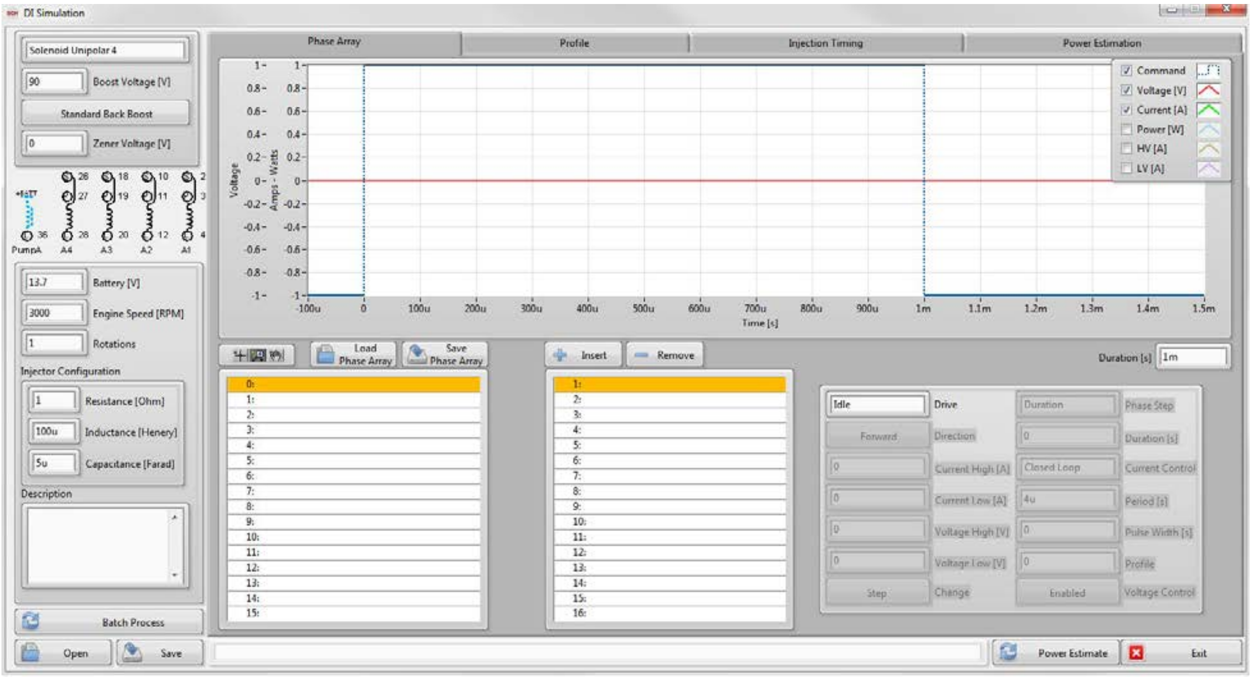
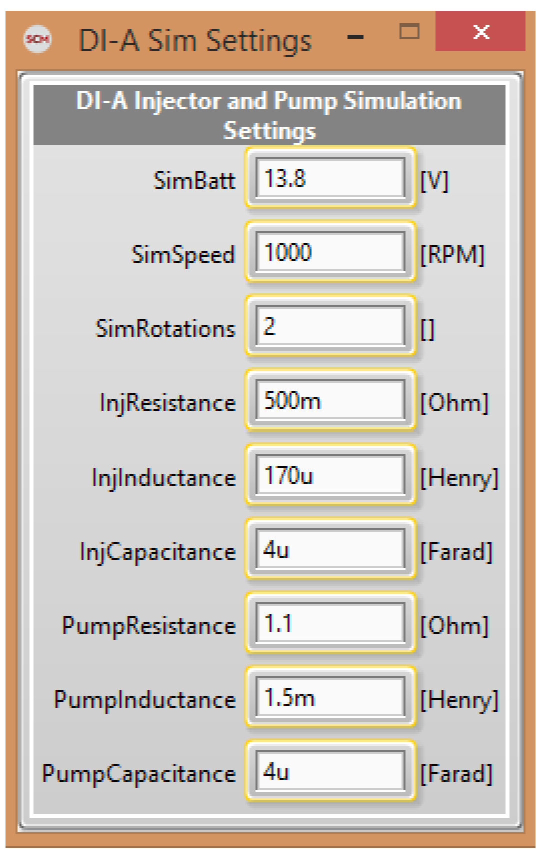


Figure 74 DCM DSI Simulation Settings



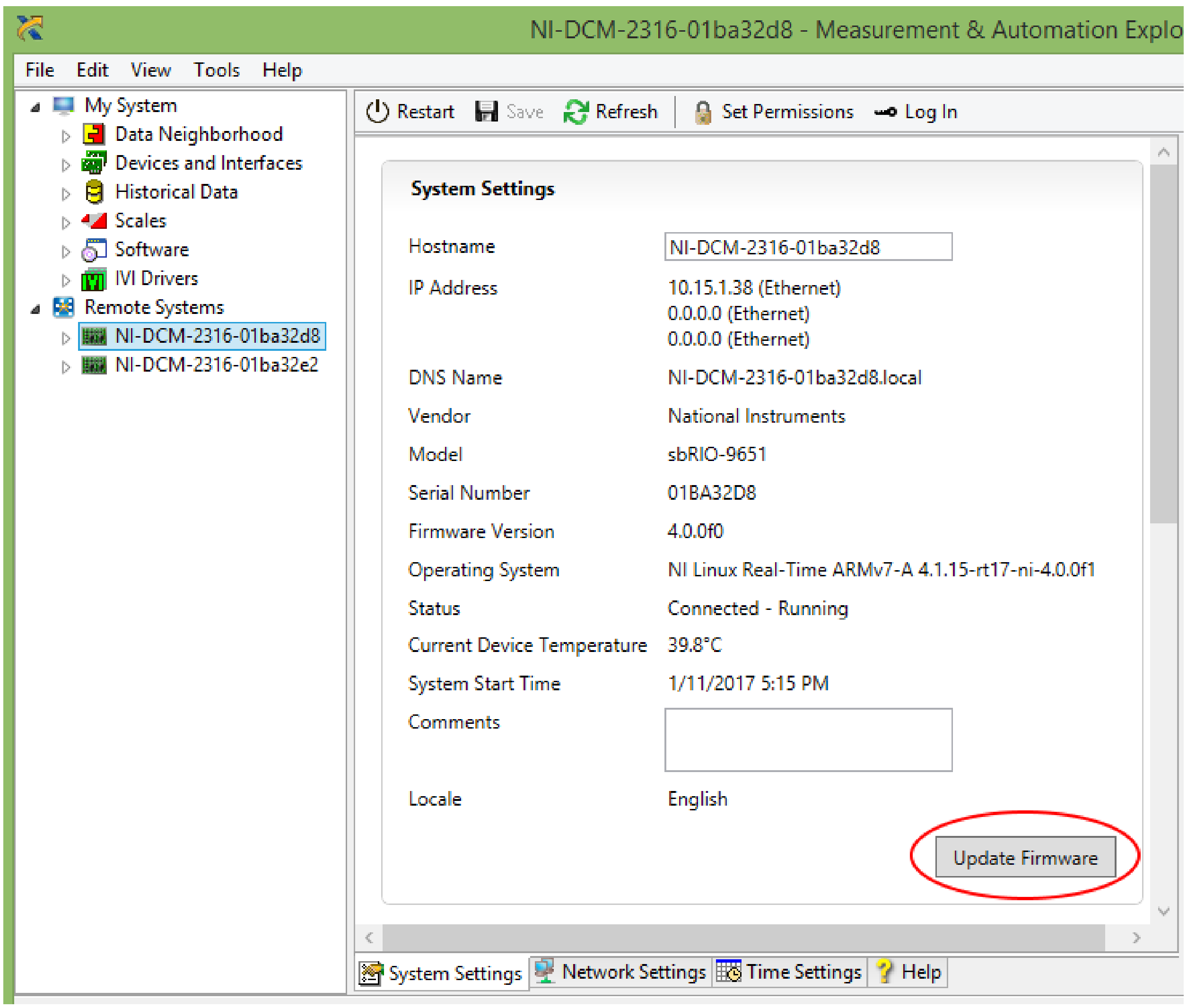
DCM Firmware Updates

There are two types of firmware associated with the DCM that may need updating from time to time.

sbRIO-9651 SOM Firmware

One type of firmware resides within the sbRIO-9651 SOM controller. This firmware is updated via NI MAX. To obtain NI MAX software, navigate to the website www.ni.com/downloads/ni-drivers/ . In the NI Drivers search field, enter 'CompactRIO'. Download and install the latest CompactRIO device driver to your host PC. Then open NI MAX. The user should check from time to time that this firmware is up-to-date by clicking the 'Update Firmware' button within your System Settings under Remote Systems, as shown in Figure 75. If the firmware needs updating, follow the remaining prompts.

