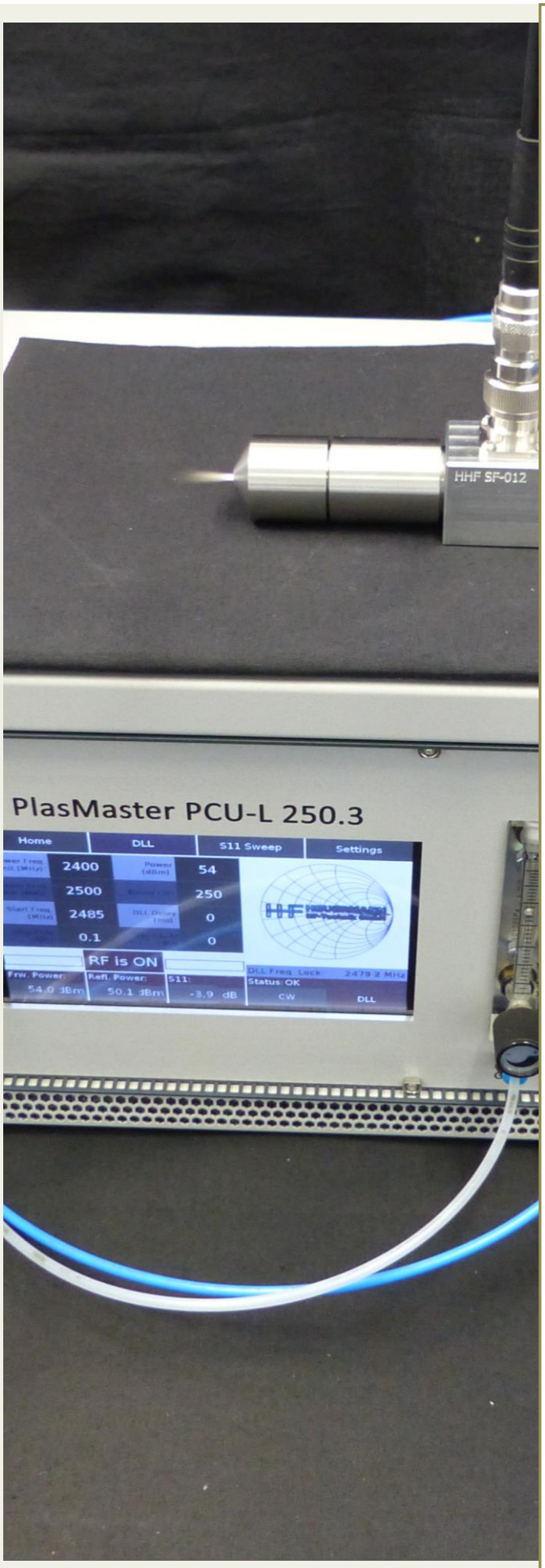


HEUERMANN
HF-Technik GmbH

# User Manual:

# PlasMaster PCU-L
# 250.2/3
# 500.2/3

Version 1.5

March 2022

## Table of Contents



# 1. Introduction

The PlasMaster generators of Heuermann HF-Technik GmbH are primarily designed to enable an efficient operation of our microwave plasma jets and couplers, and at the same time, they can be used in any microwave application where a stable and regulated microwave power is required. Details of this unique patented technology have already been published[1].

With a maximum output power of over 250 W or respectively 500 W in the ISM frequency band between 2.4 and 2.5 GHz, the PlasMaster PCU-L 250 and PCU-L 500 generators are easy to use and offer all necessary process parameters required to monitor and optimize the application or small series production such as forward power, reflected power, and application frequency[2].

Two basic versions of the generators are available:
- The PlasMaster PCU-L 250**.2** or 500**.2** is designed for processes where no gas flow monitoring is required, such as when a chamber coupler is used to run a plasma in a low-pressure chamber.
- The PlasMaster PCU-L 250**.3** or 500**.3** is primarily used to run plasma jets with a gas flow, such as the PS and the PC series. The generator monitors the gas flow and shuts down if the flow is too low, thus protecting the respective jet from a potential burn down. At the same time, the generator can also regulate two gas flows for a process gas (such as argon) and a cooling gas (such as air).

The units can be well used in laboratories for experimental purposes or product development, as well as in the production line. The preset mode of operation is the production modus, where all relevant parameters are set and monitored over the DSUB-15 connector at the rear. This can be switched off over the GUI, so that all settings are then controlled by the GUI.

This document describes the functions and features of the PlasMaster PCU-L microwave generator. It will serve as a guide to all supported hardware and software features and covers the application of the corresponding plasma jet or coupler. Following is a short overview of the features of the microwave plasma jets, driven with the PlasMaster PCU-L generators:

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[1] Heuermann, H., Sadeghfam, A.: Analog Amplitude-Locked Loop Circuit to Support RF Energy Solutions, International Microwave Symposium, San Francisco, May 2016.

[2] The PlasMaster generator carries out a so-called scalar hot S-parameter measurement at the output port.

- Pure atmospheric 2.45 GHz plasma for continuous power levels of up to 500 W
- Highly efficient, low loss plasma jets
- Relatively low plasma temperature since solely electrons are accelerated
- High absolute plasma temperature at vicinity of nozzle due to high power density
- Usable by hand or robotized, genuine 100 % potential free
- Very low power consumption
- Low Maintenance with minimal wear off
- Compact, handy form and size
- Cost efficient technology, easily applicable to production facilities
- Further advantages for diverse applications presented below

Industrial and medical applications using plasmas are increasing continuously. The following are some major applications using low power levels (below 100 W):

- Activating plastic surfaces for welding, melting, painting, varnishing, printing, coating, gluing, etc. as well as further processing steps
- Cleaning of different metallic surfaces for soldering, varnishing, coating, gluing, bonding, etc. as well as further processing steps
- Disinfection and sterilization of instruments in medical fields, even of wounds
- Aging treatment of components

Further applications using higher power levels (above 100 W) are:

- Quicker activating plastic surfaces for welding, melting, painting, varnishing, printing, coating, gluing, etc. as well as further processing step
- Soft soldering and hard soldering of metals
- Amalgamation or fusing of surfaces and boring holes or vias
- Labeling or inscription of various materials
- Firing in of paint or varnish
- Cutting various materials
- Welding various materials
- Coating various materials

