# 7-Amp x 2 H, 15 Volt D-Rex Data Sheet

The NMI-D-Rex is an inexpensive, easy-to-use 0-to-150 KHz, 7 Amp, 0-to-15 Volt H-Bridge and encoder interface designed to mate with the Plug-A-Pod.

## *Features:*

- **150 KHz PWM.**
- **0 to 15 Volt Load.**
- **Fully static operation, down to continuous DC:**
- **True dual-H 7-Amp continuous operation.**
- **Dual current sensors**
- **Directly interfaced – no wiring needed to 'Pod**
- **Synchronous Operation**
  - **Upper/Lower MOSFET exclusion.**
  - **Built-in dead-time.**
- **LED Indicators show**
  - **output polarity**
  - **VB+ presence**
- **Direct wiring to low-current Maxon motors with encoders**
- **Terminal Strip for high current**
- **B+ and Vin sensing to A2D channels**

## *Benefits:*

- High Efficiency
- Easy hookup – Plug-A-Pod compatible

## *Typical Applications:*

- Tiny motion control system
- Encoder feedback applications
- Control small Mabuchi DC motors
- Great match for Tamiya Twin motor gearbox
- Solarbotic GM2, GM3, GM4
- Mini-Sumo
- Small vehicles

## *Specification Summary:*

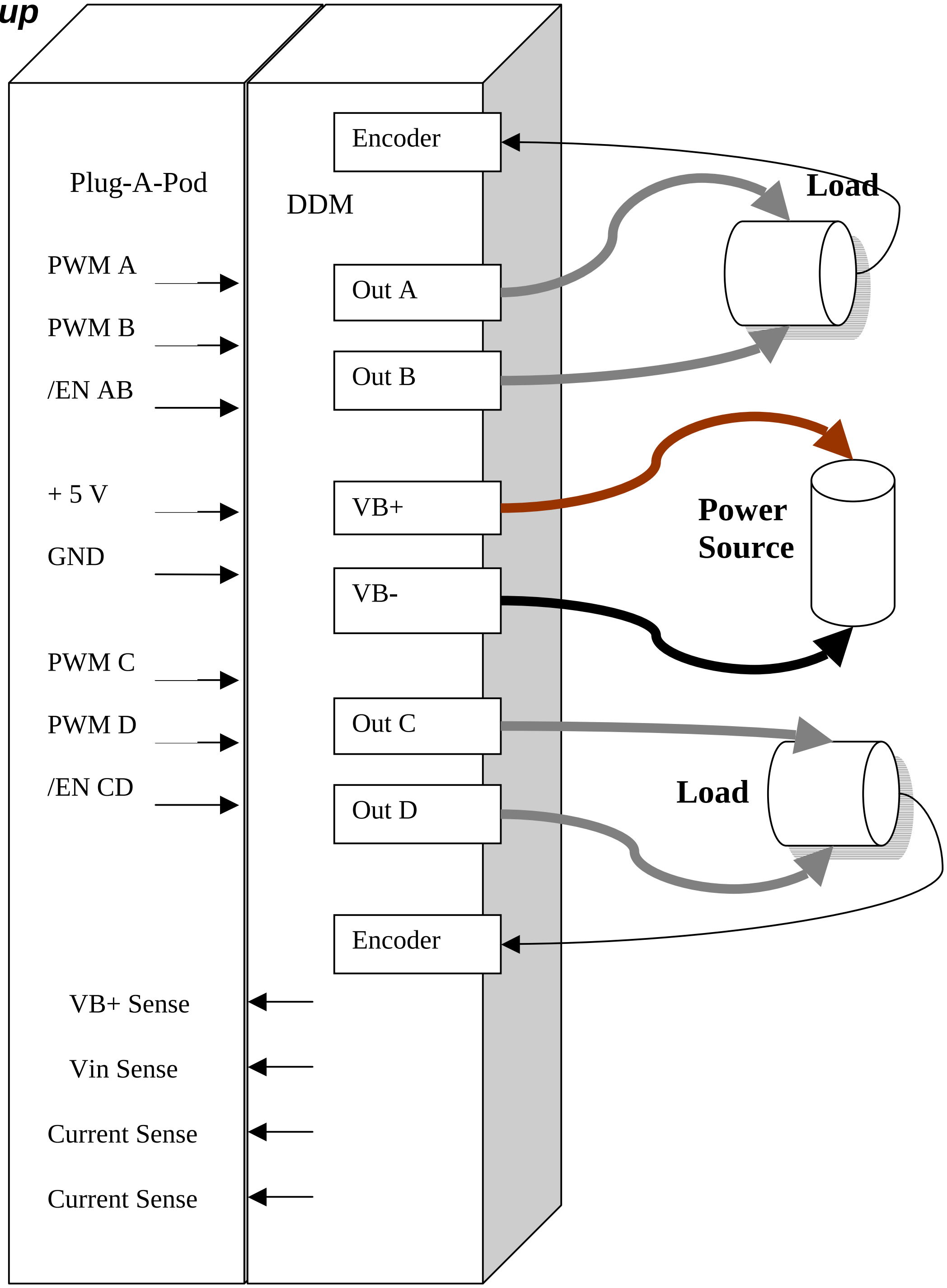
| | **Conditions** | **Min** | **Typical** | **Max** | **Units** | **Note** |
|---|---|---|---|---|---|---|
| Continuous Current | See below | 7 | | | Amps RMS | True continuous use – no time limit |
| Peak Current | Cold start | 10 for 45 sec. | 15 for 10 sec. | 25 for 1 sec. | Amps RMS | |
| VB+ Voltage | | 0 | 12 | 15 (absolute max) | Volts | |
| PWM Rate | | 0 | 2,000 to 50,000 | 150,000 | Hz | |