Figure 75 Checking sbRIO-9651 SOM Firmware Within MAX



DCM I/O Board Firmware

The other type of firmware is embedded within the DCM I/O board. It is critical that the firmware version be compatible with the DCM low level device drivers. In some cases, the DSI or DCM device drivers will not allow application execution to continue if the firmware is not updated. Be aware of this possibility if the DCM DSI will not start, especially after updating the DSI. If the DSI will not start, you should enable the console output via MAX, and observe the messages reported over the RS-232 serial port using a terminal program. If the DSI will not start due to out-of-date firmware, a message will be sent to the console stating:

```
DCM DSI: Initialization Error: The DCM Firmware Version is not compatible
with the current DCM Driver Software. Please run the Firmware Update Tool to
install the correct version of Firmware.
Current Version x.x
Required Version x.x
```

The latest DCM firmware file is included within the DSI distribution.

Updating DCM I/O Board Firmware from DSI Distribution

If you are using the DCM via DSI, follow the steps below to update the DCM firmware.

1.) Install the latest available DCM DSI to the target using SCM. New firmware is included in the DCM DSI installation. For instructions on installing the latest available DSI, refer to the DSI User Guide section, "Updating or Restoring the NI DCM DSI"
2.) Navigate to the controller using an FTP browser and download the entire DCM Tools directory. The directory will be in the following location on the RT target: home/lvuser/natinst/LabVIEW Data/DCM Tools/.
3.) Run the Firmware Update.exe utility in <…/DCM Tools/Firmware Update/> on your host PC and follow the prompts to update the DCM I/O board firmware. Your DCM may reset several times during this process. For detailed steps of this process, see the section below, "Using the DCM Firmware Update Utility".

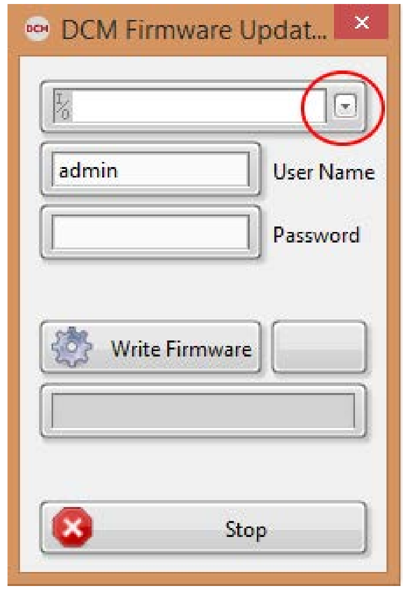
Updating DCM I/O Board Firmware from Powertrain Controls Device Drivers Distribution

If you are developing your own custom DCM application using the DCM device drivers (not using DSI), follow the steps below to update the DCM firmware. This assumes you have installed the latest version of NI LabVIEW Embedded Control and Monitoring Software Suite.

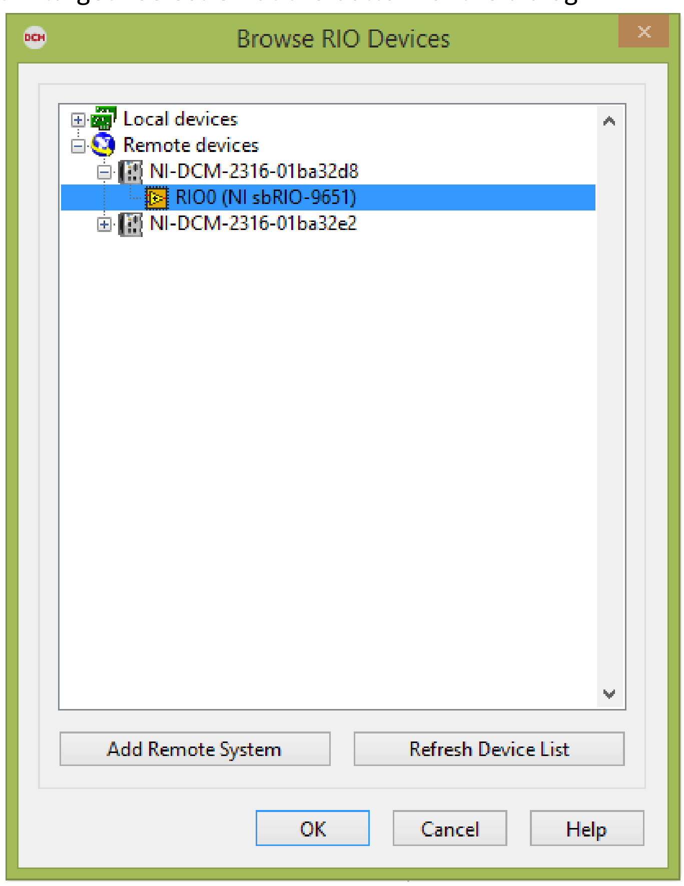
1.) Install the latest available Powertrain Controls Device Drivers using the VI Package Manager. Be sure to start the VI Package Manager as an administrator. This is done by navigating to the VI Package Manager within your Windows start menu, right-clicking on the short-cut, and selecting 'Run as administrator'.
2.) Open LabVIEW and go to the Tools menu. Select **Tools>>DCM>>Firmware Update.** Follow the prompts to update the DCM I/O board firmware. Your DCM may reset several times during this process. For detailed steps of this process, see the section below, "Using the DCM Firmware Update Utility".

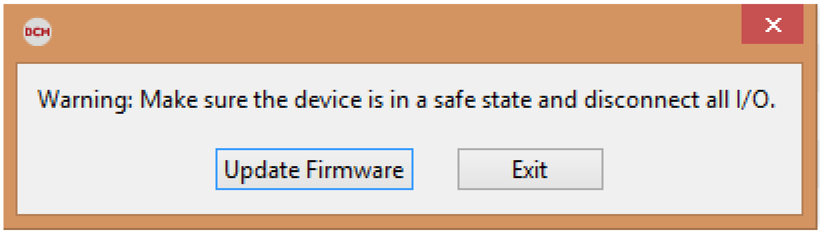
Using the DCM Firmware Update Utility

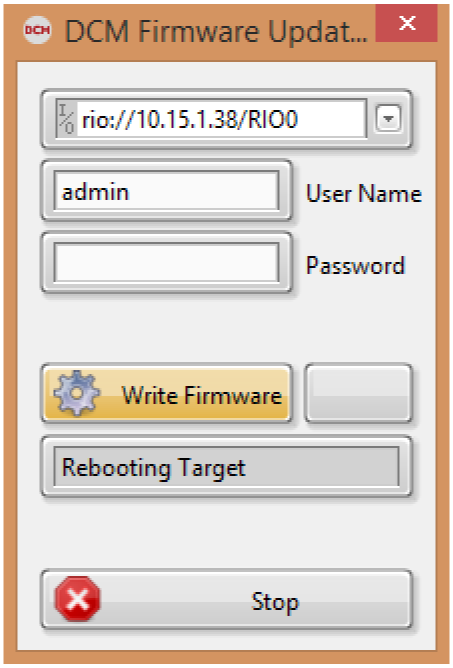
1.) After starting the DCM Update Firmware Utility, select the drop-down arrow of the upper drop-down list-box and select Browse….

a. 

