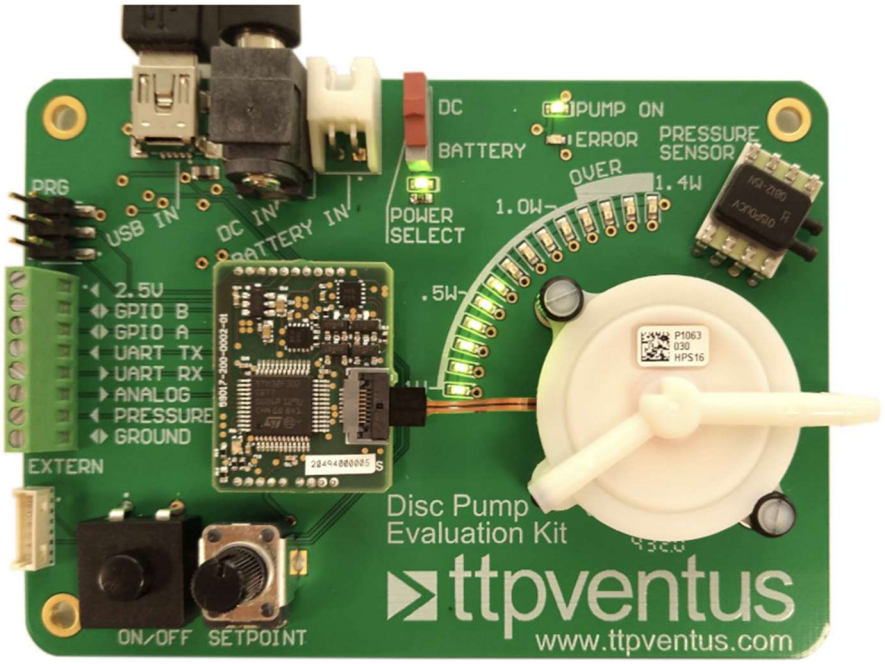
Disc Pump Evaluation Kit

User Manual



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1 DISCLAIMER

This User Manual is provided "as is" and without any warranty of any kind, and its use – and that of the Disc Pump Evaluation Kit – is at your own risk. LEE Ventus makes no warranties regarding this User Manual and the Evaluation Kit, express or implied, including as to non-infringement, merchantability, or fitness for any particular purpose. To the maximum extent permitted by law LEE Ventus disclaims liability for any loss or damage resulting from use of this User Manual and/or the Evaluation Kit, whether arising under contract, tort (including negligence), strict liability, or otherwise, and whether direct, consequential, indirect, or otherwise, even if LEE Ventus has been advised of the possibility of such damages, or for any claim from any third party.

Use of the Evaluation Kit, including all software and firmware provided with it, is subject to LEE Ventus' standard terms and conditions of sale.

2 SPECIAL NOTICES

Throughout this User Manual, special notices relating to the safe and correct operation of the Evaluation Kit are formatted and highlighted as follows:

CAUTION

Instructions to ensure correct operation of the equipment and/or for avoiding damage to the equipment.

WARNING

Instructions relating to the safety of the equipment operator and avoiding injury.

3 INTRODUCTION

3.1 Disc Pump Evaluation Kit

The Disc Pump Evaluation Kit has been designed to enable demonstration and evaluation of Disc Pump Technology and the potential for novel Disc Pump enabled products. Each system contains:

- Two LEE Ventus Disc Pumps
- Drive electronics (comprised of a Drive PCB mounted on a Motherboard)
- Drive PCB
- Power supply and USB cable
- Fixtures and fittings to connect the components
- USB flash drive containing application notes, design files and other reference material.

This document provides details of the system.

3.2 Disc Pump

TTP's Disc Pump is a multi-award-winning technology which makes use of advances in the field of non-linear acoustics to offer the following unique features:

- silent operation
- ultra-smooth flow
- millisecond responsiveness
- compact form factor
- high-precision controllability

In contrast to conventional air pumping mechanisms (such as diaphragm and piston pumps), Disc Pump does not rely on the bulk compression of air within a cavity. Instead, Disc Pump generates a high amplitude, high frequency acoustic standing wave within a specially designed acoustic cavity.

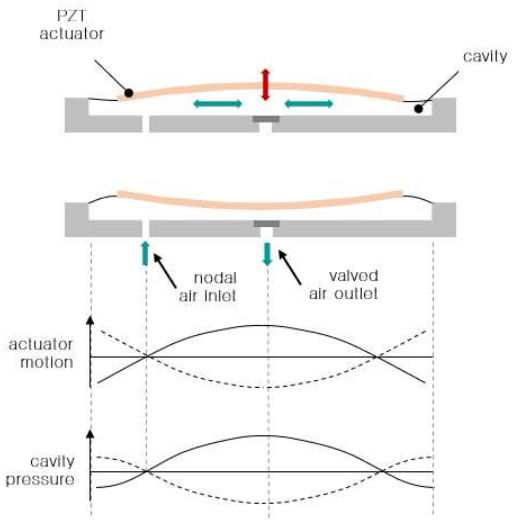


Figure 1: Principle of operation

Figure 1 shows a simplified schematic: the out-of-plane motion of the actuator drives in-plane (radial) motion of the gas in the cavity and creates a standing pressure wave, resulting in the oscillating cavity pressure shown. The motion of the actuator is highly exaggerated: there is virtually no net volume change of the cavity during operation and at any given point in time there exists both a region of compression and a region of rarefaction within the cavity.

Rectification of the alternating cavity pressure is the key to delivering useful pump performance and device lifetime. LEE Ventus has addressed this need by developing a family of innovative valve designs based on lightweight polymer valve flaps.

Disc Pump technology is protected by a portfolio of both patent applications and granted patents

