Project confidential

User Manual: Lemi-011 Digital Interface

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Contents

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Acronyms and Abbreviations

Item	Description

1. Introduction

The Lemi-011 Digital Interface provides a digital interface to the Lemi-011 analog magnetometer. The interface samples the analprimary digital interface is a serial RS232 interface that outputs the

2. Related Documentation

1. Lemi-011 DigIF Item Specification

3. Functional Overview

Figure 1 show the functional diagram of the Digital Interface.

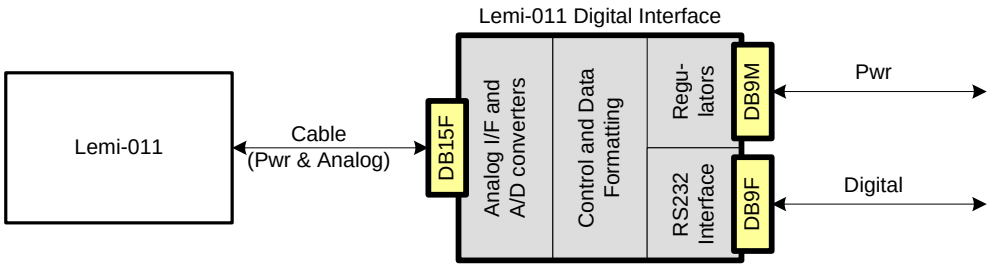


Figure 1: DigIF Functional Diagram

The Analog Interface and A/D Converters interfaces to the magnetometer (Lemi-011) and converts the analog voltages to digital numbers. The Control and Data Formatting function processes the digital numbers into the required output format. It also performs calibration. The RS232 Interface outputs the readings in an RS232 compatible format for connection to a computer serial port. The RS232 interface also allows the computer to configure the unit (see section 5.4 for the Configuration Options). External power is supplied to the unit via a power connection and regulators in the DigIF provide the required internal voltages.

The functionality provided by the interface can be summarized as follows:

- Sample and digitize the analog outputs from the Lemi-011 magnetometer.
- Optionally average the samples further.
- Optionally provide calibration (full 3x3 gain matrix and 3x1 offset vector).
- Provide a terminal-based configuration interface that allows the setting of various configuration options as well as the storage and retrieval of configuration to/from non-volatile memory.
- Provides a USB-Virtual serial port interface via the USB port.
- Allows for firmware updates via the USB port (in-field updates).

4. Interfaces

The DigIF is shown in Figure 2. The external interface are clearly marked.