### Current Rating Test Conditions

150 KHz PWM Dual H sign-mag
50% duty cycle
Inductive & resistive load
Ta = 25°C free air
VB+ = 12 Volts
Both Channels operating at the same current

NOTE: In any inductive-load application, the RMS value of current will be higher than the average value. At lower PWM rates, there will tend to be more difference (all else being equal).
If peak current is < 125% of average current the difference is not very significant, and an average current reading is relevant.

***Typical Hookup Diagram***



# User Guide

The D-Rex turns the Plug-A-Pod into a very compact and capable motion control system.

## *Features:*

- **150 KHz PWM.**
  - This bridge provides efficient, fast switching.
  - suitable for coreless motors, or other very-low-inductance loads.
- **Zero to 15 Volt operation.**
  - The load voltage has no lower limit. High current low voltage loads, such as Peltier junctions, solenoids, and low voltage motors, can be accommodated.
- **Fully static operation, down to continuous DC:**
  - Bridge will work with a continuous high (100% PWM) input.
  - Bridge will work with a continuous low (0% PWM) input.
- **True 7-Amp RMS continuous operation.**
  - Based on actual testing
  - Rated for both motor channels operating simultaneously
- **High Peak Current**
  - Allows acceleration and transient load to be handled
  - Based on actual testing
- **Direct connection to Plug-A-Pod**
  - All connections made by simply joining them together
  - Stacking connector allows option of relative position
- **Upper/Lower MOSFET exclusion.**
  - Prevents destructive shoot-through.
  - No logic input combination or timing can result in shoot-through from both upper and lower MOSFETs turning on at the same time.
- **Built-in dead-time.**
  - No need for formal dead time in PWM waveform
- **High Efficiency.**
  - Low resistance MOSFETs produce minimal heat.
  - Fast switching reduces resistive losses.
  - Synchronous operation avoids diode drop losses.
  - Built-in low-ESR bulk capacitance provides higher voltage-efficiency.
  - High frequency PWM reduces $I^2R$ losses in the load.
- **Indicators.**
  - The VB+ voltage LED indicates presence of motor voltage.
  - Output Red/Green LED displays net load voltage differential.
- **Current Sensing.**
  - Many applications require monitoring load currents to guard against overloads and sense normal load magnitude for conditions such as stall, slippage, or other out of range operation.
  - This bridge provides an analog signal for each motor channel that corresponds to the amount of current flowing through the motor.
- **Easy-ON Connectors**
  - automotive type spade connections on VB+ side and load side outputs.
  - Industry-standard, inexpensive connections.