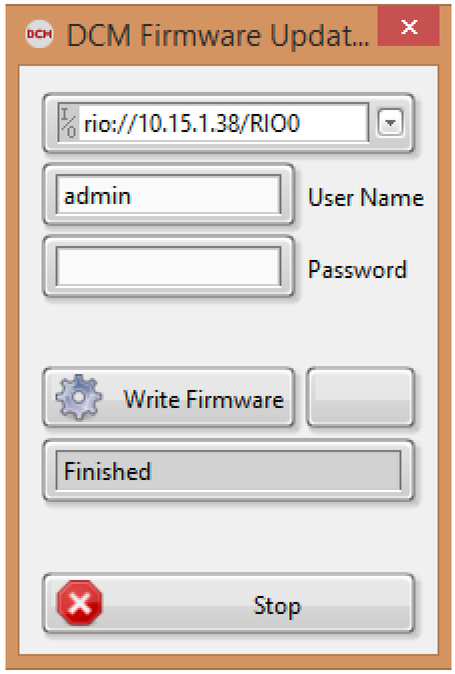
2.) Within the Browse RIO Devices dialog, expand the Remote Devices list, and then expand the DCM controller having the associated name of your target DCM. Select the RIO device that shows up under your DCM target. Select OK at the bottom of the dialog.

a. 

3.) After returning to the DCM Firmware Update Utility, your DCM RIO device IP address should be shown in the drop-down list box.
4.) If your DCM target has login credentials established, enter the User Name and Password. The default credentials of a DCM from the factory are a User Name of admin, and no password.
5.) Click the Write Firmware button.
6.) A warning dialog box will be shown. Please follow the warning message and then press the Update Firmware button.
    a. 

7.) The DCM will begin rebooting and an associated status message will be shown. The reboot takes approximately 30 seconds. This reboot process will place a special temporary firmware update program on the DCM target and begin executing.
    a. 

8.) After the DCM reboots, you will be prompted to select a firmware file within the directory structure (on your host PC) from which the firmware update utility was started. The firmware file will have a name showing the version number and an extension of .rbf.
9.) After selecting the firmware file, the firmware update utility will show the status of the firmware writing and verification process. This takes about 10 to 20 seconds.
10.) After the firmware update process completes, the status will be changed to Finished, and the DCM will be restarted using the NI MAX settings found prior to the firmware update.

a. 

11.) Click the Stop button to exit the utility.

DCM Accessories

The following accessories are available for use with the NI DCM.

Table 10. DCM Accessories

Accessory	NI PN
PDU-2300	785180-01
DCM-23XX Starter Harness	785181-01
DCM-23XX Connector 1 Mating Plug Kit	785113-01
DCM-23XX Tool Kit	785202-01
PDU-2300 Mating Plug Kit	785179-01
PDU-2300 Tool Kit	785222-01
Multiplexing Junctions	785223-01
Rack-Mount End Plates	785246-01
Panel-Mount End Plates	785247-01

PDU-2300

NI Part #: 785180-01

The PDU-2300 is specially designed for optimized power distribution and fusing to the DCM and associated external devices. The PDU houses several automotive relays and fuses that provide battery, ground, switched drive power (DRVP), and switched auxiliary power to the DCM harness. The PDU may be configured for either 12V or 24V operation.

Supporting Documents

The following documents are available from the DCM product page at ni.com.

PDU-2300 Datasheet.pdf: Shows the internal connection schematic and mating connector pinouts.

PDU-2300 Drawing.pdf: Mechanical drawing of a generic version of the PDU.

Configuring the PDU-2300 for 12 V or 24 V

The PDU-2300 fuse configurations for 12 V (default) and 24 V power supplies are shown in Figures 76, 77 and 78. The fuse configuration optimizes the internal relay coils for 12 V or 24 V operation. It is important to make this configuration correctly. If the PDU-2300 is used with a 24 V power supply, while configured for 12 V, then the relays within the PDU-2300 will be damaged. Conversely, if the PDU-2300 is used with a 12 V power supply, while configured for 24 V, then the relays within the PDU-2300 may not switch on. When configured for 12 V, the operating range for battery input is 7 V to 16 V. When configured for 24 V, the operating range is 14 V to 32 V.

Figure 76 PDU-2300 Voltage Configuration Fuses (Inside View)

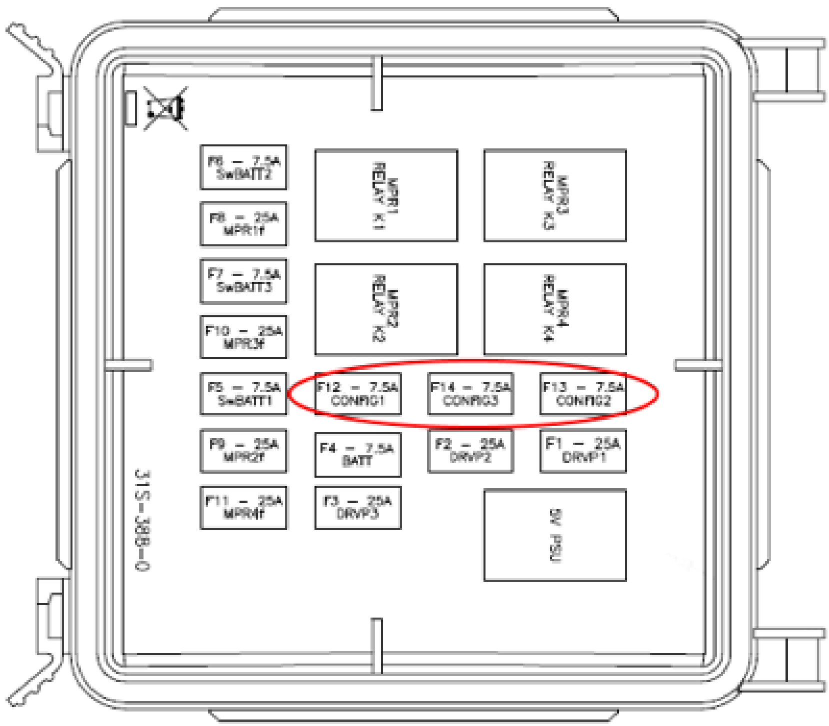


Figure 77 PDU-2300 12 V Configuration (Default)

F12 POPULATED	F14 EMPTY	F13 POPULATED

Figure 78 PDU-2300 24 V Configuration

F12 EMPTY	F14 POPULATED	F13 EMPTY

Table 11 PDU-2300 Voltage Configuration Fuse Guide

PDU Configuration	PDU Voltage Range	Populated Config Fuses	Depopulated Config Fuses	Wrong Configuration?
Nominal 12 V	7 V – 16 V	F12 & F13	F14	24 V Applied → Damaged Relays
Nominal 24 V	14 V – 32 V	F14	F12 & F13	12 V Applied → Inoperable

Battery Input

The PDU-2300 provides a heavy-duty battery input connection platform on the side with M8X1.25 threaded posts. Nuts and star washers are included with the PDU. A red battery post cover is provided with the PDU which labels the posts. Table 12 list specifications for the Battery input terminals.