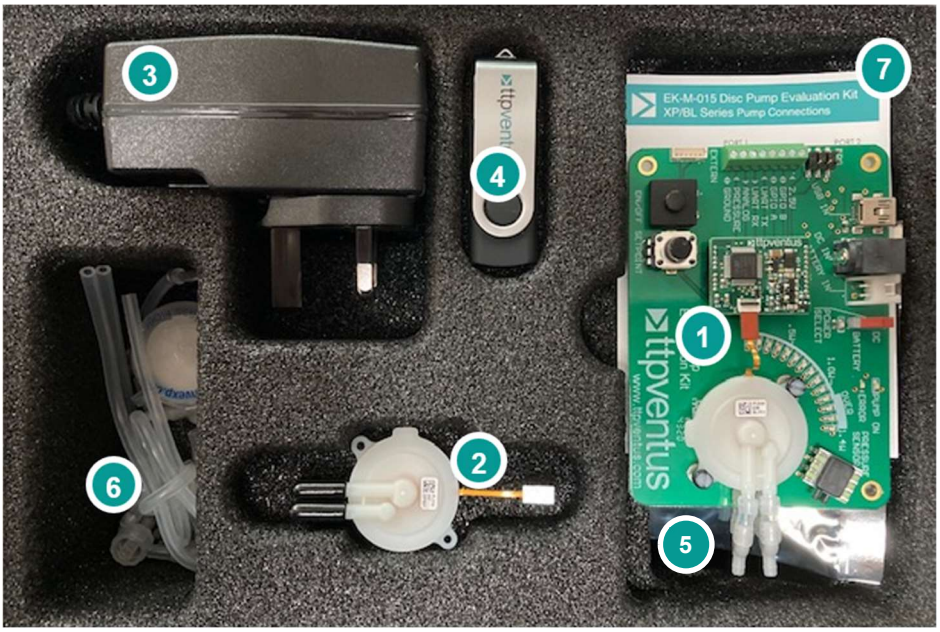


Figure 2: Disc Pump Evaluation Kit components

Item	Description
1	Motherboard PCB, on which is mounted one of the two pumps included, together with the postage-stamp sized pump drive PCB. This will be packed within an ESD (electro-static discharge) bag.
2	A second pump.
3	Mains power supply. Typically, a region-specific adapter will have been fitted for you. If requested, additional region adapters may be included in the pocket beneath the evaluation kit PCB.
4	USB flash drive containing PC application software. User Manual and supporting documentation.
5	USB cable, which enables the PC application to communicate with the drive PCB, included in the pocket beneath the evaluation kit PCB.
6	Accessories kit including tubing, luer fittings and filters.
7	Quick Start card.

Table 1: Component Description

5 SAFETY

WARNING

The equipment described in this document is research and development hardware intended for laboratory use by skilled and trained personnel only. Further, the components of this evaluation system have been provided in a 'bare' format enabling users to integrate the pump, drive electronics and power supply into test fixtures and prototype product assemblies.

The user should satisfy him or herself that the equipment is and remains fit for the intended use. The user accepts that LEE Ventus shall not be held responsible or liable for any injury, damage or loss to property, person or otherwise, resulting from use of the equipment.

In order to aid assessment of the safety of the equipment, the following indicative electrical data are provided:

A.C. voltage on the Drive PCB: 120 Vpp max. (at 19 - 23 kHz)
D.C. voltage on the Drive PCB: 60 V max.

All Disc Pumps emit ultrasound in operation. The following data are provided for operation at maximum power (1.4W) at a distance of 30cm:

Sound pressure level: 70-80 dBA typ. (at 19-23 kHz)[1]

1. Equivalent to <10 phon per ISO 226:2003 and related studies, 30 cm equivalent measurement distance

WARNING
Take care during use of the Evaluation Kit not to create short circuits between exposed conductive parts of the PCBs. Short circuits may lead to malfunctioning and heating.

6 EVALUATION KIT DETAILS

Disc Pump must be driven with an AC drive signal at a frequency optimised to suit each pump and its operating conditions. The postage-stamp sized drive PCB is responsible for generating the necessary drive signal. The pump and drive PCB are mounted onto a motherboard (Figure 3). The motherboard provides a range of convenient and easy-to-use connections, user interface elements and functionality detailed in Table 2.

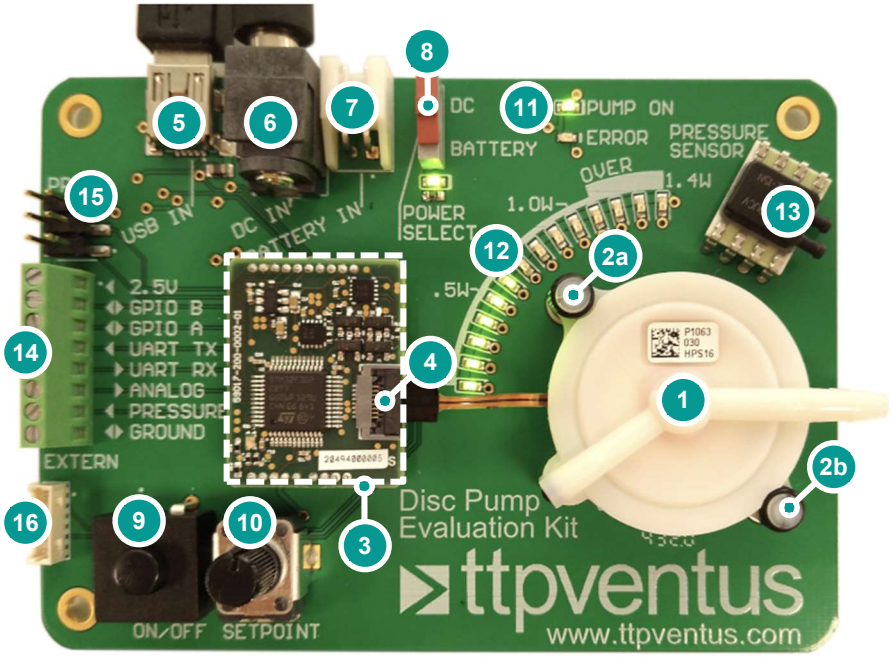


Figure 3: Evaluation Kit Motherboard

Item	Details
1	LEE Ventus Disc Pump
2a/b	Pump mounting lugs. Note that whilst Disc Pump operates ultrasonically and is therefore inaudible, there remains vibration of the pump casework. To prevent this vibration causing audible noise, the pump is mounted with compliant O-rings and nylon bolts. When swapping the pump over, be sure to repeat this mounting arrangement.
3	Disc Pump drive PCB
4	FPC connector: electrical connection between pump and PCB. The black tab on the connector is hinged and should be lifted into the vertical orientation before inserting or removing the pump flexi tail.
5	USB IN – connect at PC to the PCB with the supplied USB cable to allow the Disc Pump control software to communicate with the PCB. There is a solder bridge on the underside of the board (SB1) which, when bridged, allows the evaluation system to be powered from USB IN without the need for the mains power adapter. Note that the USB port providing power must be capable of supplying 500 mA or greater.
6	POWER IN – connection for the mains power adapter to power the system.
7	BATTERY IN – optional connection for a single cell 3.7 V lithium-ion battery (not supplied). Pin 1 (marked with a dot) is ground. Note that the motherboard includes a charge circuit that can recharge a lithium battery. With the battery connected and battery power source selected, connect the mains power supply to begin charging. Note that the charge current is limited to 100 mA.