## *Benefits:*

- High Efficiency
- Easy hookup
- Useable for very wide range of loads

## *Typical Applications:*

- Compact Motion control
- Robotics
- Controlling Coreless Motors using very high PWM frequencies. (see Application section for additional information)
- High performance Voice Coil drive
- Controlling loads with high efficiency.
- Providing load current feedback.
- Rapid-response control systems.
- Controlling thermoelectric loads.

J2 Pin Usage

| **D-Rex** | **Plug-A-PodS** | **Plug-A-PodS** | **D-Rex** |
|---|---|---|---|
| | SOUT | VIN | |
| | SIN | GND | GND |
| | ATN | RESET | |
| | GND | +5.0V | +5.0V |
| Hbridge1 (Right) | PWMA0/ISA0 | PWMA1/ISA1 | Hbridge1' (Right) |
| /Enable1 (Right) | PWMA2/ISA2 | PWMA3/FAULT0 | /Enable2 (Left) |
| Hbridge2 (Left) | PWMA4/FAULT1 | PWMA5/FAULT2 | Hbridge2' (Left) |
| | TD1 | TD2 | |
| Encoder1A (Right) | TA0 | TA1 | Encoder1B (Right) |
| Encoder2A (Left) | TA2 | TA3 | Encoder2B (Left) |
| | PE4/SCLK | PE5/MOSI | |
| | PE6/MISO | PE7/SS | |

J8 Pin Usage

| **D-Rex** | **Plug-A-PodS** | **Plug-A-PodS** | **D-Rex** |
|---|---|---|---|
| | +3.3V | CANH | |
| GND | GND | GND | GND |
| | VREF | CANL | |
| | VDDA | VSSA | VSSA |
| CurrMon Motor2 (left) | AD1 | AD0 | CurrMon Motor1 (right) |
| Voltage Vin | AD3 | AD2 | Voltage Motor+ |
| | AD5 | AD4 | |
| | AD7 | AD6 | |
| | PA1 | PA0 | |
| | PA3 | PA2 | |
| | PA5 | PA4 | |
| | PA7 | PA6 | |

Maxon Motor Connectors

These are designed to allow direct connection to a small version of a Maxon motor with encoder. The Left motor connector has reversed encoder and motor power drive connections so that a robot with differential drive can have increasing counts on both motors when going forward,

J7

| **Signal** | **Pin Number** | **Pin Number** | **Signal** |
|---|---|---|---|
| OUT 1 (Right) | 1 | 2 | Vcc +5v |
| Quadrature B | 3 | 4 | Quadrature A |
| GND | 5 | 6 | OUT 1’ (Right) |
| | 7 | 8 | |
| | 9 | 10 | |

J1

| **Signal** | **Pin Number** | **Pin Number** | **Signal** |
|---|---|---|---|
| OUT 2’ (Left) | 1 | 2 | Vcc +5v |
| Quadrature A | 3 | 4 | Quadrature B |
| GND | 5 | 6 | OUT 2 (Left) |
| | 7 | 8 | |
| | 9 | 10 | |

J3, J6

| Pin | Signal |
|---|---|
| 1 | GND |
| 2 | N.C. |
| 3 | Encoder A |
| 4 | Vcc +5v |
| 5 | Encoder B |

| | | | | | | |
|---|---|---|---|---|---|---|
| Propagation Delay | | | | | Nanoseconds | |
| Max Switching Frequency | | 250,000 | | | Hz | This is rarely a practical PWM frequency to use. |
| Recommended Coreless Motor PWM rate | | 50,000 | 100,000 | 150,000 | Hz | Good for coreless motors |
| Recommended Iron Core motor PWM rate | | 5,000 | 20,000 | 30,000 | Hz | Use 20,000 to avoid audible hum in motor windings. |
| Minimum PWM Rate | | | | 0 | Hz | Bridge is completely static |
| Current Sense Gain | | .094 | .1 | .106 | Volts/Amp | Ratiometric from 5v supply |
| Current Sense | | | Vcc5/2 | | | Half of the 5V vcc |

| | | | | | | |
|---|---|---|---|---|---|---|
| Zero-Amps voltage | | | | | | |

## *Warnings:*

Grounds:

This bridge ties the VB- connection to the GND of the Plug-A-Pod. If there are additional ground ties there may be ground loop currents. Avoid using any connection to VB- for digital or analog circuitry.