Figure 79 PDU-2300 Battery Input Connection (viewing top of PDU)

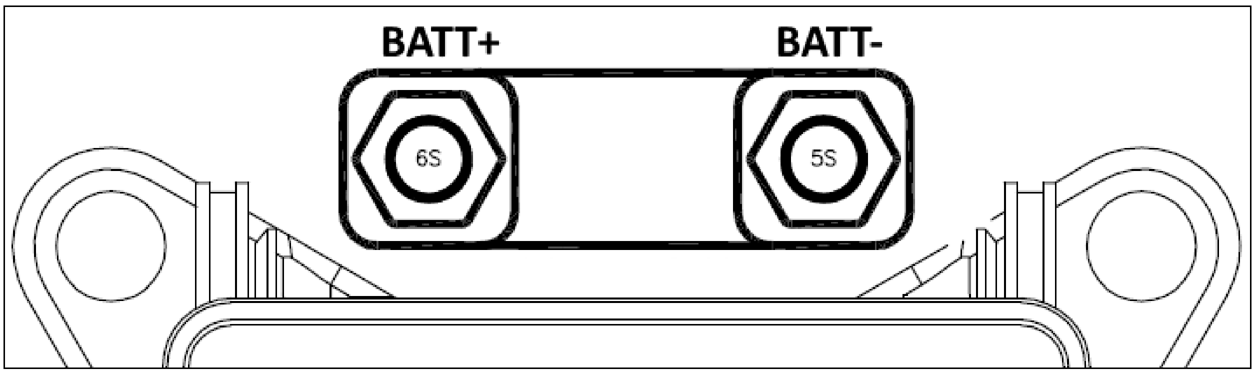


Table 12 Battery Input Terminal Specifications

Post	M8 X 1.25 Stainless Steel
Nut	M8 X 1.25 Stainless Steel Integrated Star Washer 13mm tool
Max Torque	20 Nm
Recommended Wire Size Light Load (up to 15A)	14 AWG
Recommended Wire Size Heavy Load (up to 70A)	8 AWG
Recommended Ring Terminal Light Load (up to 15A)	Molex 19056-0075
Recommended Ring Terminal Heavy Load (up to 70A)	Molex 19193-0174

Power Distribution Mating Connector Parts and Tooling

Power distribution is handled via four color-coded Delphi Packard Metri-Pack 280 Series connectors. A mating connector kit and tooling kit for the PDU-2300 is available from National Instruments. Details of those items are described in sections below.

Power Distribution Connector Pinout

Figure 80 PDU-2300 Connector Pinout

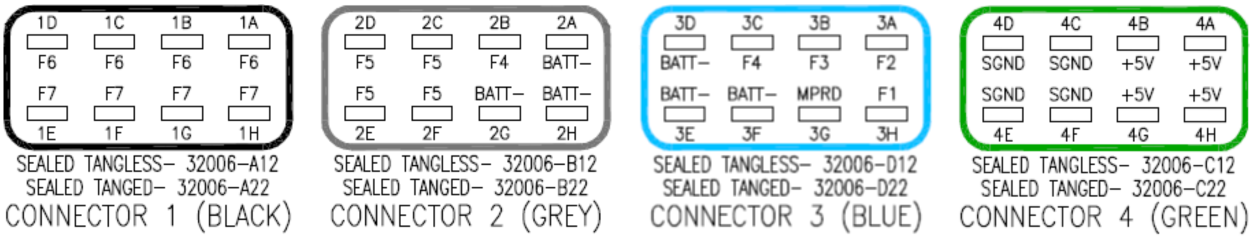


Table 13 Power Distribution Connector Pinout Description

Connector	Pin(s)	Circuit Name	Current Rating	Wire Size (AWG)	Notes
1 (Black)	1A, 1B, 1C, 1D	F6	Fused 7.5A Total	12-18	MPRD-switched battery power For external loads
1 (Black)	1E, 1F, 1G, 1H	F7	Fused 7.5A Total	12-18	MPRD-switched battery power For external loads
2 (Gray)	2C, 2D, 2E, 2F	F5	Fused 7.5A Total	12-18	MPRD-switched battery power For external loads
2 (Gray)	2B	F4	Fused 7.5A	16-18	Un-switched, fused connection to PDU BATT+ post For external loads Shared circuit with PDU pin 3C
2 (Gray)	2A, 2G, 2H	BATT-	Fused 25A Total	12-18	Direct connection to PDU BATT- post For external loads
3 (Blue)	3A	F2	Fused 25A	12	MPRD-switched battery power Connect to DCM DRVP pin 85
3 (Blue)	3B	F3	Fused 25A	12	MPRD-switched battery power Connect to DCM DRVP pin 86
3 (Blue)	3C	F4	Fused 7.5A	18	Un-switched, fused connection to PDU BATT+ post Shared circuit with PDU pin 2B Connect to DCM BATT pin 8
3 (Blue)	3D, 3E, 3F	BATT-	75A Total	12	Direct connection to PDU BATT- post Connect to DCM PGND pins 81, 82, 83
3 (Blue)	3G	MPRD	1A	18	Lowside of relay coils Connect to DCM MPRD pin 16
3 (Blue)	3H	F1	Fused 25A	12	MPRD-switched battery power Connect to DCM DRVP pin 84
4 (Green)	4A, 4B, 4G, 4H	+5V	2A	18	Reserved for future use
4 (Green)	4C, 4D, 4E, 4F	SGND	2A	18	Reserved for future use

Mounting

The PDU can be mounted, in any orientation, to a panel with four M8 bolts. The mounting hole pattern is 120 mm square.

Replacement Components

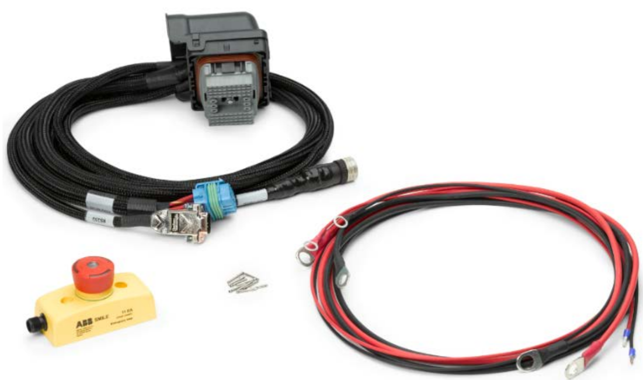
The relays required for the PDU are 12VDC relays, regardless of the nominal PDU voltage configuration. This is because the arrangement of the configuration fuses ensures that 12V is applied to the relay coils in either configuration.

Table 14 Replacement Relays and Fuses

Component	Manufacturer	Vendor	Part #
Relay (4x)	Song Chuan	Mouser	301-1C-C-D2-12VDC or 301-1C-S-D2-12VDC
Fuse, 25 A	Littelfuse	Mouser	0997025.WXN
Fuse, 7.5 A	Littelfuse	Mouser	099707.5WXN

DCM Starter Harness

NI Part #: 785181-01



The DCM Starter Harness accessory includes several items required to quickly get started using the DCM. The PDU-2300 is not included with the Starter Harness kit; however, light- and heavy-duty power supply cables are provided to connect the PDU-2300 input studs to a power source. The contents of the Starter Harness kit are as follows:

- Starter Harness (1.2 m)
- Emergency Stop button
- Light-duty power supply cables
- Heavy-duty power supply cables
- (10) size #20 Deutsch Contacts for wiring of injectors (not included)

Wire Bundle Description

There are three wire bundles of the DCM Starter Harness that terminate to a DCM Connector 1 mating connector. The DCM connector and contact parts detail are provided in the relevant accessory sections below. Each bundle is described in tables 15, 16, and 17 below.