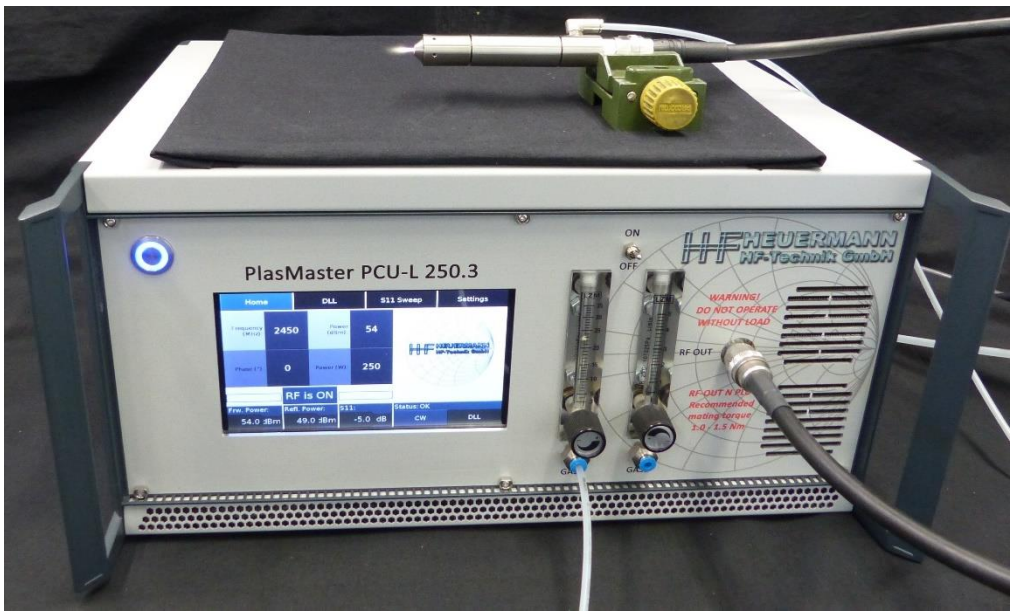


Fig. 1: The PlasMaster PCU-L 250.3 with a PS plasma jet.

The PlasMaster PCU-L can support the following applications with the corresponding jets[3]:

| Process gas | Application | Power level | Jet | Comments |
|---|---|---|---|---|
| Air / Nitrogen | Activation, cleaning, rapid heating | 40 – 250 W | PS | |
| | Rapid activation, cleaning and heating; | 80 – 500 W | PC-SF3 | |
| | Coating with powder or wires; Fluid treatment (activation, heating or vaporization) | 80 – 500 W | PC-SF4 | Induction of additives through special adapter |
| | Very rapid activation, cleaning, heating and melting | 1400 – 3000 W | PS-MJ | Magnetron jet, broad plasma |
| Argon / Varigon | Activation (low temperature) | 2 – 10 W | MiniJet-R | Manual ignition |
| | Activation (low temperature) | 5 – 100 W | PS-Ar | |
| | Cutting, welding | 50 – 250 W | PC-B | |
| | Same as PC-SF4, but with a higher energy density | 60 – 250 W | PC-SF2 | Inert surrounding due to argon |
| | Same as PC-SF3, but with a much higher energy density | 80 – 500 W | PC-SF5 | Inert surrounding due to argon |
| | Same as PC-SF4, but with a much higher energy density | 80 – 500 W | PC-SF6 | Inert surrounding due to argon |
| No gas | Low pressure chamber | 50 – 500 W | CC | |

# 2. Features and Specifications

Below is an overview of the features of the PlasMaster generators:

## Features

- Frequency range: 2400 MHz – 2500 MHz (ISM band)
- Maximum RF power output: 250 Watt or 500 W
- Hard- and software based "Safe Operating Area" protection against thermal and RF overstress as well as lack of process gas (PlasMaster PCU-L 250.3 and 500.3)
- Operational modes:
  - Continuous Wave (CW)
  - Digital Locked Loop (DLL)
- Integrated digital frequency matching and energy delivery optimization (DLL)
- Very high-resolution RF parameter settings
- Very fast S11 sweep (reflection measurement) for process control
- 7" capacitive touchscreen
- Intuitive graphical user interface (GUI)
- Minimum required matching in operation is 50 %

## Mechanical Specifications and Gas flow

- Size (h x w x l)
  250 W generator: 23 cm x 42 cm x 46 cm
  500 W generator: 23 cm x 42 cm x 46 cm

[3] Please note that the jets for 250 W use N connectors, whereas 500 W jets use 4.3/10 connectors!

- Weight
  250 W generator: 10.5 kg
  500 W generator: 15.5 kg
- Gas flow rates (PlasMaster PCU-L **250.3** and **500.3**) at up to 6 bar
  Gas 1: 0.5 – 5 sl / min (process gas e.g. argon)
  Gas 2: 5 – 35 sl / min (cooling gas e.g. air or nitrogen)
- Diameter of gas hose: 6 mm (PlasMaster PCU-L 250.3 and 500.3)
- RF connectors
  250 W generator: N-connector
  500 W generator: 7/16-connector

| Connections DSUB 15 | | |
|---|---|---|
| • Pin 1 | (digital input) | DLL activation (high active)[4] |
| • Pin 2 | - | Ground |
| • Pin 3 | (analog input) | DLL active: start frequency for DLL mode (Fig. 3b)<br>DLL inactive: manual frequency setting (Fig. 3b) |
| • Pin 4 | (digital input) | 250.**2** and 500.**2:** enables output power (high active)<br>250.**3** and 500.**3:** not connected |
| • Pin 5 | (digital input) | 250.**2** and 500.**2:** not connected<br>250.**3** and 500.**3:** enables gas flow (high active) |
| • Pin 6 | (analog output) | measured temperature of the main amplifier (Fig. 3a) |
| • Pin 7 | (analog output) | current operating frequency (Fig. 3b) |
| • Pin 8 | (analog output) | current reflected power in percentage (Fig. 3c) |
| • Pin 9 | - | not connected |
| • Pin 10 | (digital output) | error (high) when no gas detected or system overheat |
| • Pin 11 | | Ground |
| • Pin 12 | (analog input) | threshold for DLL mode (Fig. 3d) |
| • Pin 13 | (analog input) | lower frequency limit in DLL mode (Fig. 3b) |
| • Pin 14 | (analog input) | upper frequency limit in DLL mode (Fig. 3b) |
| • Pin 15 | (analog input) | power setting in remote command mode (Fig. 3e) |

- Analog input/output range: 0 V to 5 V
- Digital input/output levels: LOW: 0 V
  HIGH: 5 V

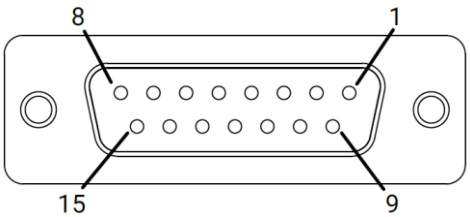


Fig. 2: Pin configutation of the DSUB-15 connector.

[4] When activating the DLL mode, start frequency, frequency limits and threshold have to be set (pins 3, 12, 13 and 14).

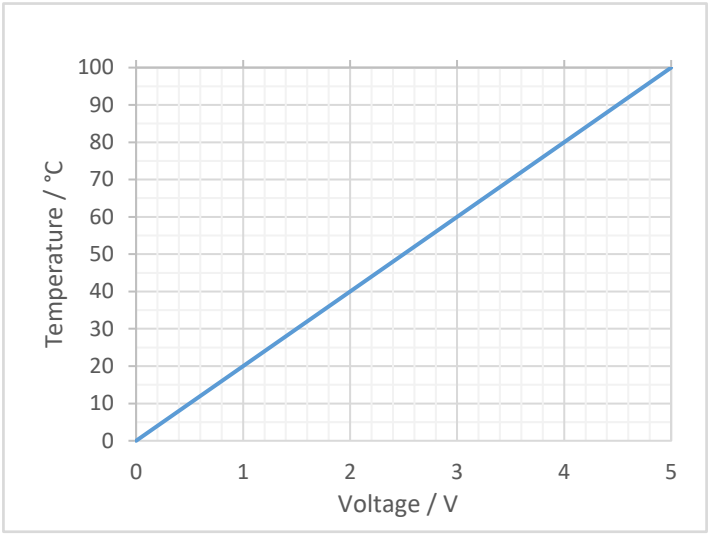


Fig: 3a: Analog output voltage against temperature plot.

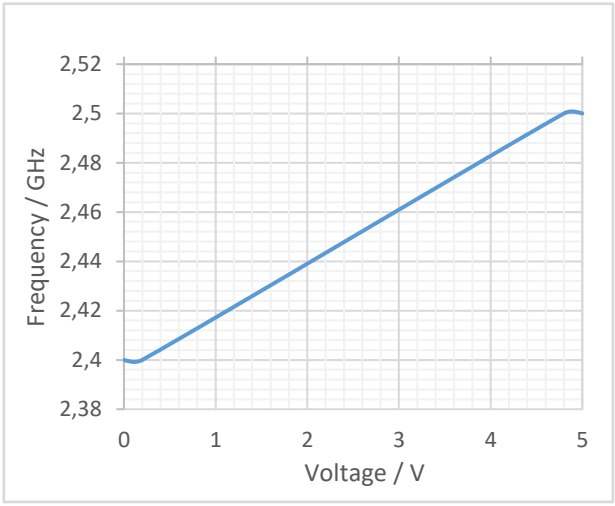


Fig: 3b: Analog output voltage against operating frequency plot.

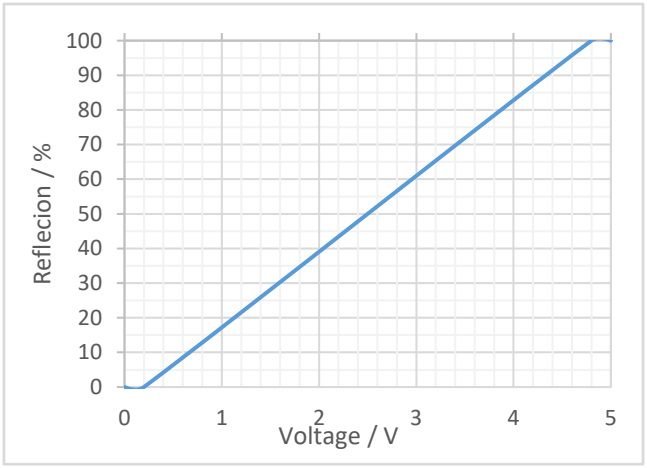


Fig: 3c: Analog output voltage against reflected power plot.

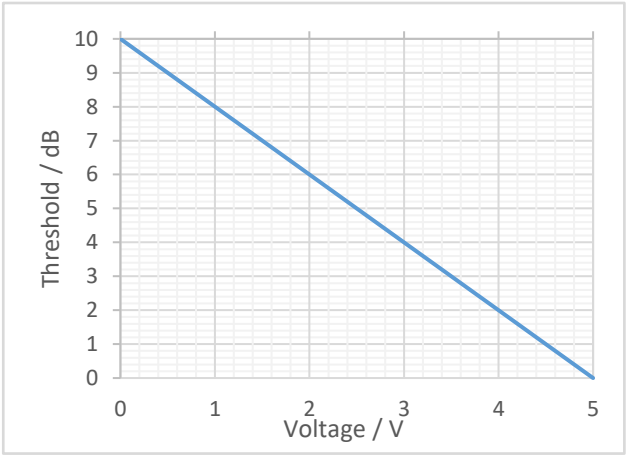


Fig: 3d: Analog input voltage against S11 threshold plot.