Overloads:

This bridge is NOT self-limiting at all. It is the responsibility of the user to ensure that the limits of the bridge and the load are respected.

The user should:

- Use series resistors on the outputs when developing controlling software or hardware. For example, connect a light bulb rated for the VB+ voltage in series with each output or at least in series with the load. If PWM is "frozen" full-on (for example when single-stepping PWM code), the light bulb will light and may avoid destroying the load. Alternatively, put the bulb in series with the VB+ connection.
- Use the current sense outputs to control the PWM signals to avoid overloads.
- Add fuses to the VB+ and possibly the motor output circuits.

Heat Generation:

This device will reach temperatures of 100 to 110 degrees Celsius in continuous operation in still air. It will operate correctly at these temperatures. With absolutely no air movement, however, the attached Plug-A-Pod may be heated above its specified operational range.

The best mounting position for the combination is to have the PC boards vertical, with the headers vertical as well, to allow convection currents to easily flow, and to avoid completely stagnant air between the boards.

Also note that the continuous ratings are for 25 degree Celsius ambient conditions. If this device is operated in a very confined space, e.g. a small robot, the ambient temperature will climb. Also, in sunny, warm outdoor operation, the ambient temperature inside a robot can easily be 40 to 50 degrees C. A cooling airflow must be supplied under these conditions, or the device must be operated below the maximum ratings. The use of temperature indicating labels, or an electronic temperature sensor, can help determine if there is a problem.

## Source Power

The VB+ power source can be a battery or a power supply.

Some batteries are relatively high impedance sources, especially in cold temperatures. The bridge contains low-ESR bulk capacitance that will markedly increase efficiency and reduce noise on the VB+ and GND lines. However, if the power source has more than .050 Ohms impedance and is providing more than 5 Amps continuous load more local bulk capacitance may be required.. An infrared thermometer can be used to measure the temperature of the electrolytic capacitor under the most strenuous operating conditions. If it reaches more than 110 degrees C some external bulk capacitance should be added near the bridge VB connections.

When using a power supply it will very likely already have sufficient bulk capacitance.

Lead-Acid Batteries

The absolute maximum voltage allowed on this bridge is 15.0 Volts. Please be aware that a “12v” lead-acid battery can see as much as 16 volts when on charge, and be 14 volts when just off charge.

The maximum rated voltage of 15v allows direct hookup to a “12v” lead-acid battery, except when performing an equalization charge or high-rate charge, when battery terminal voltage could sometimes exceed the 15 Volt maximum rating of the bridge. A normal low-rate “trickle” charger will generally be safe, since they are designed to float the battery at about 13.8 volts.

Li-Ion and Li-Ion-Polymer

Li-Ion and Li-Ion-Polymer batteries have maximum voltages of 4.1 or 4.2 volts. Therefore up to three series-connected cells can be used with this bridge.

## RFI/EMI

This high-performance H-bridge switches VERY quickly to maintain high efficiency. Given the large currents being switched so rapidly, the possibility of RF generation is high.

Careful design to avoid unnecessary current spikes may NOT meet any particular RFI generation standards. Shielding and filtering the high current inputs and outputs, as well as FET Drive power (if separately supplied) and possibly the logic signals may be required to reduce RFI/EMI.

## Driving the PWM channels

The most power-efficient arrangement for controlling a bidirectional load, such as a servo-motor, is known as “Sign-Magnitude” control. In this scheme, only one half of the bridge is pulsed with the PWM signal at a time, and the other is held steady. The load sees no waveform at zero drive, making idle efficiency very high (zero load current D.C. or A.C.). The disadvantage is that at different times the A or B PWM inputs will need to have waveforms.