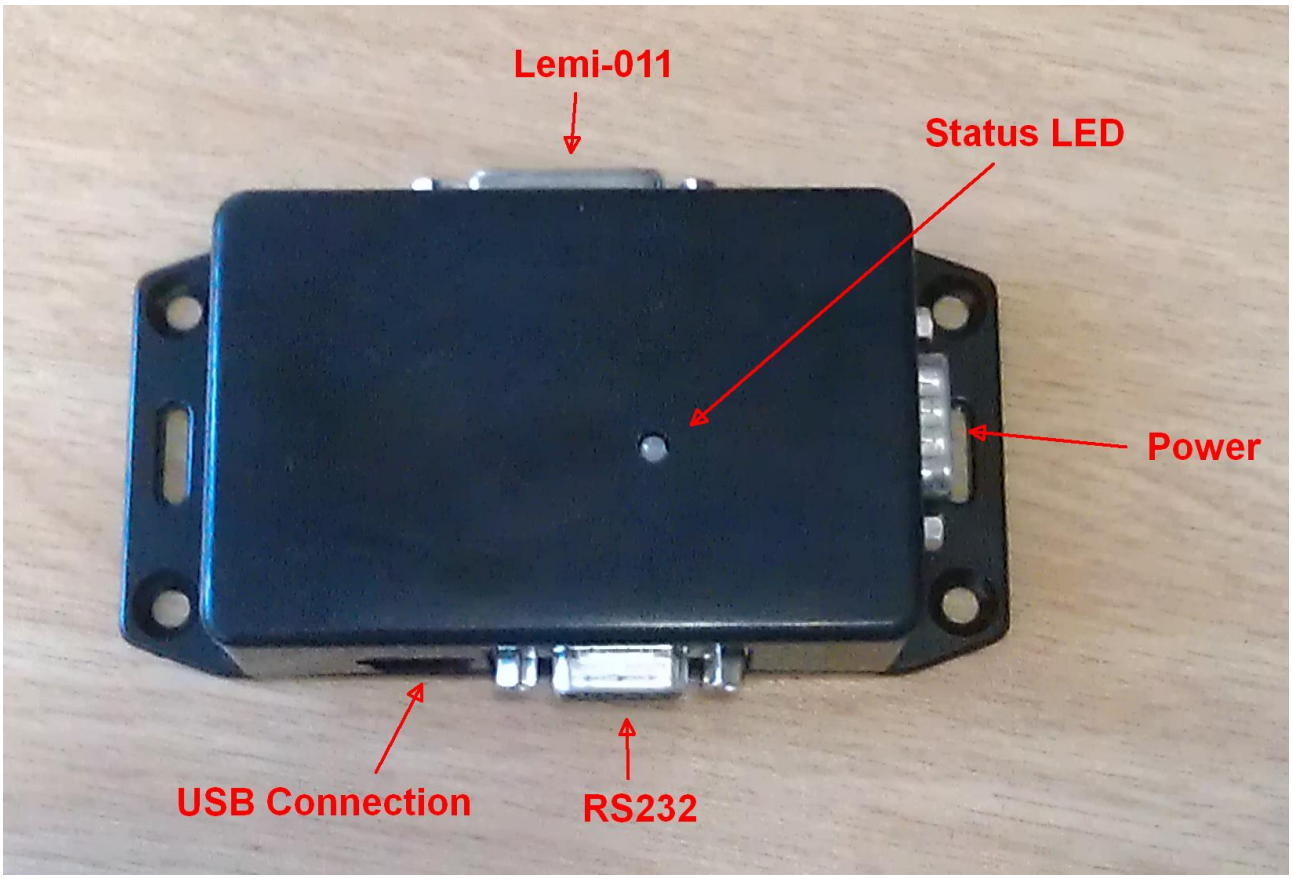


Figure 2: Lemi DigIF unit.

The unit has the following physical interfaces:

1. Power (DB9 Male): Unregulated power input to the unit. The power supply voltage must be 7.5V – 18V.
2. Lemi-011 Interface (DB15 Female): The Lemi-011 magnetometer is connected to this interface. It supplies power to the Lemi and also contains the analog output form the magnetometer. Refer to appendix A for a detail description of the interface cable between the Lemi-011 magnetometer and the DigIF.
3. RS232 (DB9 Female): The RS232 serial port interface, running at 19200 baud, 8 data bits, 1 stop bit and no parity (8N1). This should be connected to a PC serial port through a 1-1 cable.
4. USB: The DigIF provides a USB interface that can be used for a number of functions. Refer to section 6 for more detail on the USB connection.

Refer to the “Lemi-011 DigIF Item Specification” document for the pin-outs of the various connectors.

5. Operation

5.1. Quick Start

Perform the following steps (in no particular order) to get the unit up and running:

- Connect the Lemi-011 magnetometer to the DigIF through an appropriate connections harness (refer to Appendix A).

- Connect the RS232 cable from the DigIF to the PC.
- Connect power to the DigIF.
- Open a terminal program (or other data logging software) on the PC. Set the serial port to 19200, 8N1 with no flow control.

As soon as the unit is powered, it will start sampling the magnetometer and it will output the samples on the RS232 port.

5.2. Sample Output Format

The output produced by the DigIF is one line of ASCII-text per sample in the following format:

```
<CHAN_0>, <CHAN_1>, <CHAN_2>, <TEMP>, [CR][LF]
```

<CHAN_0> is typically the X-channel, <CHAN_1> the Y-channel and <CHAN_2> the Z channel of the magnetometer (the mapping depends on the cable between the Lemi-011 magnetometer and the interface). <TEMP> is the temperature channel.