8	Battery / mains power source selector switch: enables selection between mains (“DC”) or battery power. Always ensure a battery is connected when battery power is selected.
9	ON/OFF – pump on/off switch. A single click will toggle the pump on/off. The pump may also be turned on/off by the PC application.
10	SETPOINT – rotary control allowing the system setpoint to be adjusted. By default, this adjusts the drive power supplied to the pump, although it can be configured to control other parameters via the PC application.
11	PUMP ON – green LED indicating the pump on/off state. ERROR – red LED indicating the error state of the system. Errors can be cleared by toggling the pump off and on again, or by power cycling the system. If Error persists, check the contact with the flexi tail and the drive PCB. If contact appears satisfactory but the error light stays on, try installing another pump. If error disappears, the original pump may be faulty, or contact may not have been satisfactory previously.
12	Power gauge: array of LEDs to indicate the drive power being supplied to the pump. For continuous operation, LEE Ventus recommends that drive power is limited to 1 W. For intermittent use, we recommend a maximum limit of 1.4 W.
13	Differential pressure sensor: when connected to the pneumatic circuit, allows the pressure generated by the pump to be measured and displayed in the PC application. The top barb on the pressure sensor is intended to be connected to positive pressures and the bottom barb to negative pressures. The evaluation system is capable of PID/closed-loop control of the pressure that the pump generates – see for more information.
14	External signal connections: screw terminal block providing the following connections: 2.5V – output from drive PCB that can be used to power 2.5 V devices (max 10 mA). GPIOA – 2.5V-level digital toggle signal IO for enabling / disabling pumping with an external signal. GPIOB – Reserved for future use. UART T/RX – 2.5V-level serial data transmitted from / received by the PCB. The evaluation system can be controlled by the customer’s host PCB/system via these connections. ANALOGUE – 0 to 2.5V analogue input. The evaluation kit can be configured to be controlled by this signal in the PC application. PRESSURE – 0 to 2.5V analogue output representing the pressure measured by the on-board sensor. The mapping is: 0.00 V = -745 mmHg (differential between ports) 1.25 V = 0 mmHg 2.50 V = 745 mmHg
15	PRG – programming header that can be used to programme the drive PCB.
16	External Flow Sensor connector header (See AN007 for set-up, referenced in §8)

Table 2: System Details

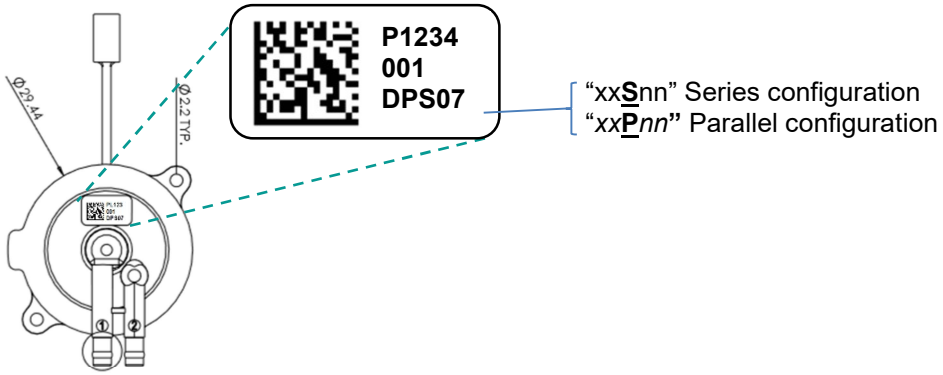
7 SYSTEM OPERATION

The system is shipped configured to run the pump when first powered. There is no need to connect the system to a PC initially.

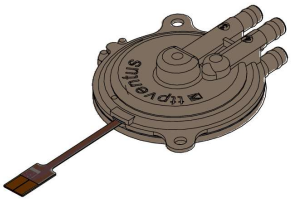
7.1 Pump pneumatic connections

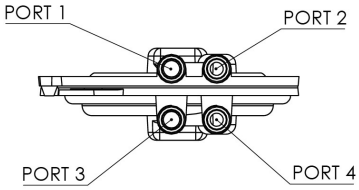
7.1.1 BL/XP/LT Series pumps

- Take note of the pump configuration according to the pump labelling:



- Ensure the pump ports are connected according to the following diagram:

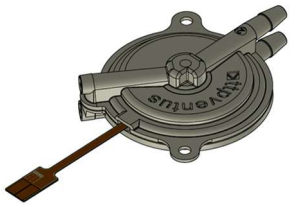


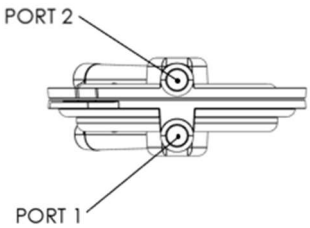


  - For series (SDC) configuration pumps**:**
    - Link ports 2 and 4 ('C' coupler included)
    - Port 3 is inlet & port 1 is outlet

  - For parallel (PDC) configuration pumps:
    - Ports 2 and 4 are common inlet*
    - Ports 1 and 3 are common outlet*
    - *Link with included 'Y' coupler

7.1.2 HP Series pumps





- Port 2 in outlet
- Port 1 is inlet

TAKE NOTE!

Ensure that a filter is connected to the pump inlet during operation.

7.2 Running the system

- Remove the motherboard PCB (Figure 2 - 1) from protective ESD bag.
- Connect the pump ports (see §7.1).
- Power the board with the mains power supply (Figure 2 - 3).
- Turn pump on/off with the ON/OFF switch (Figure 3 – 8).
- Adjust pump power with the SETPOINT dial control (Figure 3 – 10).
- The USB flash drive (Figure 2 - 4) contains manuals, a video on system operation and PC software for configuration, control and data logging.
- Also included is a second pump (Figure 2 - 2), USB cable (Figure 2 - 5) and accessories kit of tubing, filters and connectors (Figure 2 - 6).

7.3 Removing / installing a pump

CAUTION

Whether removing or installing a pump, always power down the Evaluation Kit first by removing the mains power supply (or battery, if in use) and USB cable. Failure to do so may result in damage to the system.

Removing a pump:

- Power down the system and remove the USB cable.
- Raise the black tab on the FPC connector (Figure 2 – 4) so that it is in the open position as per 4.
- Remove the pump flexi-tail from the FPC connector.
- Unscrew the pump mounting screws (Figure 2 – 2a/b).
- Retain the four o-rings used to mount the pump for later use.

Installing a pump:

- If a pump is currently installed on the board, remove it per the instructions in §7.3.
- Power down the system and remove the USB cable.
- Fit the pump to the stand-offs (Figure 2 – 2a/b) with the screws and o-rings provided (ensure that one o-ring is above each mounting eye of the pump, and one below each mounting eye).
- Raise the black tab on the FPC connector (Figure 2 – 4) so that it is in the open position as per 4.
- Insert the pump flexi-tail into the FPC connector.
- Lower the black tab on the FPC connector so that is in the closed position per 4.