The alternate approach is to have each half of the bridge exactly opposite in phase to the other. This is called “Locked-Anti-phase”. This approach is not as efficient, because both sides of the bridge will have switching losses, and the zero-drive waveform will still put some AC current through the load, causing heating. However, this bridge has Enable inputs that can be used to idle the outputs when the load needs no drive, so in some applications locked-antiphase may be a theoretically viable solution.

The DDM always has 4 PWM outputs available to it, because if its direct connection to the Plug-A-Pod. Therefore it will virtually never need to be driven in Locked-Antiphase.

## When to use the Enable lines:

- If the load needs to be disconnected e.g. let a motor “coast” on inertia.
- During initialization of hardware and software the /EN lines should be held high to make sure that the bridge does not activate the load before all of the other circuitry and intelligence is ready.

- Do not use the Enable lines for the PWM signal. This would defeat the Synchronous Rectification operation and drastically increase the heat load on the MOSFETS.

## Current Sensing

The current-sensing provides a method of monitoring the actual load current. The current sense amplifiers sense instantaneous load current at any PWM rate, percentage, or state.

The main usefulness of the current feedback is to ensure the load is getting driven roughly in the expected or acceptable range of currents, and allow closing the loop, rather than be blind to the current being drawn.

Due to the nature of the PWM environment, the current sense outputs have some noise on them. Averaging the readings over one or more complete PWM cycles may be necessary. Coordinating A to D sampling in synchronization with the PWM signal may lead to relatively lower noise readings. Sampling should be done during periods of the PWM cycle when no switching transients are taking place, because the great majority of the noise on the current sense signal comes from the switching transients.

Each current sense reading is bidirectional, floating at a middle ( ½ of Vcc5v e.g. 2.5 Volts) value when no current is flowing.

This zero-current value should be read, averaged, and stored as a calibration point for each channel. See the sample code below.

When "forward" current is flowing through the bridged load, the current sense signal will go lower then the zero-current value. Since the A2D converter has a maximum voltage input of 3.3v, this allows a higher current to be sensed in the "forward" direction. In "reverse", at .1 v per Amp, it will hit the 3.3 Volt limit at 3.3 – 2.5 = .8 Volts = 8 Amps. In "forward", it could read as much as 25 Amps before reaching zero volts, but there is a nominal 20 Amp maximum sensed current.

# *Application Hints*

### Closed vs. Open Loop H-Bridge usage

Some applications, for example propulsion of a remote-controlled vehicle, do not "close the loop" and put a microcontroller in charge of regulating the speed of the motor. Instead, the desired behavior is more like a throttle.

Very often, these applications operate the bridge such that current only flows through the motor in one direction most of the time – the direction of motion – so that the motor can "coast" between periods of power application. In these situations, the tight control of motor speed offered by continuous synchronous-rectification sign-magnitude or locked-antiphase PWM is undesirable.

There are two main approaches to providing this behavior, and a third that combines the first two:

- Use the /EN lines for PWM (see power dissipation warnings)
- Monitor the current through the load, and close a current loop with a target of zero when coasting.
    - A negative current target will provide a controlled braking torque.
- Monitor the current, and use the /EN lines for operation at low currents
    - This will avoid high power dissipation at high loads

Another situation where a more open-loop approach is necessary is when the PWM rate is so low (e.g. less than 1KHz) that the delta-I current buildup in the load during the time of each PWM cycle is very large, and it therefore (because of heating) becomes infeasible to keep the load tightly coupled. The bridge is then run with /EN being the PWM, and each PWM pulse results in a torque pulse to the motor.  Speed control will be poor, because the bridge is not operating as a voltage source but more like a current source. Attempting to operate a closed-loop motion control system in this mode is very problematic.

## Coreless Motors

Some very nice, very fast-responding and efficient coreless motors have become available.  However, they really need to be driven using a much higher PWM frequency than a regular iron-core motor.