The output can be either calibrated or in raw A/D units – depending on the current configuration. Following is an example of the uncalibrated (raw) output from the magnetometer:

```
-2269977, -788866, -2702203, 38
-2270002, -788909, -2702151, 39
-2269977, -788890, -2702150, 39
-2269975, -788882, -2702162, 38
-2270003, -788931, -2702082, 38
```

Note that the raw output is signed, A/D units.
The calibrated output is typically in nT units (but this can be changed through the calibration matrix).

The output sample rate and output format will depend on the current configuration stored within the unit.

5.3. Operating Modes

The unit has two operating modes:

1. Sampling
2. Configuration

In the Sampling mode, the unit is busy sampling the magnetometer and producing outputs on the RS232 port. The sampling rate, and other parameters, is determined by the current configuration.
In the Configuration mode, the unit stops sampling the magnetometer and allows the user to view and/or modify the current configuration.

After power-up, the unit reads the current configuration, waits a configurable number of seconds (the “startup delay”) and then automatically goes into the Sampling mode. It remains in the sampling mode until the user forces it into Configuration mode (by entering three consecutive ‘+’ characters on the terminal). In Configuration mode, the user interacts with the unit through a set of configuration commands. One of these commands

(the “exit” command) returns the unit to the Sampling mode. The state diagram depicting the transitions is shown in Figure 3.

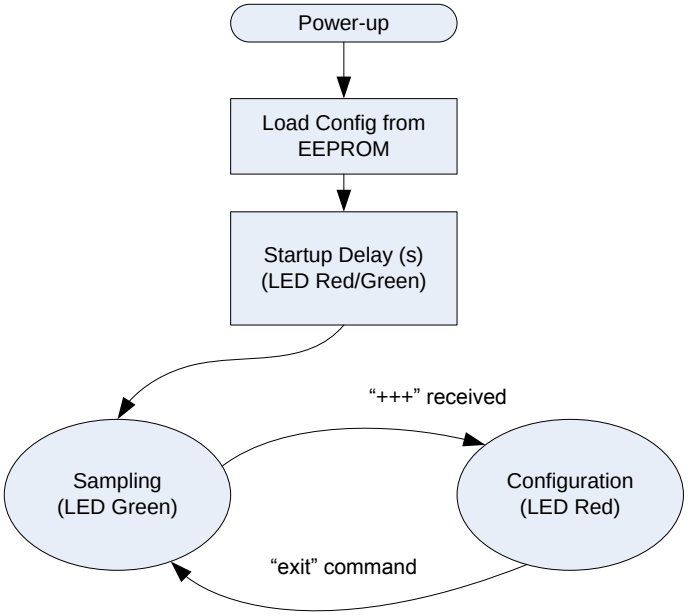


Figure 3: State Transition Diagram

Note that each time the Sampling state is entered, the A/Ds perform an internal calibration. The internal calibration calibrates internal offsets and gains on all three magnetometer channels (the temperature channel A/D does not have internal calibration capability).

The status LED indicates the current mode (or state) of the unit as described in Table 1.

Table 1: Status LED Meaning

Mode/State	LED State
Startup Delay	Red/Green
Sampling	Green. Flashes briefly each time a sample is sent out.
Configuration	Red

5.4. Configuration

The configuration of the interface is stored in non-volatile memory (EEPROM) on board the processor. At power-up the configuration is read from the memory. If configuration is corrupt, or the there is no configuration, a default configuration is used. The configuration can be changed at any time by going into the configuration mode. The changed configuration may also be written back into the non-volatile memory so that it becomes the new power-up default.