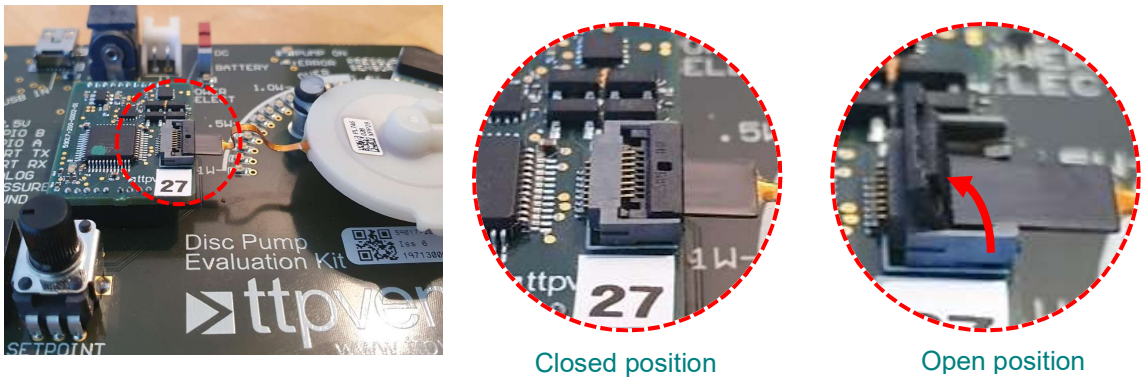


Figure 4: FPC connector in closed and open positions

7.4 Power over USB

WARNING
Enabling power over USB requires the user to apply solder to a designated solder bridge only. This operation should only be carried out by suitably trained personnel. If in doubt, do not proceed.

It is possible to power the Evaluation Kit via the USB cable provided. However, this feature is not enabled by default, as the system must be powered with a USB port capable of supplying at least 500 mA, whereas certain ports are only able to supply 100 mA.

To enable this feature:

- Power down the system and remove all cables.
- Apply solder to the solder bridge designated “SB1” on the underside of the motherboard, as per Figure 5.

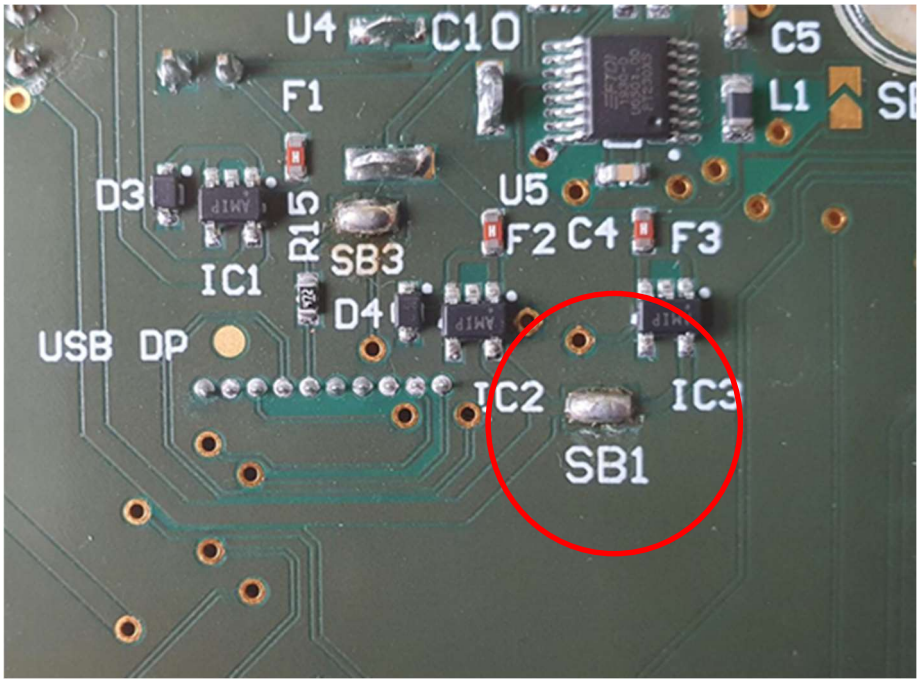


Figure 5: solder applied to solder bridge “SB1” to enable power over USB

7.5 LEE Ventus Pump Control App

To configure the PCB, a bespoke application (LEE Ventus Pump Control App) is

provided: To install the application:

- Copy the LEE Ventus Pump Control App folder from the USB flash drive provided to a destination folder on the target PC.

To download the relevant drivers:

- Ensure the PC is connected to the internet.
- Connect the PCB to the PC with the USB cable.
- If the PC is running Windows 7 or later, all drivers should automatically be downloaded and installed.

CAUTION

Ensure that the driver installation process has completed successfully before proceeding

7.5.1 Starting the application

Double click on the “LEE Ventus Pump Control App.exe” executable file.

- Select the appropriate COM port from the top-left dropdown menu and click connect.
- The application should now be connected and display all the current settings on the GUI.

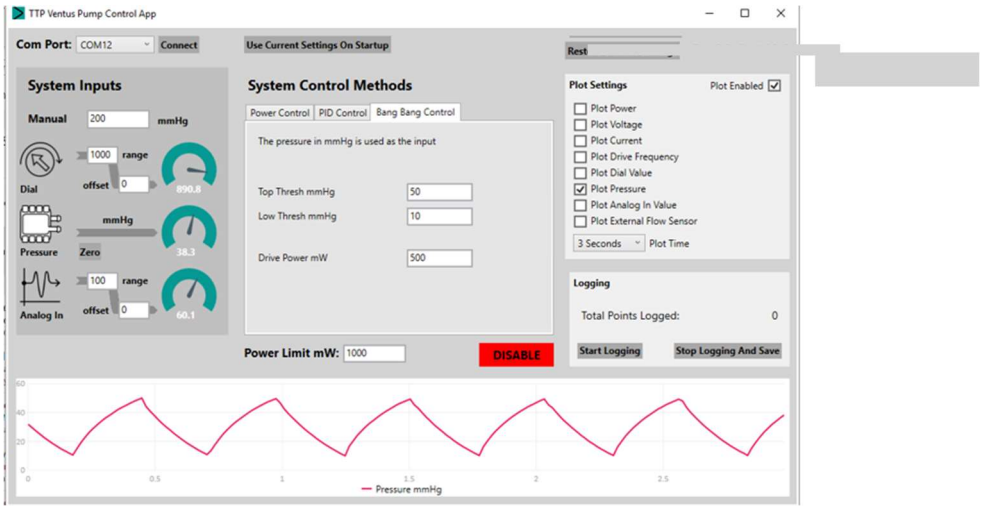


Figure 6: Ventus Disc Pump Control App GUI

7.5.2 System Inputs

The user interface has a panel displaying the System Inputs on the left-hand side – these are: a manual setpoint entered via the software; the setpoint dial on the evaluation kit motherboard; the pressure sensor, also on the motherboard; and a 0 to 2.5 V analogue input signal on the screw terminal block, also on the motherboard. The values for these inputs are displayed under the dials on the user interface.