A general rule-of-thumb for determining an efficient PWM rate for a given motor with sign-magnitude control is to ensure that at 50% PWM the peak-to-peak ripple current not exceed 50% of the rated current of the motor, if possible, and a good target would be to keep it to a maximum of 25%. (There are tradeoffs in RFI, switching losses, I2R losses, overall efficiency, motor losses versus controller losses, PWM resolution, and other factors that may lead to a higher or lower PWM rate being the best. It may even be best to vary the PWM rate according to the operational regime.)

The following calculations are simplified to ignore resistive losses, by way of assuming that BEMF is 50% of VB+ (motor operating at half the maximum (100% PWM) speed, and also at half the applied voltage). During the ON time of PWM, the inductance sees ½ of VB+, and during the OFF time sees the negative of BEMF, which is (because of our simplifications) also ½ of VB+.

So, given VB+, motor inductance Lmot , and rated current Imax, with desired max percentage Pct and duty cycle D an estimated (uses triangular wave assumption) the minimum PWM frequency:

Fmin = 1 / ( ( Pct * Imax ) / ( ( (VB+/2) /  Lmot ) * D ) )

With D = .5 = 50%, and Pct = .25 = 25%

For example, a MAXON RE35 is a 90W ironless core motor. Model 273752 specifies 4.0A max continuous current and a terminal inductance of .09 mH.

If you want to use this motor at its specified maximum voltage of 15 Volts, then:

Fmin = 1 / ( ( .25 * 4.0 ) / ( ( (15/2) /  .00009) * .5 ) ) = 41,667 Hz

At a reduced voltage, the requirements are lower:

Fmin = 1 / ( ( .25 * 4.0 ) / ( ( (5/2) /  .00009) * .5 ) ) = 13,888 Hz

But as shown, the typical PWM frequencies (such as 2 KHz to 20 KHz) used for iron-core motors can cause unnecessary and perhaps unacceptable heating on these coreless motors.

Locked Anti-phase

It should be noted that with locked-antiphase operation the demands are much higher. The peak-to-peak voltage of the PWM waveform is double that of sign-magnitude and the ripple current is at its worst when there is zero applied voltage!

Since the zero-drive condition might be continuous, it would be better to have a lower ripple current amplitude e.g. 10%. In locked-antiphase the inductance sees the full VB+ voltage:

Fmin = 1 / ( ( Pct * Imax ) / ( ( VB /  Lmot ) * D ) )

Fmin = 1 / ( ( .1 * 4.0 ) / ( (15 /  .00009) * .5 ) ) = 208,333 Hz.

Considering the increased FET drive requirements, and the increased switching losses in the MOSFETs, you can see locked-antiphase operation for low inductance applications is generally not recommended.

## *Sample Code*

### PWM

The recommended approach is to drive one output channel at a time, and hold the other low.  This gives the load a sign-magnitude drive, and is the most efficient approach. The following code will help make it easy to implement that type of control.

```
\ Forward is defined as the Master channel PWM being pulsed positive
\ which makes the rightmost output go positive
\ and results in the green LED being lit at the output

\ Right motor
: PWMFWD_R ( onCount -- )
  PWMA0 PWM-OUT   ( pulses out one side
  0 PWMA1 PWM-OUT ( hold off the other
; EEWORD

: PWMREV_R ( onCount -- )
  PWMA1 PWM-OUT   ( pulses out one side
  0 PWMA0 PWM-OUT ( hold off the other
; EEWORD

\ Takes sign, magnitude and outputs the PWM
\ sign is any number +-
\ magnitude is Zero for no output, to FFFF for 100% output
: PWMSIGNMAG_R ( sign magnitude -- )
  \ bring the sign up to test, and put the PWM count down
  SWAP
  ( test sign
  0> IF
    ( Forward
    PWMFWD_R
  ELSE
    ( Reverse
    PWMREV_R
  THEN
; EEWORD
```

```
\ Left motor
: PWMFWD_L ( onCount -- )
  PWMA4 PWM-OUT   ( pulses out one side
  0 PWMA5 PWM-OUT ( hold off the other
; EEWORD

: PWMREV_L ( onCount -- )
  PWMA5 PWM-OUT   ( pulses out one side
  0 PWMA4 PWM-OUT ( hold off the other
; EEWORD

\ Takes sign, magnitude and outputs the PWM
\ sign is any number +-
\ magnitude is Zero for no output, to FFFF for 100% output
: PWMSIGNMAG_L ( sign magnitude -- )
  \ bring the sign up to test, and put the PWM count down
  SWAP
  ( test sign
  0> IF
    ( Forward
    PWMFWD_L
  ELSE
    ( Reverse
    PWMREV_L
  THEN
; EEWORD

\ Given raw PWM ranging from unsigned 8001 (which is negative 7FFF),
\ to 7FFF which is positive,
\ Transforms it into a sign and magnitude pair on the stack
\ with the magnitude capped at FFFE
: RAW_TO_SIGN_MAG ( rawPwm -- sign magnitude ) \ magnitude is 0 to FFFF
    DUP  ( copy for magnitude, leaving it on the stack for Sign
    ABS  ( get magnitude 0 to 7FFF
    \ Multiply by two to fill out the maximum PWM value
    2*
; EEWORD
```