The configuration mode is entered by sending the DigIF three consecutive ‘+’ characters. If a terminal is used, the user simply presses the ‘+’ key three times. Note: The ‘+’ characters are not echoed and there is no timing requirement (i.e. the characters do not

have to be sent within a certain time window). Once the configuration mode is enabled, the user is presented with the configuration menu listing all the valid commands.

```
*** Lemi Interface Configuration ***

Firmware Version: 1.0
Valid commands:
  SUDEL <del> : Set startup delay (0 - 255 seconds)
  ASR <rate>  : Set ADC sample rate (5,10,15,25,30,50,60)
  AVG <rate>  : Set Averaging rate (1 - 60)
  PGA <gain>  : Set PGA gain (1, 2, 4, 8)
  CALON       : Enable calibrated output
  CALOFF      : Disable calibrated output.  Output raw samples
  MGAIN <chan> <g0> <g1> <g2> : Enter new magnetometer gain coefficients
  MOFFS <k0> <k1> <k2> : Enter new magnetometer offset coefficients.
  TGAIN <g>   : Enter new temperature gain coefficients
  TOFFS <k>   : Enter new temperature offset coefficients.
  CLOAD       : Load configuration from EEPROM
  CSAVE       : Save configuration to EEPROM
  CSHOW       : Show current configuration
  BLOAD       : Enter bootloader
  EXIT        : Exit configuration mode, start sampling

>
```

The user can now interact with the unit by entering commands. Some commands require one or more parameter(s).

Note: The commands are **not** case sensitive.

Commands are echoed as they are typed and back-space is allowed, but cursor movement and insert and delete is not supported. Each command will now be explained in more detail.

5.4.1. SUDEL

The start-up delay is a delay specified in seconds before the unit enters the Sampling time after power-up. The purpose of the delay is to allow the A/D reference to settle before starting to sample. As noted in section 5.3, an internal A/D calibration is done each time the unit enters the Sampling state. In applications where the units must start producing accurate results after power-up, without any human intervention, the start-up delay can be used to delay the transition into the Sampling state until the reference has settled. Under normal circumstances, a delay of 1 or 2 seconds should be sufficient.

The command format is:
`SUDEL <del>`
Where `<del>` is the startup delay in seconds. The parameter can be set from 0 to 255 seconds.

5.4.2. ASR

This command sets the sample rate of the A/D converters. The A/D converter used for the magnetometer channels are 24-bit Sigma-Delta converters that support a number of

discrete sample rates. Generally, the lower the sample rate the lower the sampling noise. Also, the digital filters employed in the A/D converters allow rejection of 50/60Hz noise on the analog inputs depending on the sample rate chosen. This is summarized in Table 2.

Table 2: A/D Sample Rate vs 50/60Hz Rejection

Sample Rate	50Hz Rejection	60Hz Rejection
5	Yes	Yes
10	Yes	Yes
15	No	Yes
25	Yes	No
30	No	Yes
50	Yes	No
60	No	Yes

The command format is:
`ASR <rate>`
Where `<rate>` is the A/D sample rate required. The following values are allowe: 5, 10, 15, 25, 30, 50 and 60.

5.4.3. AVG

The samples output by the A/D converter can be further averaged to reduce the final output sample rate. The averaging is done within the microcontroller. The averaging rate, together with the A/D sample rate, determines the final measurement sample rate as follows:
Output Rate = (A/D Sample Rate) / (Averaging Rate)
For example, of the A/D sample rate is set to 5 SPS and the averaging rate is set to 10, then the output measurement rate will be 5/10 = 0.5Hz (one sample every two seconds).

The command format is:
`AVG <rate>`
Where `<rate>` is the averaging rate required. Values from 1 to 60 are valid.

5.4.4. PGA

The A/D converters used for the magnetometer channels have a programmable gain amplifier which can be set to a number of discrete gain settings. The gain determines the full scale voltage as show in Table 3.

Table 3: PGA Gain Settings vs. FS Input

PGA Setting	Full Scale (differential)
1	+-5V
2	+-2.5V
4	+-1.25V

8	+-0.625V

Note: The default value of 2 should be used when interfacing to the Lemi-011 magnetometer.

The command format is:
`PGA <gain>`
Where `<gain>` is the gain required. The following values are valid: 1,2,4 and 8.