The dial and analogue-in inputs have a range and an offset associated with them. This allows these inputs to be arbitrarily mapped to power and pressure setpoint variables. Use of the range and offset values is explained in §7.5.4 and §7.5.5.

7.5.3 System Control Methods

In the centre of the user interface is the System Control Methods panel. There are three control modes – power control, PID pressure control, and bang-bang pressure control.

7.5.4 Power Control mode

Power Control mode controls the drive power supplied to the pump.

- Select the Power Control tab.
- Select the target power source from the dropdown menu:
    - **Manual**: the power target is entered manually into the “System Input” section. The units are milliwatts.
    - **Potentiometer**: the power target is controlled by the position of the SETPOINT potentiometer control on the motherboard.
    - **Analogue Input**: the power target is controlled by the 0 to 2.5V analogue input supplied on the external connections screw terminal block on the motherboard.
    - Note that the potentiometer and analogue in control input values are displayed in the “System Inputs” section of the PC application. Each has a range and offset associated with it, allowing the mapping of the input to the target power to be configured.
    - Example mappings:

Desired full-scale range mapping	Range	Offset
0 to 1000 mW	1000	0
0 to 500 mW	500	0
200 to 400 mW	200	200

Table 3: Example mappings of the Range and Offset variables

- Click the “Enable/Disable” button on the GUI to toggle the pump output. Alternatively, use the ON/OFF button on the motherboard.
- Tick the “Plot Power” check box to observe the drive power supplied to the pump.

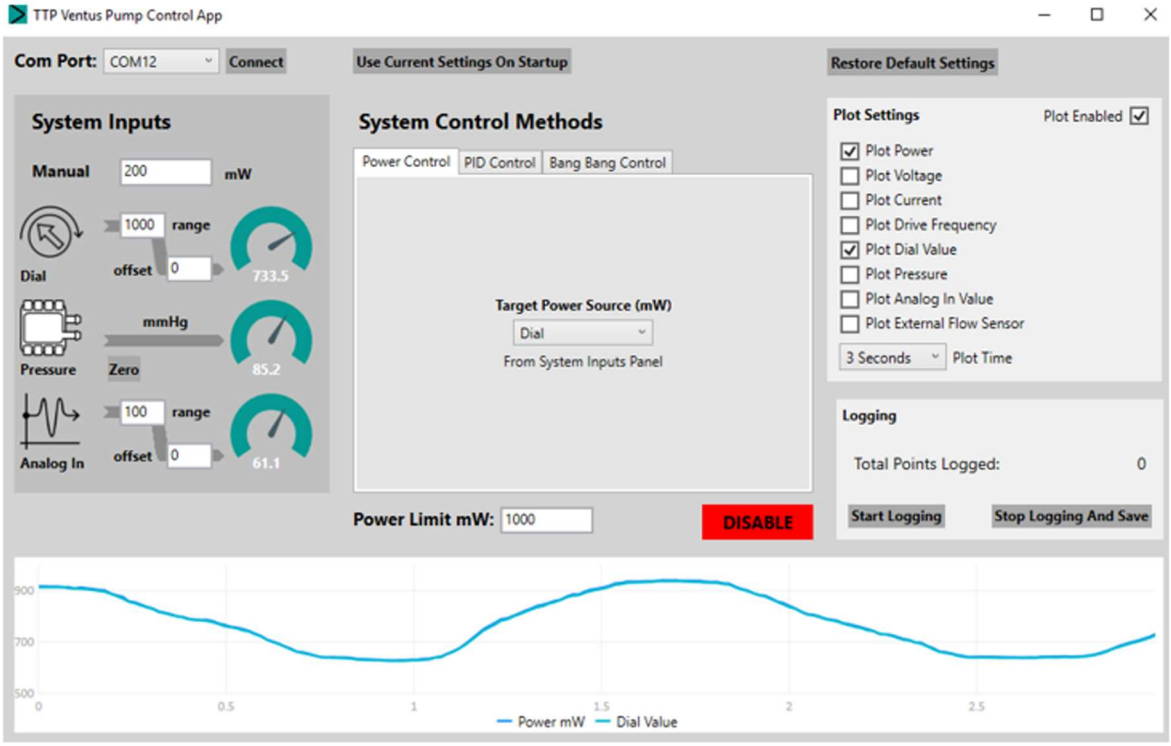


Figure 7: power controlled to a target controlled by the SETPOINT dial on the motherboard.

7.5.5 PID Control mode

PID Control mode adjusts the pump drive power until a target pressure is reached.

TAKE NOTE

Connect the upper barb of the pressure sensor to the pneumatic circuit.

For positive pressure control, connect the pressure sensor to the outlet of the pump, and use positive pressure setpoint targets and positive values for the P, I and D coefficients.

For negative pressure control, connect the pressure sensor to the inlet to the pump, and use negative pressure setpoint targets and negative values for the P, I and D coefficients.

The pressure sensor reading can be zeroed by clicking the “Zero” button next to the pressure sensor icon. The zero offset can be reset by clicking “Restore Default Settings”

- Connect the on-board pressure sensor to the pneumatic circuit.
- Select the PID Control tab.
- Select the pressure control setpoint from the dropdown menu:
    - **Manual:** the pressure target is entered manually into the “System Input” section
    - **Dial:** the pressure target is controlled by the position of the SETPOINT dial control on the motherboard.

      Note that the dial control input value is displayed in the “System Inputs” section of the PC application. It has a range and offset associated with it, allowing the mapping of the input to the target pressure to be configured.

Example mappings for the Dial control are:

Desired full-scale range mapping	Range	Offset
0 to 100 mmHg	100	0
0 to 200 mmHg	200	0
100 to 200 mmHg	100	100

Table 4: Example mappings of the Range and Offset variables

- **Analogue Input**: the pressure target is controlled by the analogue input. See §7.5.9 for further details.

- Click the “Enable/Disable” button on the GUI to toggle the pump output. Alternatively, use the ON/OFF button on the motherboard.
- Tick the “Plot Pressure” check box to observe the pressure measured by the sensor.
- The P, I and D coefficients should be configured to optimise performance of the loop for the customer’s specific setup. Factors such as the volume of the pneumatic circuit need to be considered when tuning the pressure control loop.