Table 15 Power Bundle

Wire	Source	Destination
Power Ground (PGND)	DCM Connector 1: 81	PDU 3 (Blue): 3D
Power Ground (PGND)	DCM Connector 1: 82	PDU 3 (Blue): 3E
Power Ground (PGND)	DCM Connector 1: 83	PDU 3 (Blue): 3F
Driver Power (DRVP)	DCM Connector 1: 84	PDU 3 (Blue): 3H
Driver Power (DRVP)	DCM Connector 1: 85	PDU 3 (Blue): 3A
Driver Power (DRVP)	DCM Connector 1: 86	PDU 3 (Blue): 3B
Battery (BATT)	DCM Connector 1: 8	PDU 3 (Blue): 3C
Main Power Relay Driver (MPRD)	DCM Connector 1: 16	PDU 3 (Blue): 3G

Table 16 E-STOP Bundle

Wire	Source	Destination
IO_LOCK+	DCM Connector 1: 32	ESTOP: 1
IO_LOCK-	DCM Connector 1: 40	ESTOP: 5

Table 17 RS-232 Bundle

Wire	Source	Destination
RS-232 Transmit	DCM Connector 1: 72	DB-9: 3
RS-232 Receive	DCM Connector 1: 80	DB-9: 2
Isolated Ground (IGND)	DCM Connector 1: 64	DB-9: 5

Using the DCM Starter Harness

The DCM Starter harness is intended for use with the PDU-2300. The steps below describe connecting the DCM, Starter Harness, PDU, and power supply so that the DCM can be powered to communicate with a host PC. This enables the user to begin interacting with the DCM DSI. The user is responsible for making additional connections to external loads, and using the other DCM connector and tooling accessories. The steps below are also provided in the DCM Getting Started Guide. Detailed steps for making a network connection to the DSI are provided in the DSI User Guide.

1.) Select the battery input cables required for the expected current draw.
2.) Connect the selected battery input cables to the PDU and a power supply.
3.) Connect the blue harness connector to the blue PDU-2300 connector.
4.) Connect the black Deutsch 86-pin connector to Connector 1 of the DCM and fasten with a 4mm hex key tool.
5.) Connect the circular M12 harness connector to the ESTOP switch.
6.) Connect a Windows host PC (user supplied) to the DCM Ethernet port using a CAT5E Ethernet cable (user supplied).
7.) Turn on power supply.
8.) Follow instructions within the DSI User Guide to make a host connection with the DSI.

DCM Mating Plug A Connector Kit

NI Part #: 785113-01

The DCM mating plug A connector kit includes the Deutsch 86-pin connector housing, back shell, and female contacts required to fully mate with Connector 1 of the DCM. Table 18 lists the parts and quantities provided in the kit.

Supporting Documents

The following documents are available from the DCM product page at ni.com.

Deutsch DRCP28-86S.pdf: Mating connector housing drawing

Deutsch Contact Sz12 0462-203-12141.pdf: Contact drawing

Deutsch Contact Sz20 0462-005-20141.pdf: Contact drawing

Deutsch Contact Sz20 0462-201-20141.pdf: Contact drawing

Kit Contents

Table 18 DCM Mating Plug A Connector Kit Parts

Component	Qty	Manufacturer	Part Number
DRCP28 Connector, Plug Key A	1	TE-Deutsch	DRCP28-86SA
DRCP28 Back Shell	1	TE-Deutsch	4828-007-8605
Contact, Socket, Size 12, 12-14awg, 25A	8	TE-Deutsch	0462-203-12141
Contact, Socket, Size 20, 16-18awg, 7.5A	85	TE-Deutsch	0462-005-20141
Contact, Socket, Size 20, 20awg, 7.5A	40	TE-Deutsch	0462-201-20141
4mm Hex Key, Right Angle	1		Various

Instructions

For detailed instructions on using the DCM mating plug connector kit, refer to the DCM-23XX Tool Kit accessory section below.

DCM-23XX Tool Kit

NI Part #: 785202-01

The DCM-23XX Tool Kit includes all tools needed to assemble and disassemble the DCM Connector 1, including Deutsch Crimp Tool HDT-48-00 (required to crimp DCM Plug A pins), a removal tool for the pin alignment shell, NI screwdriver, and a right angle 4mm hex key. Table 19 lists the parts and quantities provided in the kit.

Supporting Documents

The following documents are available from the DCM product page at ni.com.

Deutsch HDT-48-00 Crimper Guide.pdf: This document should be consulted for proper use of the Deutsch contact crimper. The detailed instructions within this document are not listed in this section.

Kit Contents

Table 19 DCM-23XX Tool Kit Parts

Component	Qty	Manufacturer	Part Number
Deutsch Crimp Tool	1	TE-Deutsch	HDT-48-00
Screwdriver, Slotted, 5/16 x 3” (Contact Cover Removal Tool)	1	AMPCO	S-48
NI Screwdriver (Contact Removal Tool)	1	NI	781015-01
4mm Hex Key, Right Angle	1		Various

Removing the Mating Connector from DCM Connector 1

The mating connector is fastened to Connector 1 by a center screw which accepts a 4-mm hex key tool. Loosen the screw and pull the mating connector away from Connector 1. The screw is captured by the mating connector housing so it will not get lost. The mating connector is fastened to Connector 1 by pushing the mating connector into Connector 1 while tightening the screw to approximately 5 Nm.

Removing the Contact Cover from the Connector Housing

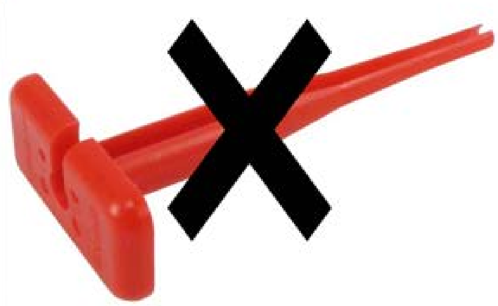
To remove socket contacts from the mating connector housing, the contact cover must be removed. To remove the contact cover, insert a wide-blade screwdriver into the slot on the side of the contact cover, just above the sealing gasket. Use a twisting motion of the screwdriver to release the cover from the body. This step must be repeated on the opposite side. Then the cover may be pulled away from the connector body to reveal the contacts. The cover is replaced by aligning the tabs of the cover with the slots in the housing and pressing the cover until it clicks into place. The cover can only be replaced in an orientation determined by the keyed slots. Sometimes a few contacts may be misaligned enough to prevent the cover from snapping into place. It should be obvious which contacts require adjustment to allow the cover to be installed.

Figure 81 Removing the Contact Cover from the Connector Housing

Removing the Contacts from the Connector Housing

After removing the contact cover from the connector housing, the contacts will be exposed. To remove a contact, use a small blade screwdriver to gently pull the locking tang away from the contact ridge. While doing this, pull the wire/contact out of the connector housing from the other side. Some Deutsch connection systems require a special contact removal tool that is inserted from the wire side. Do not use those removal tools – they are not required and will not be effective for this type of connector housing.

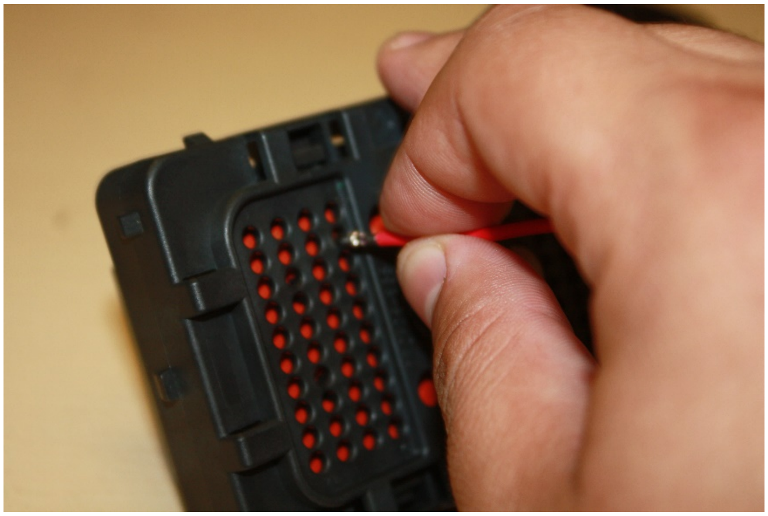
Figure 82 Removing a Contact from the Connector Housing Using a Small Screwdriver



Adding New Wires to Connector Housing

Before adding new wires to the connector housing, the contact cover must be removed. Otherwise the contacts will not snap correctly into place, and will likely back out of the connector housing when fastened to the DCM Connector 1. Follow the instructions for using the HDT-48-00 crimp tool to properly crimp contacts to wires. Then insert the open socket end of the contact into the desired cavity and use the wire to push the contact into the housing until it firmly snaps into place. The wire should not come out with a gentle tug. After all desired contacts are inserted, replace the contact cover as described above.