Normally, the motion control PID loop will be giving the +/- PWM values to be used.

To set up the PWM frequency and basic channel operation:

```
DECIMAL \ very important, in order to caclulate PWM period correctly
: INIT_PWM
  2500 \ value for calculating PWM count from KHz ( period is 2500/KHz )
  50   \ KHz - choose according to the load, desired resolution etc.
  / PWMA0 PWM-PERIOD

  0 PWMA0 DEADTIME             \ no deadtime is needed for D-Rex
  0 PWMA4 DEADTIME

  PWMA0 INDEPENDENT            \ non-complimentary outputs
```

```
  PWMA4 INDEPENDENT

  0 PWMA0 PWM-OUT       \ initial 0% duty cycle
  0 PWMA1 PWM-OUT
  0 PWMA4 PWM-OUT
  0 PWMA5 PWM-OUT

  \ Enable both sides - this could be delayed until all setup is done
  PWMA2 ON
  PWMA3 ON
; EEWORD
```

To simply test the above, issue:

```
HEX
INIT_PWM
1000 RAW_TO_SIGN_MAG PWMSIGNMAG_L
1000 RAW_TO_SIGN_MAG PWMSIGNMAG_R
```

interactively. The outputs will become active if Vbatt is present. (This is best done with the load disconnected! You will be able to see the output LEDs glow green if everything is operational.)

## Current Sensing

The current sensing can be noisy. Therefore we typically need some means of filtering it.  There is a low-pas filter already implemented on the board, but it is set conservatively to allow fast response if desired.

The following code will set up an averaging filter that can be set for whatever number of samples are desired, up to 32,000.

```
DECIMAL
100 CONSTANT NUM_CURRENT_SAMPLES  \  for this demo we'll always heavily
average
LOOPINDEX CURRENT_SAMPLE_INDEX EEWORD
NUM_CURRENT_SAMPLES CURRENT_SAMPLE_INDEX END
1 CURRENT_SAMPLE_INDEX START  \ make number of counts the same as the
end value

2VARIABLE CURRACC_L EEWORD \ current reading accumulator
2VARIABLE CURRACC_R EEWORD \ current reading accumulator

: INIT_SAMPLING
  0. CURRACC_L D!  ( clear the accumulator
  0. CURRACC_R D!  ( clear the accumulator
  CURRENT_SAMPLE_INDEX RESET
; EEWORD

( leaves TRUE on stack if full count of samples has been accumulated
( leaves FALSE otherwise
: SAMPLE_CURRENT ( -- fullFlag
  ( Left
```

```
  ADC1 ANALOGIN
  S->D CURRACC_L 2@ D+ CURRACC_L D!
  ( Right
  ADC0 ANALOGIN
  S->D CURRACC_R 2@ D+ CURRACC_R D!

  CURRENT_SAMPLE_INDEX COUNT
; EEWORD
```

The current sensing is bi-polar, in that it senses both positive and negative current flow through each H bridge.  It therefore has an offset voltage when no current is flowing.

The following code will take an averaged reading and save the value for later use when calculating operational current.

```
2VARIABLE CURRENT_ZERO_L EEWORD
2VARIABLE CURRENT_ZERO_R EEWORD

: SET_CURRENT_ZERO
  ( in order to set the zero, they must first be cleared
  0. CURRENT_ZERO_L 2!
  0. CURRENT_ZERO_R 2!
  INIT_SAMPLING

  BEGIN SAMPLE_CURRENT UNTIL  ( loop, as long as sampling gives FALSE
value

  CURRACC_L 2@
  CURRENT_ZERO_L 2!  ( save the zero value

  CURRACC_R 2@
  CURRENT_ZERO_R 2!  ( save the zero value

; EEWORD
```

To make it all work properly, we set up a couple of variables to hold the result of calculating the current, and make them easy to read:

```
\ average, calibrated and scaled values
VARIABLE CURRENT_VALUE_L EEWORD
VARIABLE CURRENT_VALUE_R EEWORD

\ returns the net current through the load
\ more positive when current is forward
\ scaled to tenths of an amp
: GETCURRENT_L
  CURRENT_VALUE_L @
; EEWORD

: GETCURRENT_R
```

```
  CURRENT_VALUE_R @
; EEWORD
```

But the real work of ensuring the averaging takes place, and the current readings are offset and scaled is done by this code:

```
DECIMAL
\ use a negative value to invert the value
\ - the sensors lower the voltage with what we consider forward current
\ gives approximately tenths of amps
-76. 2CONSTANT CURRENT_SCALING_DIVISOR_L
-76. 2CONSTANT CURRENT_SCALING_DIVISOR_R

( Note: the zero value could be subtracted unscaled or scaled
(       - we chose scaled to be able to have more concise code

( Calculates and stores the average, scaled, zero-referenced value of
current
( pre-requisite is to have an accumulated value representing exactly
( the correct number of samples

: CALC_AVERAGE_CURRENT_L
  CURRACC_L 2@
  CURRENT_ZERO_L 2@ D-
  NUM_CURRENT_SAMPLES S->D D/   ( now we have the average, unscaled
  CURRENT_SCALING_DIVISOR_L D/  ( best to use divisor on double-
precision value
  DROP ( make single precision, keeping least significant word
  CURRENT_VALUE_L !
  0. CURRACC_L D!  ( clear the accumulator
; EEWORD

: CALC_AVERAGE_CURRENT_R
  CURRACC_R 2@
  CURRENT_ZERO_R 2@ D-
  NUM_CURRENT_SAMPLES S->D D/
  CURRENT_SCALING_DIVISOR_R D/  ( best to use divisor on double-
precision value
  DROP ( make single precision, keeping least significant word
  CURRENT_VALUE_R !
  0. CURRACC_R D!  ( clear the accumulator
; EEWORD
```

And to get the samples to happen and do the averaging calculations at the appropriate intervals, this needs to be called periodically (and relatively frequently):

```
: CURRENT_AVERAGING
  SAMPLE_CURRENT  ( leaves flag on stack
  IF
    ( have accumulated full set of samples
    CALC_AVERAGE_CURRENT_L
    CALC_AVERAGE_CURRENT_R
```

```
  THEN
; EEWORD
```

## Voltage Sensing

The two voltage sensing dividers allow straightforward monitoring of the Vbatt and the Vin, so that, for example, a robot could stop using its main battery if the voltage gets too low.

```
DECIMAL
\ set scaling values for voltage sensing - nominal value is 129
129 CONSTANT VBATT_SCALING_DIVISOR
129 CONSTANT VIN_SCALING_DIVISOR
HEX

( our convention is to report Vbatt in tenths of a volt
: GET_VBATT_SCALED
  ADC2 ANALOGIN
  VBATT_SCALING_DIVISOR /
; EEWORD

( our convention is to report Vin in tenths of a volt
: GET_VIN_SCALED
  ADC3 ANALOGIN
  VIN_SCALING_DIVISOR /
; EEWORD
```