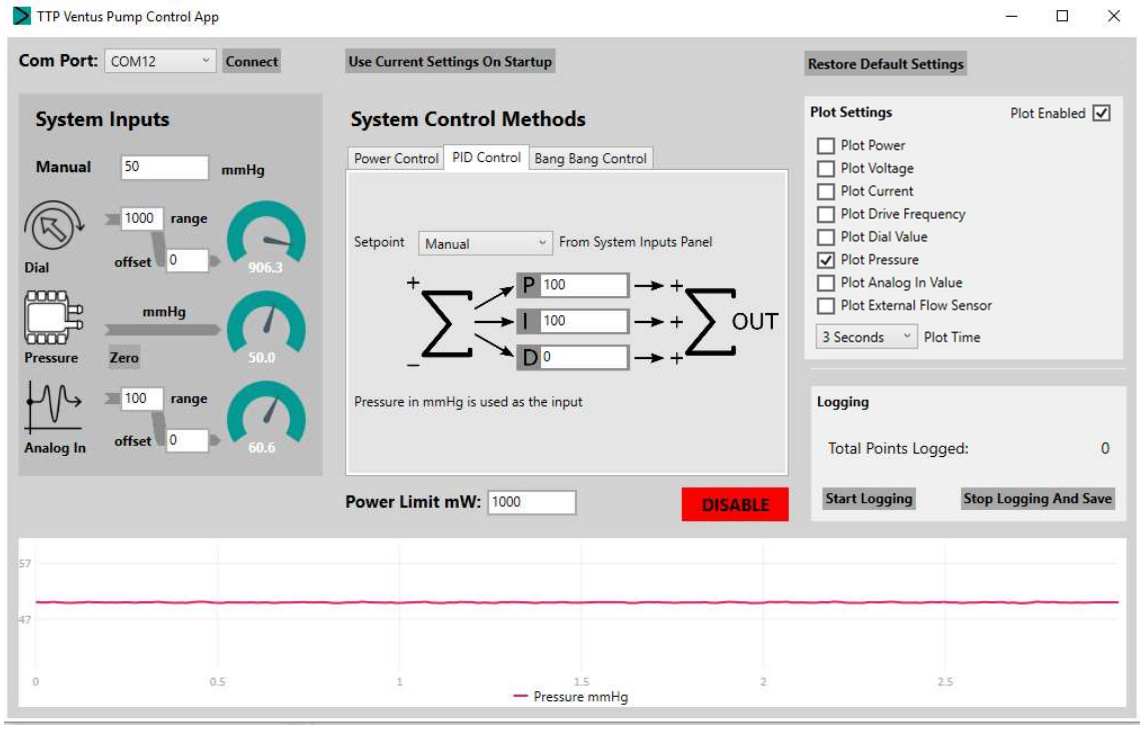


Figure 8: Pressure controlled to 50 mmHg under PID control mode

7.5.6 Bang Bang Control mode

“Bang Bang” control mode is a simple on-off controller that switches the pump on and off to control the output pressure between two defined pressure limits.

TAKE NOTE

For positive pressure control, connect the ***upper*** barb of the pressure sensor and the outlet of the pump to the rest of the system.

For negative pressure control, connect the ***lower*** barb of the pressure sensor and the outlet of the pump to the rest of the system. Note that for negative pressure control, positive pressure values should be interpreted as vacuum values: use **positive** upper and lower threshold values and interpret positive measured pressure as vacuum magnitude.

- Connect the on-board pressure sensor to the pneumatic circuit.
- Select the Bang Bang Control tab.
- Enter the upper pressure limit in the Top Thresh field.
- Enter the lower pressure limit in the Low Thresh field.
- Enter a value for Drive Power mW – this is the drive power supplied to the pump when it is on; if in doubt, start with 1000, but back this off if pressure overshoot above the upper threshold is an issue, or to reduce the rate of inflation.
- Click the “Enable/Disable” button on the GUI to toggle the pump output. Alternatively, use the ON/OFF button on the motherboard.
- Tick the “Plot Pressure” check box to observe the pressure measured by the sensor.

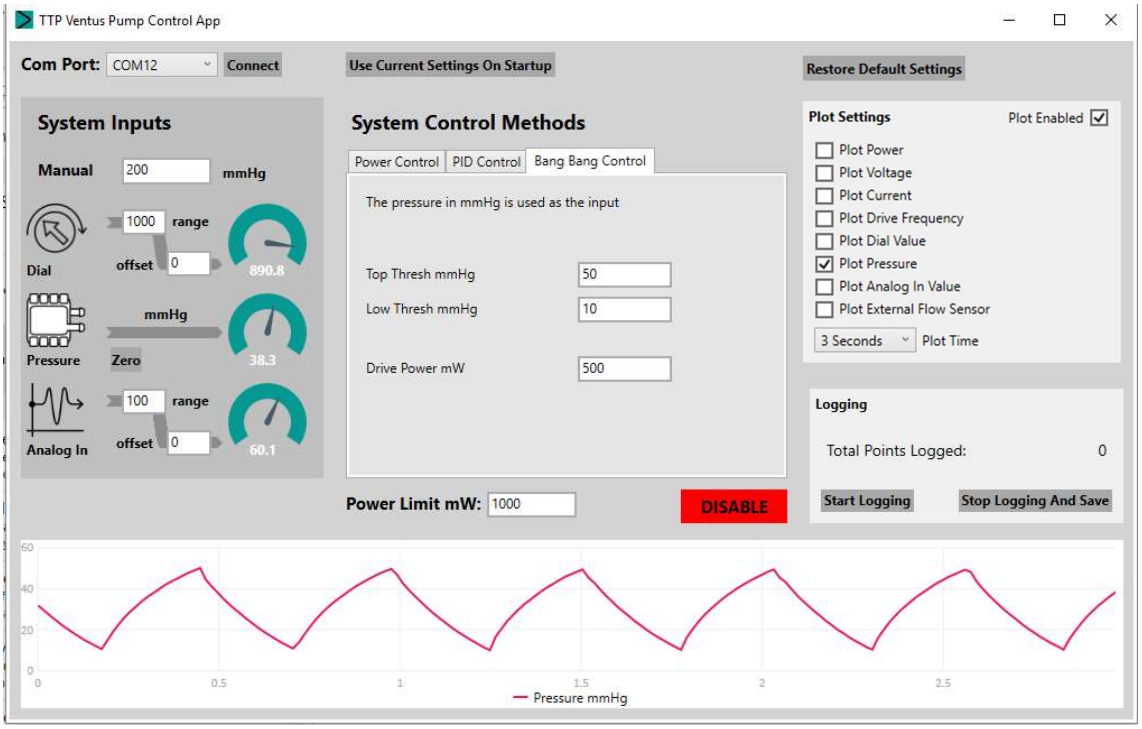
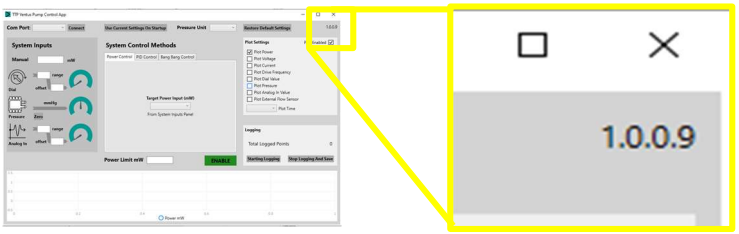


Figure 9: *Pressure cycling between two limits under bang-bang control.*

7.5.7 Toggling the pump output with GPIOA

TAKE NOTE

Feature only available for LEE Ventus Pump Control App v 1.0.0.9 or later with compatible firmware. If in doubt, please contact LEE Ventus support to discuss (support@ttpventus.com) .



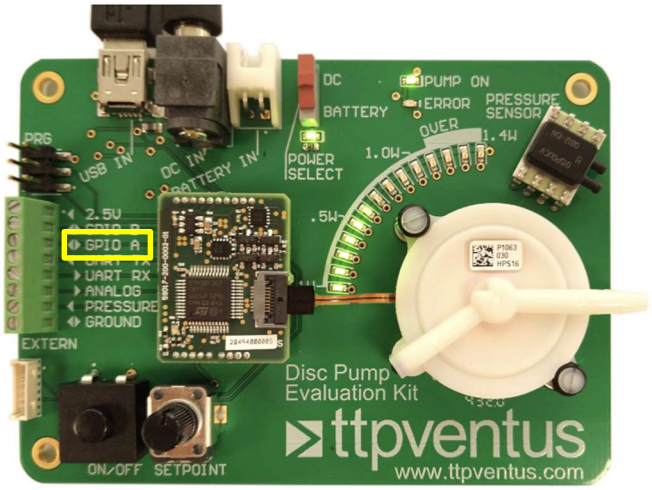


Figure 10: *GPIO A is used for gating*

GPIO A on the screw terminal block is a 2.5V-level digital control input that enables toggling of the pump output. This pin is normally pulled high by the Disc Pump Driver PCB. A state change on this pin will toggle the enabled state of the pump. This functionality can be used as a simple means of enabling / disabling the pump from an external source. It can also act as a rudimentary gate, allowing higher frequency duty-cycling of the pump up to approximately 10 Hz.

Note that in the System Control Methods panel of the Pump Control App, there is a check box to reset the PID loop on pump enable. When checked, the integral term of the PID loop will be reset each time the pump is enabled; when unchecked, the integral value will persist. In essence, when unchecked, the system's closed-loop control behaviour is to 'pick up where it left off' through a gating cycle, whereas when checked the behaviour is to reset each cycle. For high frequency (>1 Hz) gating, it is recommended to leave this check box *unchecked*, as resetting the PID loop each cycle may cause undesirable results. For lower frequency gating and simple enable/disable functionality, this box should be checked/unchecked on a case-by-case basis, depending on the desired functionality.

7.5.8 Using the Analogue Input

The analogue input can be used in a variety of ways to deliver external control of pump performance. This can be useful for initial system integration work, for example.

To control pump power	The analogue input can be used to variably control the pump drive power. See §7.5.4 for further details.
To ‘gate’ the pump drive for short pulse control	The analogue input is sampled at around 1kHz, enabling the pump to be switched on and off quickly to any desired power level using power control mode (see §7.5.4). This feature can be used to deliver a short pulse of air, e.g. for microfluidic control applications.
To control the output pressure setpoint	The analogue input can be used to provide the target pressure for the on-board PID control loop, with the on-board pressure sensor being used to monitor the actual pressure. See §7.5.9 for further details.
As an input from an external pressure sensor	The analogue input can be used as an input from an external pressure sensor to the on-board PID control loop, with the target pressure set manually or via the software. See §7.5.9 for further details.

7.5.9 Tracking pressure via the Analogue Input

It is possible to use the evaluation kit to follow a specific pressure profile controlled through the analogue input to the board. The following set up shows how this can be achieved.

For the purpose of this guide an XP series pump (part number DP-P2-008) has been used. The same set up applies for any model Disc Pump providing that the pump discharge is connected as detailed below.

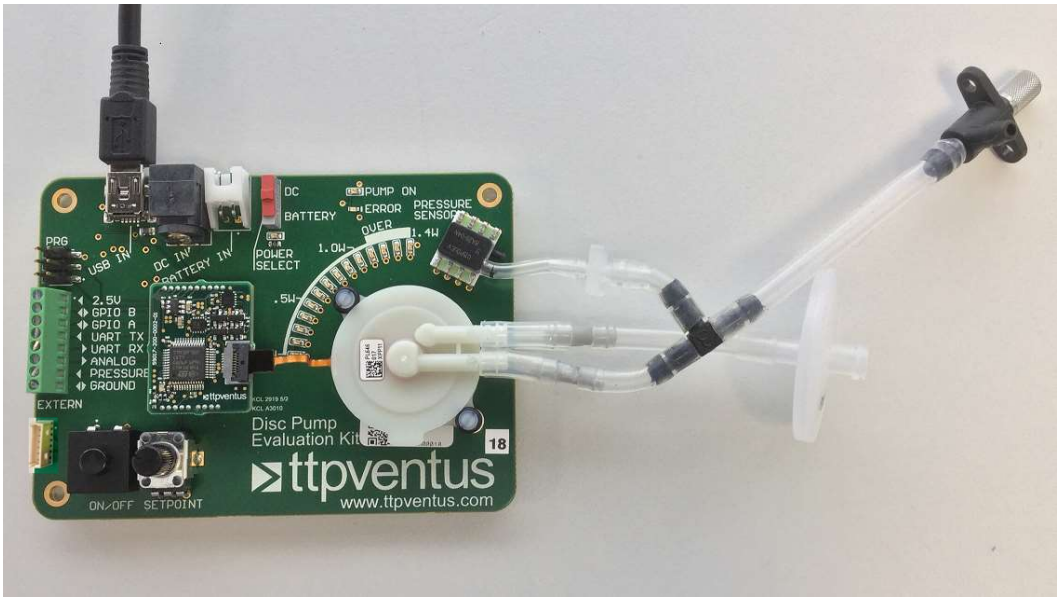


Figure 11: Pump setup tracking pressure via analogue input.

To set up pressure tracking:

1. Connect the output of the pump to the PCB-mounted pressure sensor and to a small valve via a T-piece.

The valve acts as an adjustable orifice, allowing the pressure in the discharge line (or system) to decay when the pump is not running. A fixed orifice could also be used. The size of the vent orifice needed will depend on the system requirements and the response time needed.

2. Having set up the system as shown, open the LEE Ventus Pump Control App and select the PID Control tab.
   For the purposes of this example, the setpoint dial on the PCB has been selected as the control input (Dial). To control using the analogue input instead, select 'Analogue Input' as the control input. The range and offset parameters associated with the control input can be mapped as detailed in §7.5.4.

3. In the second drop down box below the PID variables, select Pressure Sensor. (This is the variable which is controlled by the PID loop to match the control input). See Figure 12 for further details.

4. Enable the pump.
   The pump drive power will be adjusted by the PID loop to achieve the desired target pressure.

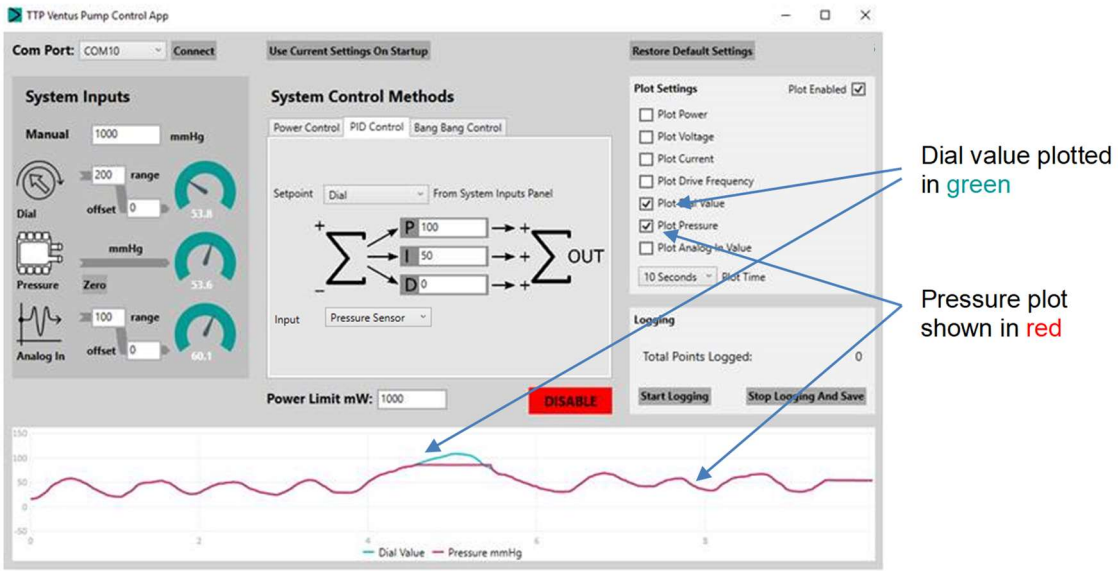


Figure 12: GUI showing PID control set up

Figure 12 shows how the output pressure profile matches the setpoint dial value (our simulated analogue input) exactly. The only time the waveforms do not match is when the pump is asked to produce a pressure higher than it is capable of achieving against the vent orifice and within the constraints of the power limit set in the software.

TAKE NOTE

Since every system is different it will be necessary to adjust the proportional and integral coefficients (i.e. the values in the P and I boxes) to achieve the best response to setpoint changes.

To make the pump follow a pressure profile defined by the analogue input voltage you will need to change the Setpoint to ‘Analogue Input’ in the GUI and provide a control voltage that corresponds to the target pressure signal.

Finally, where an external pressure sensor is used to monitor pressure, this can be used as the “Input” to the PID loop (appropriately scaled using the “System Inputs” panel), with the “Setpoint” set to either “Manual” or “Dial”.

7.5.10 Plotting

Various parameters can be plotted on the graph presented in the PC application.

- In the Plot Settings panel, tick the Plot Enabled check box.
- Tick the check boxes for the values to be plotted.
- Select the Plot Time from the dropdown menu – this is the maximum duration of data displayed in the graph.
- It is possible to zoom on the graph by scrolling whilst hovering over it with the mouse cursor.
- Panning up and down the Y axis is possible by clicking and dragging up and down.
- The value at a given point for a given curve on the graph can be displayed by rolling over the point.

7.5.11 Logging

Data can be logged to a CSV file for offline analysis.

- In the Logging panel, click the Start Logging button.
- Observe that the Total Points Logged counter is increasing.
- When finished, click the Stop Logging And Save button.

7.5.12 Power Limit

The evaluation kit has a function to limit the drive power supplied to the pump to prevent damage to the pump. The Power Limit mW field allows this limit to be set. Initially, we recommend that this limit is set to 1000 mW. For intermittent (i.e. non-continuous) use, higher limits can be used up to a maximum of 1400 mW. Intermittent use is defined as having:

- Mean power ≤ 1000 mW
- A duty cycle period of less than 20 s.

7.5.13 Saving Settings

It is possible to save the evaluation kit settings to be used at start up (when the system is next powered). To do this, click the Use Current Settings On Start-up button.

8 SUPPORT

The support section of LEE Ventus website (https://www.ttpventus.com/support) provides technical information, FAQs, troubleshooting, a “How To” video on the operation of the evaluation kit and documentation for download, including a range of application notes, including:

- “TN001: Disc Pump Drive Guide”: a guide on how to drive Disc Pump effectively with your own electronics.
- “TN003: Communications Guide”: a serial communications guide, for taking control of the evaluation kit (or smaller drive PCB) with your own hardware.
- “TN004: Disc Pump Driver PCB”: a guide on how to integrate the smaller drive PCB with your own set up, prototype or product.
- “AN007: Microfluidics Driver”: – Prototyping with the Disc Pump Evaluation Kit and Sensirion SLF3x Series Flow Sensor
- “Disc Pump Reference Design Package”: a pack of reference designs for the firmware and drive PCB.

For additional technical support, please contact LEE Ventus at support@ttpventus.com.

9 REVISION HISTORY

Revision	Date	Details
210809	09 August 2021	Corrections/updates to Table 2, Figure 12 and § 7.5.12. & Support section document numbers.
210324	24 Mar 2021	Updates for v7 motherboard.
200713	13 July 2020	Corrected error in gating information.
200624	26 Jun 2020	Added information on gating pump output.
191112	12 Nov 2019	Added § 7.2.7
190521	21 May 2019	Updated Quick Start in § 6. Corrected typing error in § 4.
190128	28 Jan 2019	Clarifications to § 6.2.5.
190121	21 Jan 2019	Initial release.