5.4.5. CALON

This command enables calibrated output mode. The samples from the A/D converter are averaged (according to AVG setting) and then passed through a calibration matrix which consists of a 3x3 gain matrix and an offset vector. Refer to section 5.5 for more detail on the calibration process.
Note: Calibration needs to be switched on before the calibration constants can be viewed of edited.

The command format is:
`CALON`

5.4.6. CALOFF

This command switches off calibrated output mode. All samples output will be in the native digital number format as it was read from the A/D.

The command format is:
`CALOFF`

5.4.7. MGAIN

This command allows the gain matrix used to calibrate the magnetometer channels to be modified.

The command format is:
`MGAIN <chan> <g0> <g1> <g2>.`

`<chan>` is the channel number to be modified. This refers to the output channels number and effectively determines which *row* in the matrix to modify. The value may be 0 to 2.
`<g0>` to `<g2>` are the three gain constants in the matrix row selected by `<chan>`. These are floating point numbers and the units are nT/mV. If only one or two values need to be changed, the values to leave unchanged can be indicated entering a '`*`' instead of a number. For example, to change only the middle value of channel 0 (corresponding to g_{01} in the calibration calculation – refer to section 5.5.1) to -0.015, enter the following command:

```
mgain 0 * -0.015 *
```

Note: All three gain values must be specified – either with a number of with a '`*`'.
Note: Scientific notation is not supported (i.e. "1.2e-3", enter "0.0012" instead).

Note: The current calibration values can be view through the `CSHOW` command.

5.4.8. MOFFS

This command allows the offset vector used to calibrate the magnetometer channels to be modified.

The command format is:
`MOFFS <k0> <k1> <k2>`
`<k0>` to `<k2>` are the offset values corresponding to output channels 0 to 2. The values are floating point and the units are nT. If only one or two values need to be changed, the values to leave unchanged can be indicated entering a '`*`' instead of a number. For example, to change only the offset of channel 2 (corresponding to k_2 in the calibration calculation – refer to section5.5.1) to 35.8, enter the following command:

```
moffs * * 35.8
```

Note: All three offset values must be specified – either with a number of with a '`*`'.
Note: Scientific notation is not supported (i.e. "1.2e-3", enter "0.0012" instead).
Note: The current calibration values can be view through the `CSHOW` command.

5.4.9. TGAIN

This command allows the gain value used to calibrate the magnetometer temperature output to be modified.

The command format is:
`TGAIN <g>`.

`<g>` is the gain constant to be used. This is a floating point number and the unit is K/mV. Refer to section 5.5.2.

Note: Scientific notation is not supported (i.e. "1.2e-3", enter "0.0012" instead).
Note: The current calibration values can be view through the `CSHOW` command.

5.4.10. TOFFS

This command allows the offset value used to calibrate the magnetometer temperature output to be modified.

The command format is:
`TOFFS <k>`.

`<k>` is the offset constant to be used. This is a floating point number and the unit is K. Refer to section 5.5.2.

Note: Scientific notation is not supported (i.e. "1.2e-3", enter "0.0012" instead).
Note: The current calibration values can be view through the `CSHOW` command

5.4.11. CLOAD

This command forces a re-load of the configuration from non-volatile memory (EEPROM). The configuration from the non-volatile memory replaces the current configuration.

The command format is:
`CLOAD`

5.4.12. CSAVE

This command writes the current configuration to the non-volatile memory ro that it will become the power-up default configuration.

Note: When changing the configuration (through the commands in the configuration mode) the configuration in the non-volatile memory is not automatically updated. The changes will be lost of power is removed before the configuration is stored.

The command format is:
`CSAVE`

5.4.13. CSHOW

This command shows the current configuration. Note that may differ from the configuration stored in the non-volatile memory (the power-up configuration) of changes were made to the configuration that have not yet been saved (using the `CSAVE` command).