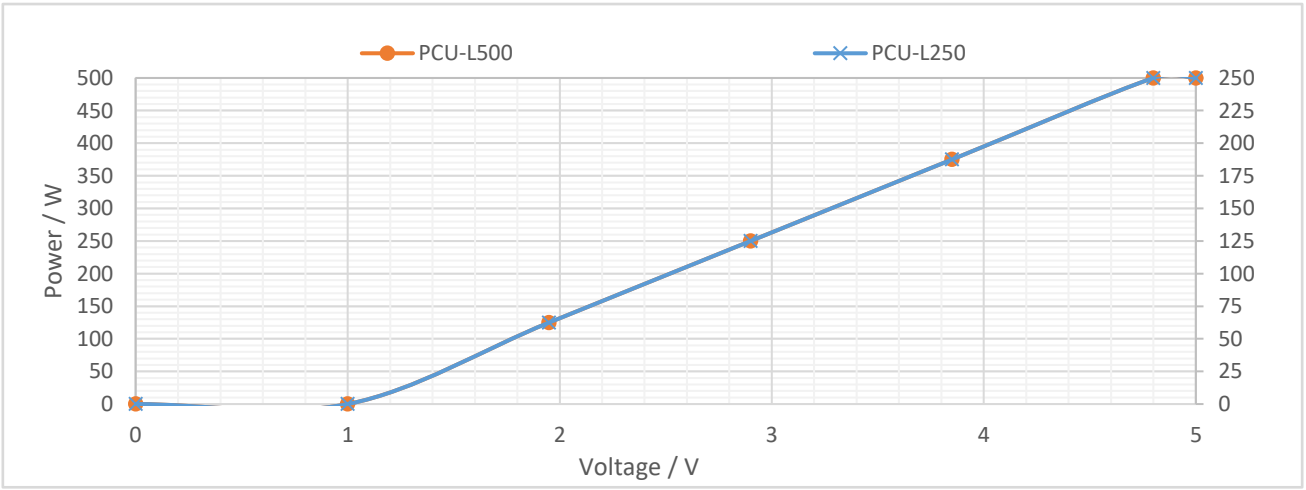


Fig: 3e: Analog input voltage against output power plot for 250W (rigth axis) and 500W (left axis) systems.

Fig. 3: Voltage graphs of the analog signals.

# 3. Operating the Generator

The PlasMaster generator is operated through the graphical user interface (GUI) visible on its touch display or using the 15 pin DSUB connector at the rear. Upon starting, the system goes in to the Remote Command Mode, where the settings are carried out over the DSUB 15 connector at the rear (please refer to section *Remote Command Mode*). Switching off the Remote Command Mode enables the control of the unit over the GUI.

Fig. 4 and Fig. 5 show the front side and the rear of the PlasMaster PCU-L 250.3 (similar to 500.3), showing the electrical and the gas connections, as well as the N-connector for the cable to the applicator (**the PCU-L500 units have a 7/16-connector**).

Fig. 6 shows the front side of the PlasMaster PCU-L 250.2 (similar to 500.2).


Fig. 4: Front side of the PlasMaster PCU-L 250.3.

Use the main switch at the rear to power on the generator and then use the stand-by switch to activate the unit. The operation of the generator is described in the following sections.

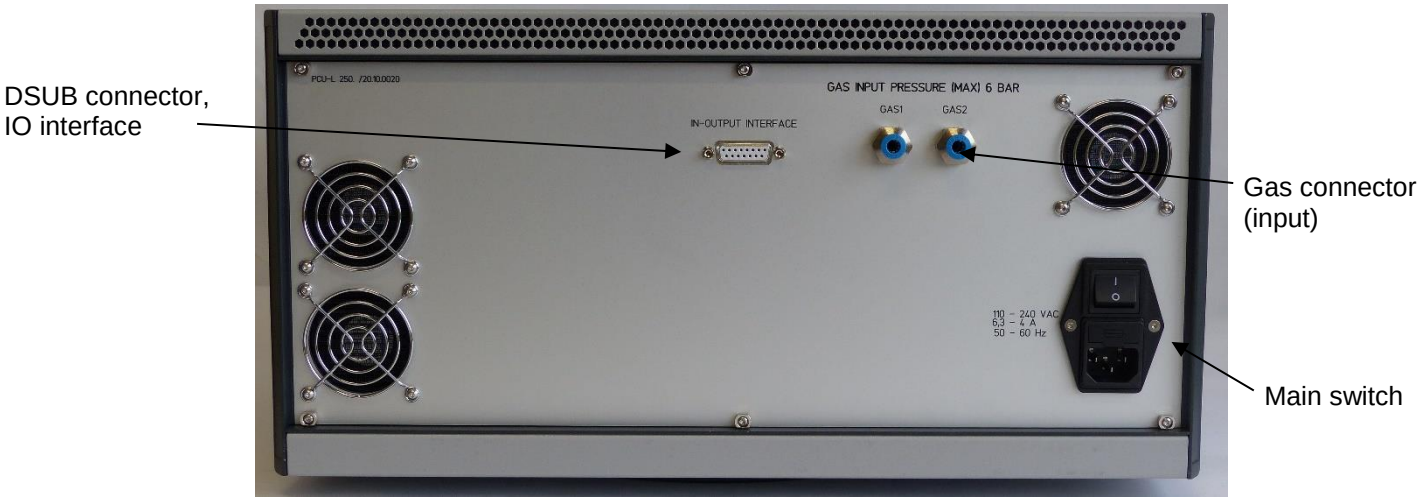


Fig. 5: Rear view of the PlasMaster PCU-L 250.3.


Fig. 6: Front side of the PlasMaster PCU-L 250.2 without gas control.

## 3.1 Gas Connection

The PlasMaster PCU-L 250.3 and the PlasMaster PCU-L 500.3 can manage two gas connections in accordance to the application. To protect the jets, the generator is not enabled unless a gas flow is detected[5]. The generators have built-in magnetic valves to enable the gas flows, which can be either enabled manually over the gas enable switch or over pin 5 of the DSUB connector at the back when in Remote Command Mode. Both gases are enabled simultaneously. Please note that the gas pressure should be in the range of 4 to 6 bar.

- Gas 1: Process gas, generally argon with at a flow rate of up to 5 sl/min, which can be set using flowmeter 1.
- Gas 2: Generally used for cooling (normally air). Nitrogen can alternatively be used here, which can be advantageous in certain applications, where oxidization is an issue (this generally leads to a higher level of activation). The flow rate is normally in the range between 15 – 30 sl/min (depending on the jet) and can be set using flowmeter 2.

# 4. The Graphical User Interface

When started, the system starts in the Remote Command Mode and can be controlled over the DSUB connector at the rear (section *4.5 Setting: Remote Command Mode*) by setting voltages as described in Section 2. Switching off the Remote Command Mode activates the GUI described as follows.

This chapter describes in detail how the GUI works and what you can do in each menu (Fig. 7).

## 4.1 Basic Page Layout

Most pages of the GUI use the same basic layout.

### ① Menu Buttons

The menu buttons are used to navigate the various tabs of the GUI. These buttons are visible at all times and on all page. There are four menus in total:

- Home
- DLL
- S11 Sweep (reflection measurement)
- Settings

For more information about each of these tabs, please see the respective sections below.

[5] This does not apply to the 250.2 and the 500.2 versions without gas monitoring.

### ② Operation Mode Selection

These buttons determine the operational mode of the generator. The operational modes are:

- CW Mode (Continuous Wave)
  The default mode. Generates a continuous wave signal with the possibility to change the frequency, power and phase[6] of the incident power.
- DLL Mode (Digital Locked Loop)
  Digital frequency matching and energy delivery optimization for fast applications (system reaction is below 1 second). This mode is recommended for all general applications.

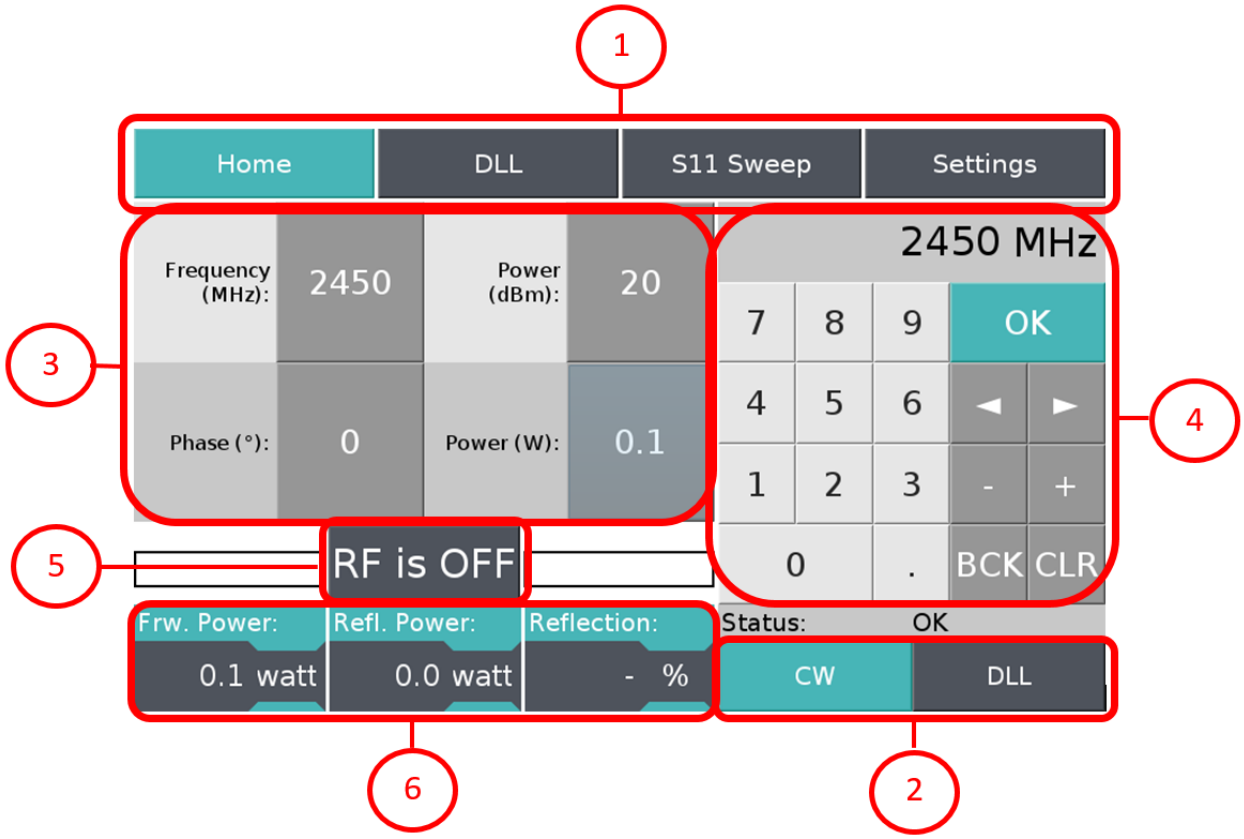


Fig. 7: The basic layout of the GUI.

### ③ Parameter Control Buttons

These buttons are used to configure the working parameters of the generator. The exact contents of these buttons will differ in each menu, but their purpose and functionality remains the same. In most cases, pressing one of these buttons will cause a numeric keypad to appear on the right side of the screen, through which parameter values can be entered.

### ④ Numeric Keypad

The numeric pad only appears when a parameter configuration button has been pressed, and is used to set the value of the respective parameter. The inputs appear in the small entry field at the top of the numpad and are only applied after pressing the OK button.

### ⑤ RF Power Button

This button enables or disables the RF power output of the generator.

[6] **Optional feature** for applications with multiple generators, where the respective phases needs to be aligned, e.g. in heating applications.

⑥ **Power Readings**

These three boxes indicate the forward power, reflected power and the reflected power in percentage of your system. The unit scale can be swapped between dBm and watt according to your preferences, by pressing on the dBm/watt indicators, or between dB and percentage in the case of the reflected power.

## 4.2 Home Menu

This is where the most important controls are present. The controls on this page are used to change the basic properties of your RF signal. By default, only the buttons for continuous wave (CW) mode are visible, but more controls become available as you enable other operational modes with the mode selection buttons in the bottom right.

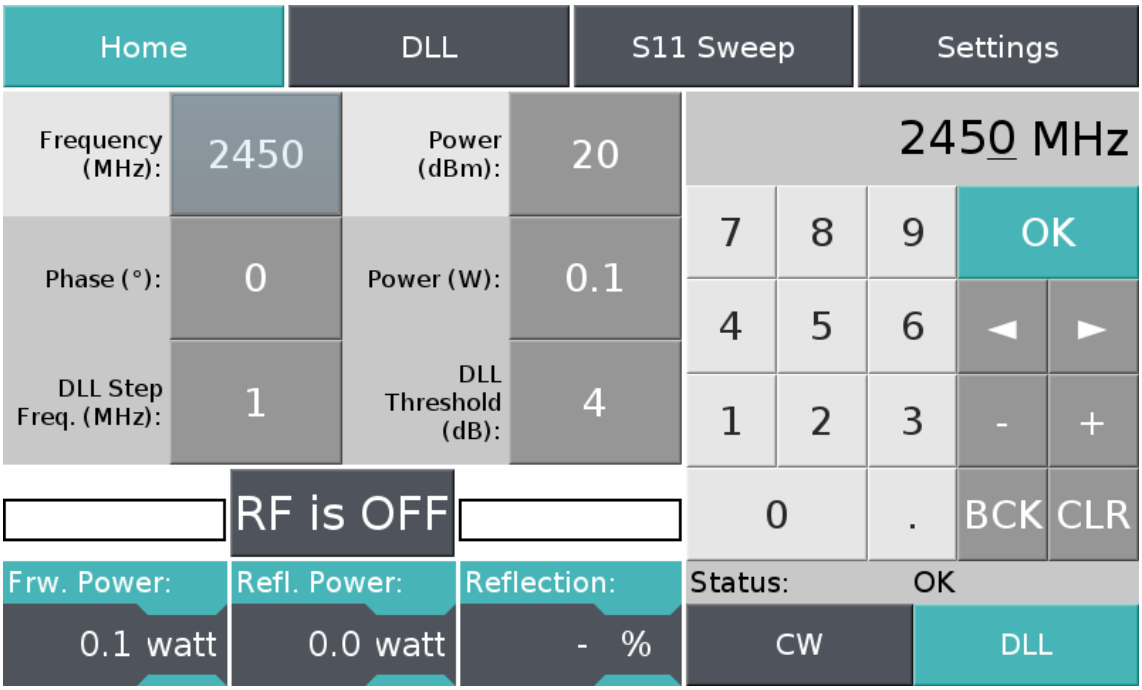


Fig. 8: The home menu of the GUI.

Below are the properties you can control in the Home menu for each mode. The properties for CW mode are always relevant, so they remain permanently visible on the screen.

**Continuous Wave (CW):**

- RF power in dBm
- RF power in watt
- Frequency of the signal in MHz
- Phase of the signal (optional feature)

**Digital Locked Loop (DLL):**

Using this mode, two further parameters become visible:

- DLL step in MHz
- DLL threshold in dB

Furthermore, there are three messages:

1. Temperature: This denotes the temperature of the power amplifier. The system will shut down if this reaches a critical value of over 82 °C. If this should happen, please check the cooling system (coolant level and free ventilation path).
2. Gas flow monitoring: The system will not start if there is no gas or not sufficient gas flow, since this would lead to the plasma jets being damaged (versions 250.3 and 500.3).
3. DLL Frequency: Displays the current operational frequency optimized by the DLL.

## 4.3 DLL Menu: Energy Delivery Optimization

The DLL menu serves as an advanced control panel for the DLL mode.

The DLL mode adjusts the working frequency to obtain the best matching (i.e. minimum in reflected power or minimum in reflection value S11, and thus a maximum of energy transported to applicator) in a bandwidth defined by the user (within the ISM bandwidth between 2400 and 2500 MHz). The optimization algorithm changes the frequency by "stepping" a certain amount of MHz (Step Frequency with a standard value of 1 MHz) to the right and left of the current "center" frequency, measuring the reflected power for each frequency and moving into the direction of a lower S11 value, IF THIS VALUE IS BETTER THAN THE "THRESHOLD" VALUE. This way it can dynamically follow changing impedance conditions of the applications while retaining the best energy delivery efficiency for the process. If the Threshold value is not reached, the frequency will be swept!

The system reacts within milliseconds and is fast enough to drive most applications with changing impedances, such as plasma torches and plasma lamps, while compensating ignition and changes in the operating conditions, e.g. thermic effects.

The DLL menu has the same layout as the Home menu but has a new set of control buttons for input parameters relating to the DLL mode. The current frequency setting is displayed during operation.

The following parameters can be set in the DLL mode:

- Power dBm (same as value in Home menu)
- Power in watt (same as value in Home menu)
- Upper frequency limit of the optimization interval in MHz
- Lower frequency limit of the optimization interval in MHz
- Start frequency of the optimization search in MHz (preferably as close as possible to the ignition frequency for plasma applications)
- DLL step offset in MHz
- DLL threshold in dB
- DLL algorithm loop delay in milliseconds, where a delay is required before the optimization mode

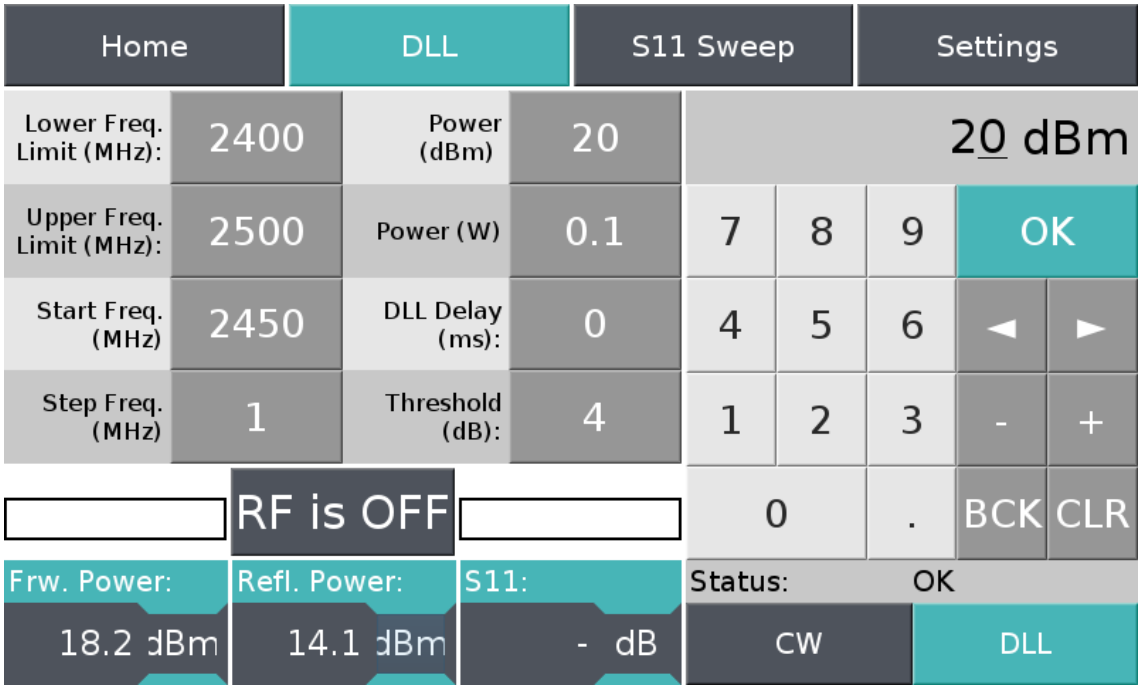


Fig. 9: The DLL menu of the GUI.

## 4.4 S11 Sweep Menu: Reflection Measurement

S11 is the ratio between the reflected power and the incident power to the applicator. The S11 sweep menu allows the user to configure the parameters for an S11 sweep, which measures the

S11 parameter across a frequency band specified by the user and generates a graph to visualize the results. This is the same functionality as in a scalar network analyzer.


Fig. 10: The S11 sweep menu of the GUI.

The following parameters can be set for the S11 sweep:

- RF Power in dBm
- RF Power in Watt
- Start frequency of the measurement interval in MHz
- Stop frequency of the measurement interval in MHz
- Step frequency of the measurement in MHz

Note that the “Power' settings on this screen are disconnected from the RF Power settings in the other menus. Altering the power values for the S11 sweep will not cause a change in your RF signal.

Additionally, this menu differs from the norm since it adds a 'Sweep' button next to the existing RF enable button. Pressing this button will execute the S11 sweep with the provided parameters and lead you to the second page of the sweep menu as described below.

The second page of the sweep menu shows a graph of the S11 measured across the specified frequency band (Fig. 11).

When you arrive at this page, it is important to note that the RF Power output of the generator has been disabled (after the sweep). This is a safety precaution, because this screen has no power readings and ON/OFF controls.

| | |
|---|---|
| ! | The dynamic range of the measurement is limited by the power setting.<br>Using a minimum of about 5 Watt ensures a reliable measurement.<br>Please ensure that gas is activated and available for PCU-L250.3 and 500.3. |

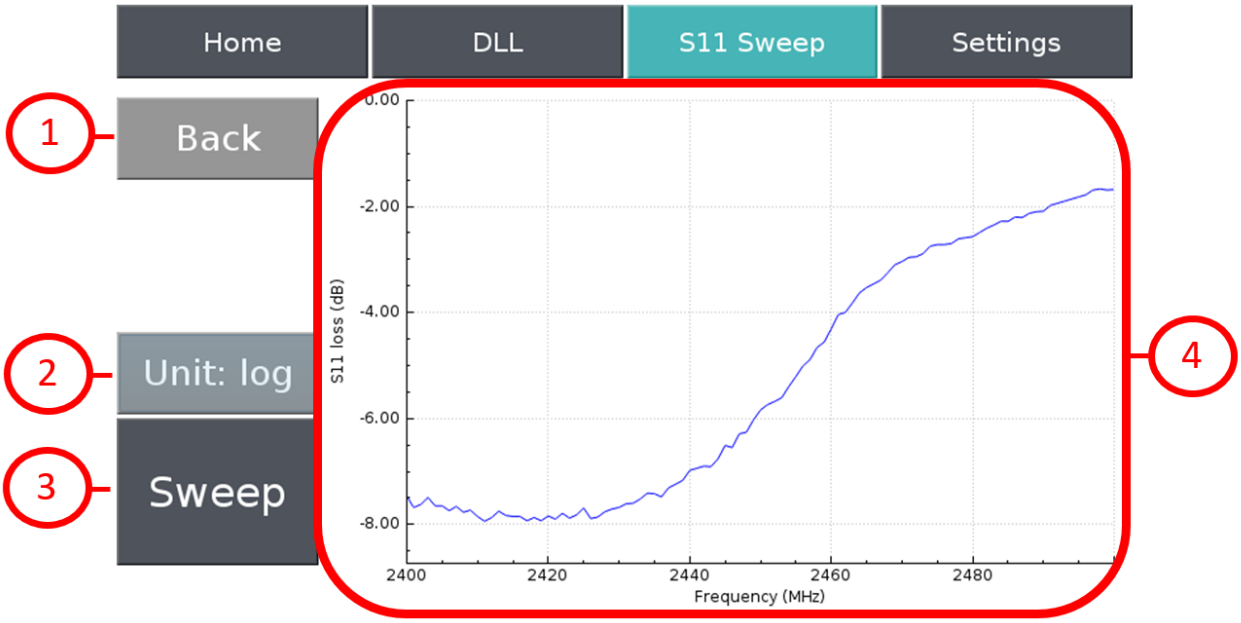


Fig. 11: S11 sweep of a microwave plasma jet in operation.

There are four items of interest on this page:

① **Back Button**
Returns the user to the first page of the S11 sweep menu.

② **Unit Swap Button**
Changes the unit / scaling of the graph between logarithmic and linear.
By default, the notation of the graph is consistent with the notation of the power readings.

③ **Sweep Button**
Runs a new sweep with the same sweep parameters.

④ **S11 Reflection Graph**
The S11 reflection graph denotes the efficiency of the RF signal coupling into the attached RF load within the selected frequency band and is the ratio between reflected and incident wave:

- Linear scale: ratio between the waves.
- logarithmic scale / dB notation: ratio between the waves in decibels (corresponding to the so-called input loss).

Using this sweep, you can determine the threshold for the DLL settings. In this example from Fig. 11, a threshold of 6 dB would be recommendable.

## 4.5 Setting: Remote Command Mode

This option enables you to control the PlasMaster over the DSUB connector at the rear, making this unit easy to use for production. To activate this function, **USB** has to be activated in the Settings mode (**this mode is the standard configuration and is activated when the unit is powered on**).

The PlasMaster PCU-L 250.3 (or 500.3) is enabled when the gas flow is activated on pin 5 (PlasMaster PCU-L 250.2 (or 500.2) are activated through pin 4). The output power can now be set over pin 15 of the DSUB 15 connector at the rear according to 3.e.

The function “TCP” is currently inactive and reserved for a future functionality.

| | |
|---|---|
| ! | When switching off the Remote Command Mode, the DLL functionality has to be explicitly activated. |

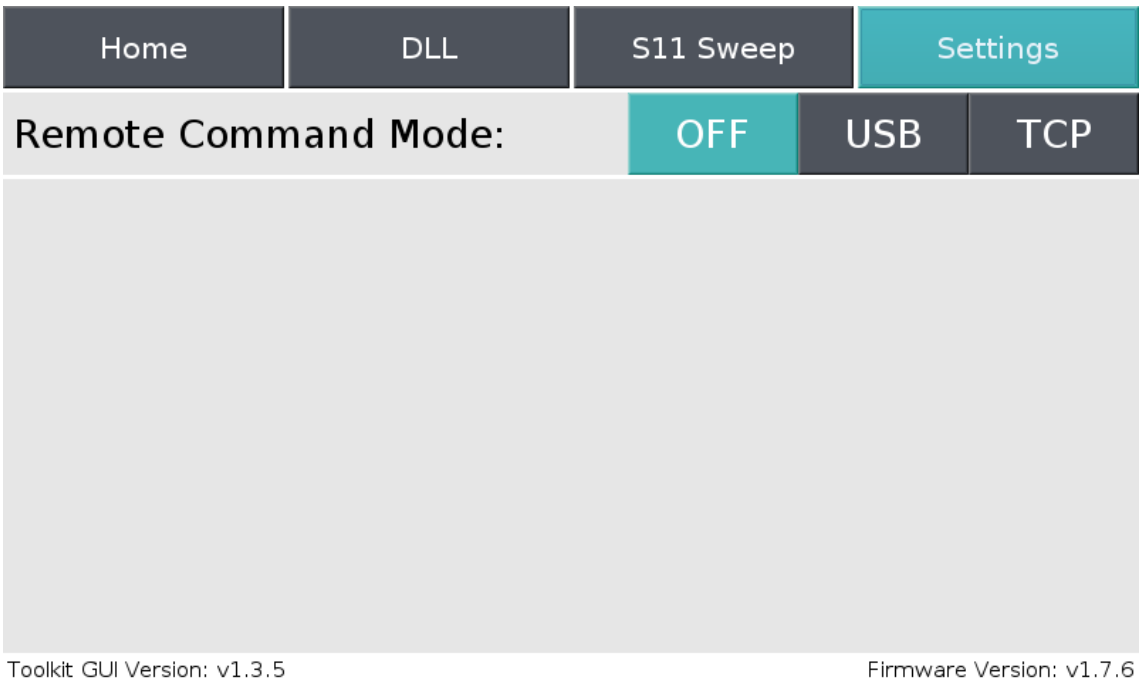


Fig. 12: The settings for the remote command mode.

# 5. Quick Start for External Control with a Coupler or Plasma Jet

The unit can be controlled over the DSUB connector at the rear as well over the GUI using the touch screen. To use the Remote Command Mode:

A. Connect the coupler or jet to the generator with the corresponding cable. **Make sure both sides of the cable are firmly connected.**

B. Activate the Remote Command Mode (standard setting when started).

C. When DLL is desired, active DLL (pin 1 high) and set the optimization parameters accordingly (pin 3 and pin 12 to pin 14, in accordance to Fig. 3b, 3c, and 3d).

   Alternatively, when operating with manual frequency setting, deactivate DLL (pin 1 low) and set the output frequency using pin 3 (Fig. 3b).

D. When using the PlasMaster PCU-L 250.2 or 500.2 with a coupler for low pressure plasma:

   a Enable the output power on pin 4 (high active).

   b Use pin 15 to set the output power (Fig. 3.e) for ignition and if required, change the power level according to the application.

   When using the PlasMaster PCU-L 250.3 or 500.3 with a plasma jet using process and/or cooling gas:

   a Enable the gas flow using pin 5 (high active), enabling the system, and regulate the gas flow according to your application (Section 3.1).

   b Use pin 15 to set the output power (Fig. 3.e) for ignition and if required, change the power level according to the application.

The 5 V error signal (pin 10) goes high if the main amplifier unit has shut down due to overheating (over 82 °C). In case of the PlasMaster PCU-L 250.3 or 500.3, this pin also shows that the gas flow is not available or not sufficient. Other process parameters such as the operating frequency and reflection factor are also available over the connector (see section 2).

# 6. Quick Start as Laboratory Unit with a Coupler or Plasma Jet

To control the unit using the GUI over the touch screen (described in the previous sections):

A. Connect the coupler to the generator with the corresponding cable. **Make use both sides of the cable are firmly connected.**

B. Deactivate the Remote Command Mode in the Settings menu (OFF).

C. We recommend the DLL mode of operation, where the operating frequency is constantly monitored and optimized to ensure the highest possible efficiency.

   To determine the actual ignition frequency, a SWEEP can be performed with e.g. 5 W. The frequency with the best matching (lowest reflection factor) should be used as the initial frequency in the DLL mode.
   The operating bandwidth defined by the Lower and the Upper Freq. Limits should be a little broader (like 5 – 10 MHz) than the actual bandwidth defined as the difference between the frequency of ignition and operation to obtain a degree of freedom incorporating changes arising through operating conditions.
   The THRESHOLD value should be set to about 1 dB lower than the matching at ignition and operation[7]. These values are available in the datasheet of the applicator.

D. With a PlasMaster PCU-L 250.3 or 500.3, switch on the gas flow and regulate the gas flow according to your application (Section 3.1).

E. Set the required power for ignition.

F. Switch the power on.

G. Eventually change the power setting according to the application.

# 7. Specifications of the Cooling Unit

The generators are efficiently cooled using a low-maintenance fluid-cooling system. Over time, the system can however acquire air bubbles and lose some coolant. We recommend controlling the fluid level regularly and filling it up to the MIN level. The coolant can be filled using the port at the rear (Fig. 13).

| | |
|---|---|
| **!** | Please ensure that only corresponding coolant is used to fill up the cooling system, e.g. Phobya ZuperZero Pure Water. |

# 8. Safety Instructions

A. The plasma jets and couplers are hand-tuned. Do not disassemble! Assembling is only possible using complex hot S-parameter measurements.
B. At higher power levels, the housing of the applicator may turn very hot. Do not hold these in your bare hands. Since the radiated microwave power also increases, automated operation is recommended.
   Keep a 50 cm distance to the applicator. To monitor the radiated power, a simple hand held device (e.g. EME Guard 3140 from ANTENESSA) is recommended.
C. For longer usage, a good ventilation is essential.
D. In most applications, the plasma tends to be very bright. Refrain from looking at it directly.

[7] E.g. a 4 or 5 dB THRESHOLD value would be suitable for a coupler or jet with a 6 dB matching for ignition and 12 dB for operation.


Fig. 13: Back view of a PlasMaster PCU-L 250.2 with the Refill Port for the coolant.

# 9. Contact

Heuermann HF-Technik GmbH
Auf dem Anger 29
D-52076 Aachen, Germany

Mail: info@hhft.de
Internet: http://www.hhft.de
Tel.: +49 2408/9379019
Fax: +49 2408/9379952