Adding a Wire/Contact to the Connector Housing



PDU-2300 Mating Connector Kit

NI Part #: 785179-01

The PDU-2300 Mating Connector Kit includes four color-coded connector housings and all contacts needed to fully populate the PDU-2300 connectors. One connector kit is needed per PDU-2300.

Supporting Documents

The following documents are available from the DCM product page at ni.com.

Cooper Bussmann Transportation Products.pdf: Page 6 of this document shows the Eaton 32006-XXX connector system and associated part numbers.

Kit Contents

Table 20 PDU-2300 Mating Connector Kit Parts

Component	Qty	Manufacturer	Part Number
Connector, Tang-less, Black	1	Eaton	32006-A12
Connector, Tang-less, Gray	1	Eaton	32006-B12
Connector, Tang-less, Green	1	Eaton	32006-C12
Connector, Tang-less, Blue	1	Eaton	32006-D12
Terminal, 18-16awg, Female, Tang-less, Metripack 280 Series	30	Delphi Packard	12110847
Terminal, 12-14awg, Female, Tang-less, Metripack 280 Series	10	Delphi Packard	12110845
Seal, Green, 2.03-2.85mm OD Wire	30	Delphi Packard	15324982
Seal, Gray, 2.85-3.49mm OD Wire	10	Delphi Packard	15324980
Terminal, Ring, 16-14awg, 5/16”	1	Molex	19056-0075
Terminal, Ring, 8awg, 5/16”	4	Molex	19193-0174
Terminal, Ring, 8awg, 3/8”	4	Molex	19193-0184

Tanged Versus Tang-Less Connectors and Contacts

This connector kit includes Tang-less style connector housings and contacts. The term “Tang-less” refers to the contacts, since there are no metal tangs on the back side of the contact. Instead there is a rectangular opening. The “tang-less” connector housing does indeed have plastic tangs which snap into the tang-less opening of the contact.

To Summarize:

Tang-less contacts DO NOT have metal tangs on the back, but instead have a rectangular opening.

Tang-less connector housings DO have plastic tangs inside each cavity which snap into the contact.

We prefer the tang-less style connector system over the tanged because it is easier to remove the tang-less contacts by prying the connector housing plastic tang away from the contact to release the contact. You should only use tang-less contacts with “tang-less” connector housings.

Figure 83 Tang-less Contacts and "Tang-less" Connector Housing

Instructions

For detailed instructions on crimping contacts, adding wires to the PDU connector housings, and removing wires, refer to the PDU-2300 Tool Kit accessory section below.

PDU-2300 Tool Kit

NI Part #: 785222-01

The PDU-2300 Tool Kit includes all tools needed to assemble and disassemble the PDU-2300 connectors, including 280 Series Crimp Tool (20-14 awg), 280 Series Crimp Tool (12-10 awg), and a terminal extraction tool.

Supporting Documents

The following documents are available from the DCM product page at ni.com.

None

Kit Contents

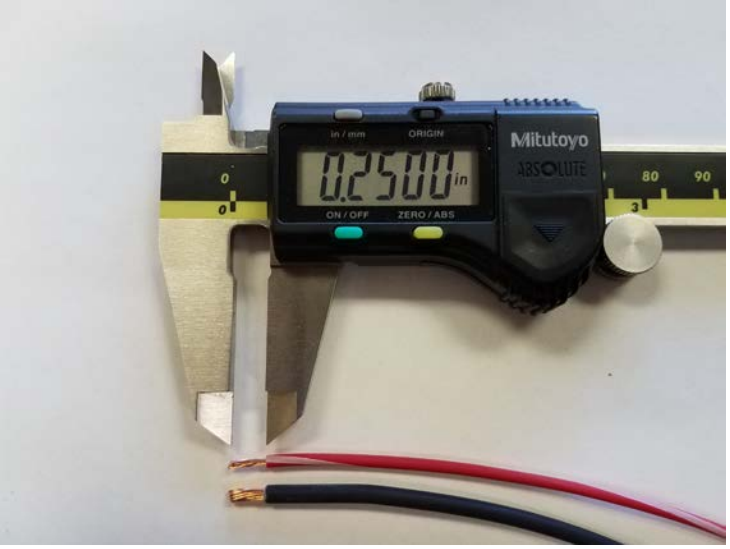
Table 21 PDU-2300 Tool Kit Parts

Component	Qty	Manufacturer	Part Number
280 Series Crimp Tool, 14-20 awg, Black Handle	1	Delphi Packard	12155975
280 Series Crimp Tool, 10-12 awg, Yellow Handle	1	Waytek Wire	474
Terminal Extraction Tool	1	White Products	T-5

Stripping Wires for PDU Contacts

The wires used for all PDU contacts should be stripped to approximately 0.25 in.

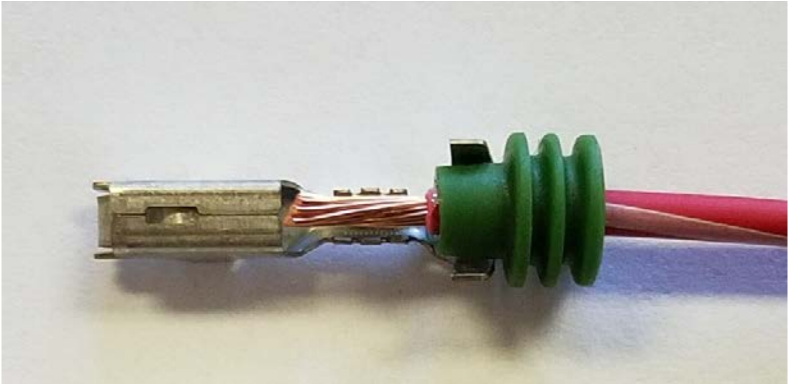
Figure 84 Wire Strip Length for PDU Contacts



Crimping 16-18 AWG Contacts

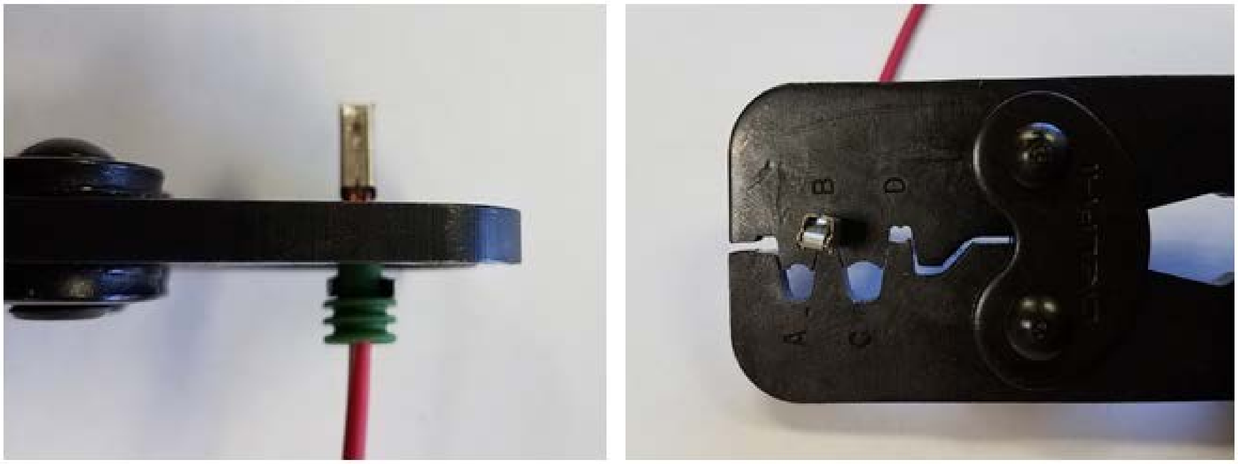
Place the green seal over the stripped wire, so that the smaller diameter of the seal is flush with the stripped edge of the wire jacket.

Figure 85 Placing Green Wire Seal



While holding the stripped wire within the contact crimp area opening, place the contact crimp area within the jaws of slot B (Delphi Crimper), with the contact crimp area opening facing the letter B. Squeeze the crimper handles fully until the ratcheting mechanism releases the handles.

Figure 86 Crimping 16-18 AWG Contacts with Slot B Using Delphi Crimper



Check that the larger diameter of the seal is fully positioned against the seal crimp area of the contact. Place the seal crimp area within the jaws of slot C, with the seal crimp area opening facing the letter C. Squeeze the crimper handles fully until the ratcheting mechanism releases the handles. Similarly, place the seal crimp area within the jaws of slot A, with the seal crimp area opening facing the letter A. Squeeze the crimper handles fully until the ratcheting mechanism releases the handles. The two-step seal crimp process is useful to get the seal crimp started using the larger slot C, while following up with a crimp in the smaller slot A to fully secure the seal.

Figure 87 Crimping 16-18 AWG Seal with Slot C, and Then Slot A Using Delphi Crimper

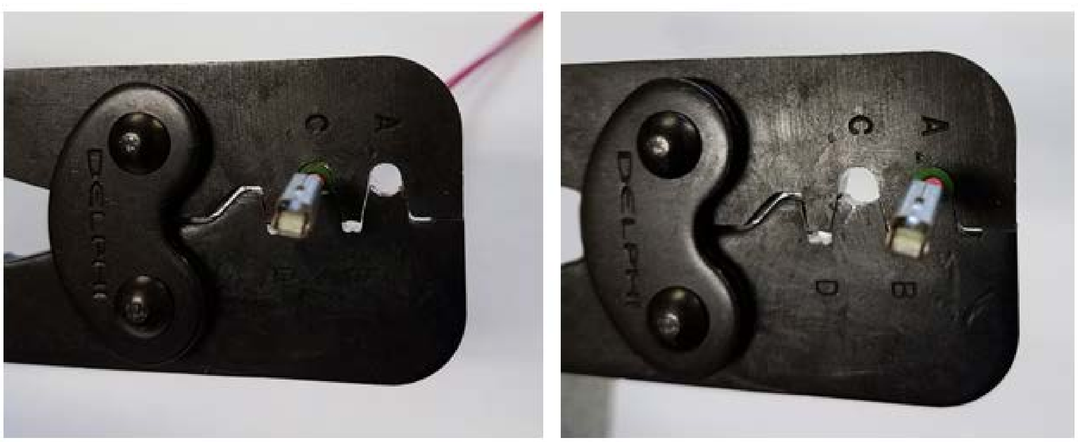
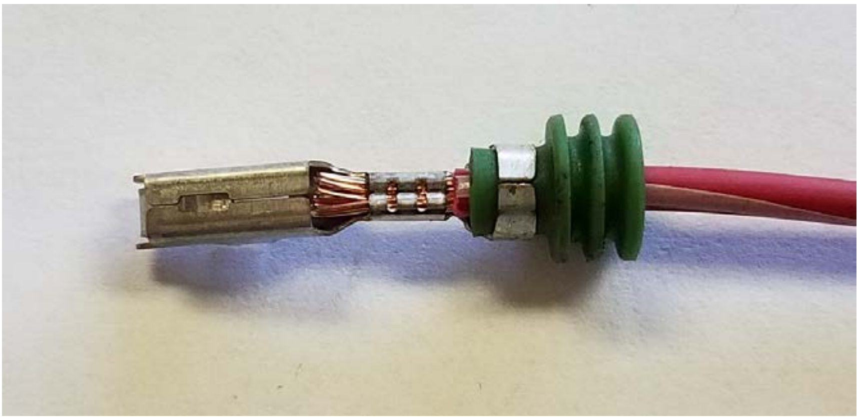


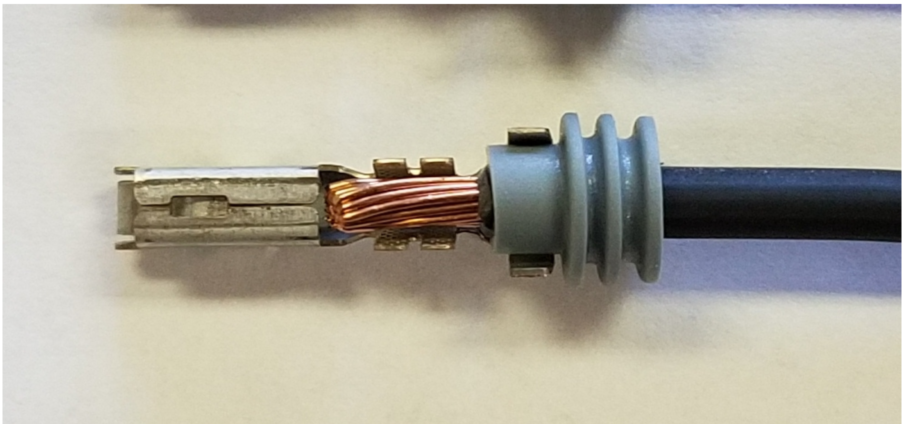
Figure 88 Fully Crimped 16-18 AWG Contact and Seal



Crimping 12 AWG Contacts

Place the gray seal over the stripped wire, so that the smaller diameter of the seal is flush with the stripped edge of the wire jacket.

Figure 89 Placing Gray Wire Seal



While holding the stripped wire within the contact crimp area opening, place the contact crimp area within the jaws of slot 12 (Waytek crimper), with the contact crimp area opening facing the number 12. Squeeze the crimper handles fully until the ratcheting mechanism releases the handles.

Crimping 12 AWG Contacts With Slot 12 Using Waytek Crimper

Check that the larger diameter of the seal is fully positioned against the seal crimp area of the contact. Place the seal crimp area within the jaws of slot INSUL, with the seal crimp area opening facing away from the INSUL label. Squeeze the crimper handles fully until the ratcheting mechanism releases the handles.

Figure 90 Crimping 12 AWG Seal with Slot INSUL Using Waytek Crimper

Figure 91 Fully Crimped 12 AWG Contact and Seal

Inserting Contacts/Wires into Connector Housing

While holding the connector housing so that the back-side cavity letters are facing you, insert the contact into the desired cavity so that the tang-less rectangular opening in the back of the contact is facing the outside of the connector housing (plastic tangs of housing are on the outside of the connector). This orientation is important because the plastic tang within the connector housing must snap into the back of the contact. Push on the wire so that the contact and seal fully seat into the housing until you hear the plastic tang snap (faint) into the contact. This is confirmed by gently pulling on the wire to see that it will not come out.

Figure 92 Inserting Wire/Contact into Connector Housing from Back

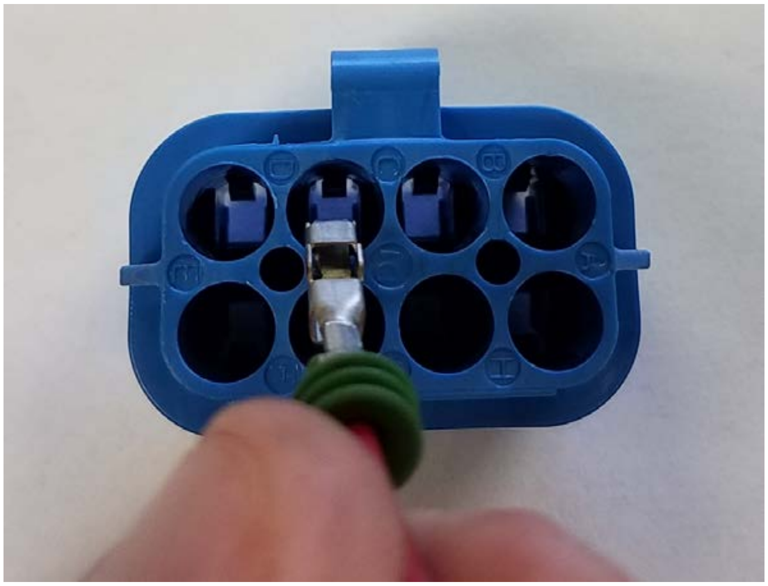
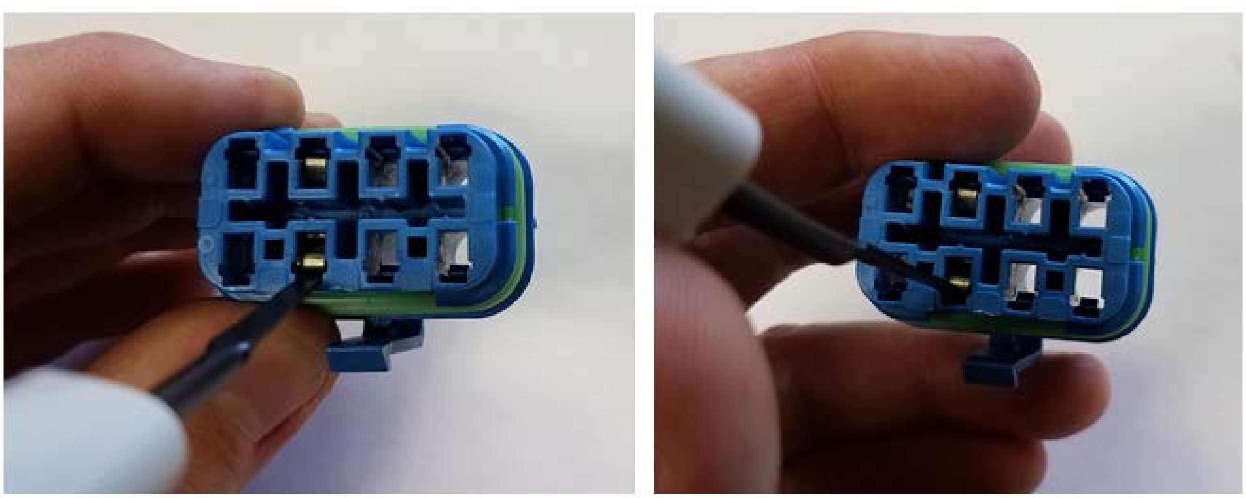


Figure 93 Proper Orientation of Fully Inserted Contacts (Notice the contacts are oriented in opposite directions when placed on opposite sides of the connector housing)

Removing Contacts/Wires from Connector Housing

To remove a PDU contact from the housing, insert the tip of the extraction tool between the outside of the contact and the inside of the plastic housing tang, as shown in the left picture of Figure 94. Gently pivot the handle of the extraction tool toward the middle of the connector housing, which pries the plastic tang away from the contact, as shown in the right picture of Figure 94. This does not require much force. While prying the tang away from the contact, pull the wire on the back-side of the connector housing and the wire/contact will completely pull out of the housing.

Figure 94 Removing Contacts/Wires from the PDU Connector Housing



Crimper Selection

The tool kit includes two crimpers for use on the two different contact sizes included with the PDU connector kit.

Black-Handle Crimper

The black-handle Delphi crimper is to be used with the smaller 16-18 AWG contacts that have three fingers on each side of the wire crimp area. The green seals should be used with the 16-18 AWG contacts. The black-handle crimper has crimp slots labeled A, B, C, and D.

Figure 95 Black-Handle Delphi Crimper, 16-18 AWG Contact, and Green Seal

Yellow-Handle Crimper

The yellow-handle Waytek crimper is to be used with the larger 12 AWG contacts that have two fingers on each side of the wire crimp area. The gray seals should be used with the 12 AWG contacts. The yellow-handle crimper has crimp slots labeled 10, 12, and INSUL. Slot 10 will not be used because 10 AWG wires will not fit the larger contacts of the DCM pins 81-86.

Figure 96 Yellow-Handle Waytek Crimper, 12 AWG Contact, and Gray Seal

Multiplexing Junctions

NI Part #: 785223-01

This accessory provides a solderless solution for those injector configurations, e.g., multiplexed configurations, which require DCM pins to be shared or jumpered together. The 12-position connector contains three-pin shorts for up to four three-way-junctions.

Several injector configurations require two wires attached to the same DI driver pin. While the diagrams show two wires terminating at the DCM pin, this is not recommended in actual wiring practice. It is not possible to fit two 16 AWG wires into the back of a single contact, and it is not recommended to use smaller wires for the sake of doing so. A special type of connector system, made by Deutsch (DT04 and DT06) is designed to act as a robust wiring junction for automotive use. The connector body contains 12 cavities for female contacts. The cavities are arranged in four groups of three. Each group is internally connected. Therefore, three wires can each be terminated with the proper Deutsch contacts and inserted into the connector body for a secure junction. We recommend this splitter-junction system be used for any necessary DCM-pin wire split. Four independent splitter-junctions can be achieved in a single connector housing.

Please note that the connector housing for the multiplexer junction accessory uses Deutsch size 16 contacts. These contacts are larger than, and not compatible with, the DCM mating connector plug. The same crimp tool, HDT-48-00, is used among all the Deutsch contact sizes for the DCM and its accessories. However, the crimp tool settings must be configured specifically for each contact size.

Supporting Documents

The following documents are available from the DCM product page at ni.com.

Deutsch HDT-48-00 Crimper Guide.pdf: This document should be consulted for proper use of the Deutsch contact crimper. The detailed instructions within this document are not listed in this section.

Deutsch DT Series Instructions.pdf: This document should be consulted for proper assembly and disassembly of the Deutsch DT06-12SA connector housing

Deutsch DT04-12PA-P030.pdf: Connector housing drawing

Deutsch DT06-12SA.pdf: Connector housing drawing

Deutsch Wedgelock W12S.pdf: Wedgelock drawing

Deutsch Contact Sz16 0462-201-16141.pdf: Contact drawing

Kit Contents

Figure 97 Multiplexer Junction Kit Parts

Component	Qty	Manufacturer	Part Number
Connector, Deutsch DT, 12-Pos, Pins	1	TE-Deutsch	DT04-12PA-P030
Connector, Deutsch DT, 12-Pos, Sockets	1	TE-Deutsch	DT06-12SA
Wedge-lock, 12-Pos	1	TE-Deutsch	W12S
Contact, Socket, Size 16, 16-18 AWG	15	TE-Deutsch	0462-201-16141

Rack Mount End Plates

NI Part #: 785246-01

The DCM rack-mount end plates, with handles, come standard and installed with each DCM. Front flanges are provided on these end plates to allow DCM installation to a standard 19" rack. The end plates are fastened to the ends of the DCM by six (6) flat-head Phillips metric screws, M5X0.8, 8mm long. Screws are included with the end plate accessory. The screws should be tightened to 22 in-lb.

Supporting Documents

The following documents are available from the DCM product page at ni.com.

DCM Rack Mount End Plates.pdf: Mechanical drawing

Panel Mount End Plates

NI Part #: 785247-01

The DCM panel-mount end plates are an optional accessory. Rear flanges are provided on these end plates to allow DCM installation to a panel. The end plates are fastened to the ends of the DCM by six (6) flat-head Phillips metric screws, M5X0.8, 8mm long. Screws are included with the end plate accessory. The screws should be tightened to 22 in-lb.

Supporting Documents

The following documents are available from the DCM product page at ni.com.

DCM Panel Mount End Plates.pdf: Mechanical drawing