The command format is:
`CSHOW`

Note: In order to see the current calibration values, calibrated output must be enabled (`CALON`). If calibration is disabled, the calibration constants are not shown. Below is an example of the output from the `CSHOW` command with calibration enabled:

```
** Current Configuration **
Startup Delay:   2 seconds
ADC Sample Rate: 5 sps
Averaging:       1 samples
Gain Setting:    2x
Enable Calibration: Yes
Mag. Gain Matrix (nT/mV):
        27.397261       0.000000       0.000000
         0.000000      27.397261       0.000000
         0.000000       0.000000      27.397261
Mag. Offset (nT):
         0.000000
         0.000000
         0.000000
Temp. Gain (K/mV):   0.2500
Temp. Offset (K) : -273
```

5.4.14. BLOAD

This command forces the unit into the bootloader and is required when performing firmware updates. Refer to section 6.3.

5.4.15. EXIT

This command exits the Configuration Mode and enters the Sampling Mode. Any changes made to the configuration (whether saved to non-volatile memory or not) will take effect.
Note: The startup delay is not applied when entering Sampling mode from the Configuration Mode.

The command format is:
`EXIT`

5.5. Calibration

The unit performs calibration of the output samples when the calibration mode is enabled. This section describes the calibration equations used in more details. The magnetometer channels and temperature channel calibration will described separately since the use different A/D converters.

5.5.1. Magnetometer Channel Calibration

The calibration equation applied is as follows:

$$\begin{bmatrix} M_0 \\ M_1 \\ M_2 \end{bmatrix} = G_0 \cdot \begin{bmatrix} g_{00} & g_{01} & g_{02} \\ g_{10} & g_{11} & g_{12} \\ g_{20} & g_{21} & g_{22} \end{bmatrix} \begin{bmatrix} DN_0 \\ DN_1 \\ DN_2 \end{bmatrix} + \begin{bmatrix} k_0 \\ k_1 \\ k_2 \end{bmatrix}$$

M_x are the three calibrated output components (normally M_0 is the X-axis, M_1 the Y-axis and M_2 the Z-axis).
DN_x are the digital numbers read from the A/D.
G_0 is a calibration constant which converts the digital numbers to mV as follows:

$$G_0 = 1000 \cdot \frac{V_{FS}}{2^{24}}$$

$$V_{FS} = 10/PGA$$

V_{FS} is the full scale voltage of the A/D, which depends on the PGA setting (1, 2, 4 or 8).
$[g]$ is the gain matrix which can be modified using the `MGAIN` command. The units are nT/mV, and together with G_0, the units become nT.
$\bar{k}$ is the offset vector added after the gain matrix has been applied. The units are therefore nT.

The default gain matrix, based on the Lemi-011 data sheet, is as follows:

$$g = \begin{bmatrix} 27.397261 & 0 & 0 \\ 0 & 27.397261 & 0 \\ 0 & 0 & 27.397261 \end{bmatrix}$$

The default offset vector is:

$$k = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

Note: The offsets need to be specified for a specific Lemi-011 and therefore no defaults other than 0 are used.

All calibration calculations are done in single precision (32-bit) floating point format.

5.5.2. Temperature Channel Calibration

The temperature channel is converted by the A/D converter built into the microprocessor. This is a 10-bot converter. A pseudo-differential measurement is made by first converting the reference output from the Lemi-011, then converting the temperature channel and then calculating the difference between the two values.

Both gain and offset calibration is done according to the following equation:

$T = G_0 \cdot g \cdot DN + k$

T is the calibrated temperature output.

G_0 is a constant value that converts the digital number into mV according to the following equation:

$$G_0 = 2 \cdot 1000 \cdot \frac{2.56}{2^{10}}$$

g is the gain constant which can be modified by the `TGAIN` command. It has units of K/mV.

k is the offset constant which can be modified by the `TOFFS` command. It has units of K.

The factor 2 is due to the fact that the temperature channel analog voltages are divided by 2 before entering the A/D due to input range limitations of the A/D.

The default gain constant is:

$g = 0.25$

The default offset constant is:

$k = -273$

This offset will produce temperatures in degrees C.

6. The USB Interface

The USB interface was not part of the original design requirement, but was added since it does provide addition functionality that could be very handy and it also came at virtually no addition hardware cost. The USB interface provides the following functionality:

1. Power. The interface (and the attached Lemi-011 magnetometer) can be powered from the USB port. This provides the ability to quickly connect the unit to any PC or notebook with a USB port in order to change/verify the configuration - without the need for an external power supply.
2. Virtual Serial Port. The USB port provides a virtual serial port interface when connected to a PC. It implements the standard USB-Serial Port protocol based on the CDC USB class. No additional drivers are required since the drivers are already part of any Windows installation. This allows the unit to be connected to a laptop or notebook which does not have an RS232 serial port and to communicate with it using a standard terminal program.
3. Firmware update. The unit includes a bootloader that can perform a firmware upload via the USB port. This may be useful to do remote firmware updates without the need for dedicated programming hardware or the need to open up the device.

6.1. Powering the Unit over USB

The USB port provides 5V which can directly power the DigIF and the Lemi-011 magnetometer. By connecting the DigIF to a USB host port (PC), it will use the 5V supplied on the USB bus.

Although the unit can be operated (in both configuration and sampling modes) when powered from USB, it is not recommended to do high accuracy sampling in this way. The 5V from the USB may be noisy and may influence the accuracy of the A/D converters. The intended use of this feature is to do quick checks of the hardware or adjust configuration settings before taking the unit into the field.

Important: It is recommended that the DigIF only be powered *either* from the USB *or* from an external power supply, but **not both at the same time**.

6.2. Virtual COM Port

The Lemi Interface is meant to be used with an RS232 serial connection. If this is not available, it also provides a virtual serial port over the USB connection.

NOTE: The USB port should only be connected while the unit is not being powered from an external power supply. The USB port will supply the unit with power. Refer to section 6.1.

In order to use the virtual serial port, connect the unit the USB port. If this is the first time the unit is connected to the particular PC, the familiar Add New Hardware window will open as Windows detects the new device. Choose to select you own driver (do not use Windows Update). Browse to the \Tools\usbser_driver folder on the software CD that accompanies the DigIF. Windows will use the selected .inf file and will install the correct driver.
NOTE: The actual driver is already contained in any standard Windows installation and only the .inf file is required. It merely points Windows to the correct drivers.

A new COM port should become available shortly after the driver has installed. If not, remove and re-connect the device. The number of the COM port will vary with the

computer used and the USB port used. Using your favourite terminal program, connect to the new COM port. The behaviour of the interface is the same as with the normal RS232 com port.

NOTE: The virtual COM port has no baud rate setting and it is not necessary to select any particular baud rate.

The terminal program "TeraTerm" is incuded in the \Tools folder of the software CD.

6.3. Firmware Updates

The Lemi Interface contains a bootloader which allows the application to be updated via the USB connection. Only the .HEX file containing the updated application is required. The procedure us as follows:

1. Copy the contents of \Tools\bootloader from the software CD to a folder on your hard drive.
2. Also copy the new .hex file, containing the new firmware, into the folder.
3. Open a command window and go the the folder on your hard drive. (i.e. type “cd c:\<foldername> where <foldername> is the name of the folder. This assumes it is on you c drive).
4. Execute the command: "bload LemiIF.hex" (assuming the .hex file is called Lemi.hex. Substitute with the correct name if different).
5. The bootloader client will start and will be waiting for the device to be connected.
6. Connect the Lemi to a USB port. Wait for the application to start running and connect via the terminal (either RS232 or USB)
7. At the terminal, enter the configuration mode by entering three consecutive '+' characters. Enter the 'bload' command. This will activate the bootloader
8. The upload should start within a second or two and should complete within a second or two. Once the client exits, the update is done.
9. Power down the unit by un-plugging from the USB port.

The firmware is now updated. The current firmware version is displayed when you enter the configuration mode:

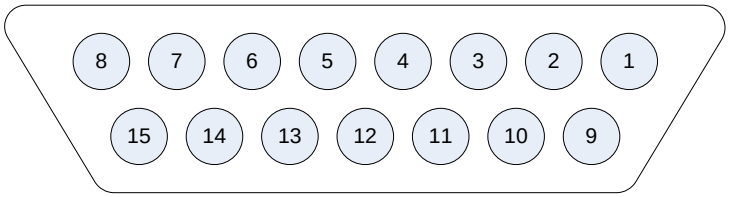
```
*** Lemi Interface Configuration ***

Firmware Version: 1.0
Valid commands:
  SUDEL <del> : Set startup delay (0 - 255 seconds)
...
```

Each successive firmware update should increment (either the minor or major) version number.

A. Appendix – Cable Harness between Lemi-011 and DigIF

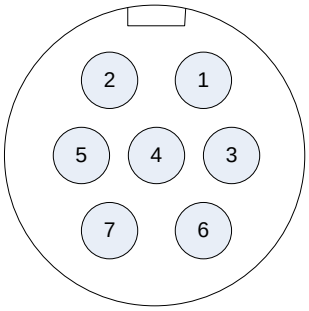
The Lemi-011 and Lemi Digital Interface cable connectors (the connectors to be used on each end of the interconnecting cable) are shown below:

Lemi-Interface Cable Connector (Rear View)



(DB15 Male)

Lemi-011 Cable Connector
(Rear View)



Pin #	Signal
1	Chan_X+
2	Chan_Y+
3	Chan_Z+
4	Temp+
5	NC
6	NC
7	GND
8	GND
9	Chan_X-
10	Chan_Y-
11	Chan_Z-
12	Temp-
13	NC
14	+5V
15	+5V

Pin #	Signal
1	Chan_X
2	Chan_Y
3	Chan_Z
4	Temp
5	Ref
6	+5V
7	GND

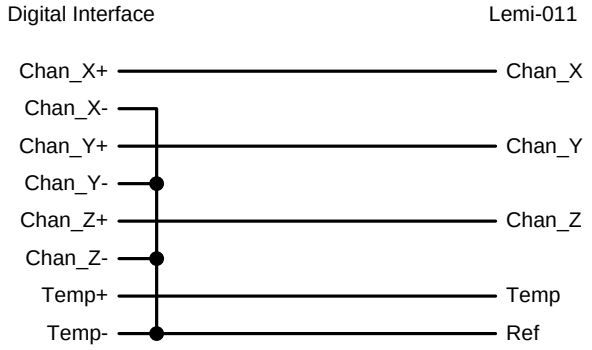
The Lemi Digital Interface has a fully differential input for each channel. The Lemi-011 output is semi-differential with all channels being relative to the “Ref” signal. The following interconnection between the Lemi-011 and Lemi Digital Interface is recommended:

Lemi Digital Interface		**Lemi-011**	
pin #	Signal	Signal	pin #
1	Chan_X+	Chan_X	1
2	Chan_Y+	Chan_Y	2
3	Chan_Z+	Chan_Z	3
4	Temp+	Temp	4
9,10,11,12	Chan_X-, Chan_Y-,Chan_Z-, Temp-	Ref	5
14,15	+5V	+5V	6
7,8	GND	GND	7

Notes:

- It is not required to connect both power pins (pin 14 and 15 for +5V, pins 7 and 8 for GND). For long cables, however, a separate conductor for each pin (two wires for +5V and two wires for GND) is recommended to reduce voltage drops across the cable.
- It is (probably) ok to use a single conductor for all four "Ref" signals (i.e. to connect pins 9, 10, 11 and 12 together at the Digital Interface side. This may increase cross coupling between the channels due to the shared return path. For the lowest possible coupling, connect a separate wire in the cable for each of the negative inputs (Chan_X-, Chan_Y-, Chan_Z- and Temp-) and connect these together, and to Ref at the Lemi-011 connector.

Probably OK:



Lowest Cross-Coupling: