

User Manual:

PlasMaster PCU-L 250.1

Version 1.3

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1. Introduction

The PlasMaster generators from Heuermann HF-Technik GmbH are designed to enable an efficient operation of our microwave plasma jet, where an automated frequency adjustment is required to ensure an optimal energy transmission into the plasma. Details of this special patented technology have already been published¹.

With a maximum output power of over 250 W in the ISM frequency band between 2.4 and 2.5 GHz, the PlasMaster 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, or application frequency².

The standard version also covers the switching and monitoring of the gas flow required by the microwave plasma jets and automatically shuts down the unit when the gas flow cannot be detected. For applications using a coupler e.g. to generate a plasma in a low-pressure chamber, these functions can be deactivated.

The unit can be well used in laboratories for experimental purposes or product development, as well as in the production itself. In the production mode, which is the preset mode of operation, all relevant parameters can be controlled over a DSUB-15 connector at the rear.

This document describes how to use the PlasMaster 250.3 (250 W, 2.45 GHz-band) microwave generator. It will serve as a guide to all supported hard- and software features and covers the application of the corresponding plasma jet or coupler.

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 carries out a so-called scalar hot S-parameter measurement at the output port.

Following is a short overview of the features of microwave plasma jet, driven with the PlasMaster:

- Pure atmospheric 2.45 GHz plasma for continuous power levels of up to 250 W
- Highly efficient, low loss plasma jets
- Relatively low plasma temperature since solely electrons are accelerated
- Relatively high 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):

- Quicker activating plastic surfaces for welding, melting, painting, varnishing, printing, coating, gluing, etc. as well as further processing steps
- 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

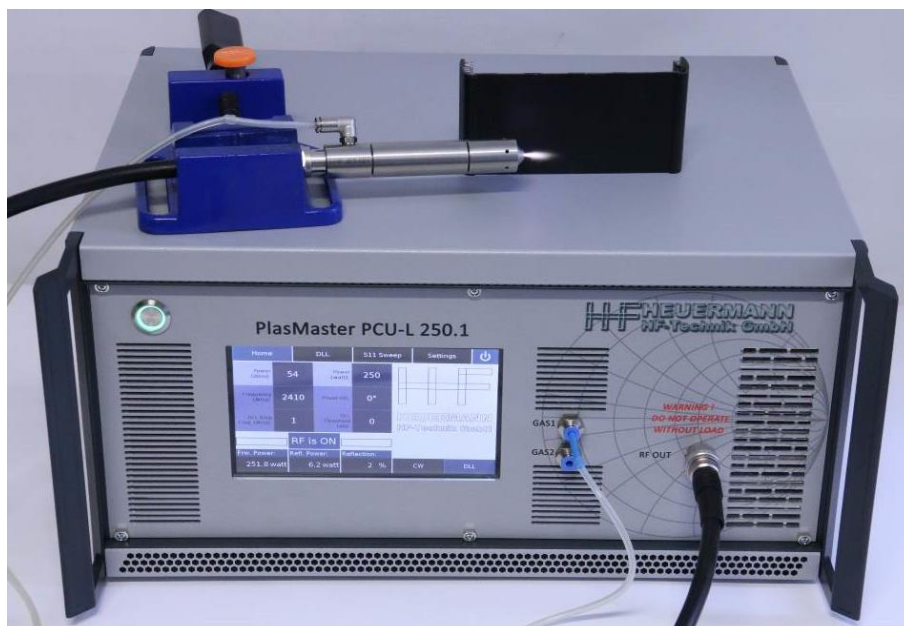


Fig. 1: The PlasMaster PCU-L 250.1 with a PS plasma jet.

The PlasMaster can support the following applications with the corresponding jets:

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 generator:

Features
<ul style="list-style-type: none"> Frequency range: 2400 MHz – 2500 MHz Maximum RF power output: 250 Watt Hard- and software based "Safe Operating Area" protection against thermal and RF overstress as well as lack of process gas (in the case of plasma jets) Operational modes: <ul style="list-style-type: none"> 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)

Mechanical Specifications and Gas flow
<ul style="list-style-type: none"> Size: 23 cm x 46.5 cm x 32 cm (h x w x l) Weight: 13.5 kg

- Gas flow rates (when applicable)
Gas 1: 5 – 35 sl / min (cooling gas e.g. air or nitrogen)
Gas 2: 1 – 5 sl / min (process gas e.g. argon)
- Diameter of gas hose: 6 mm (when applicable)

Connections DSUB 15

- Pins 1,3, 4, 9, 12, 13, 14: do not connect
- Pin 2, 11: ground
- Pin 5: digital input, gas enable (high, when applicable)
- 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 10: digital output, error (high), no gas detected / system overheat
- Pin 15: analog input, power setting in extern trigger mode, output power proportional to amplitude (Fig. 3d)

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

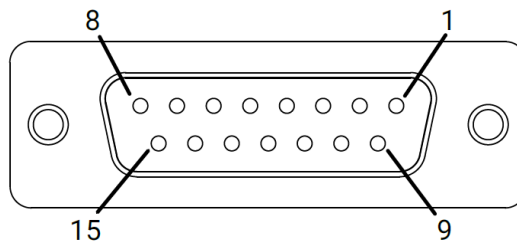


Fig. 2: Pin configuration of the DSUB-15 connector.

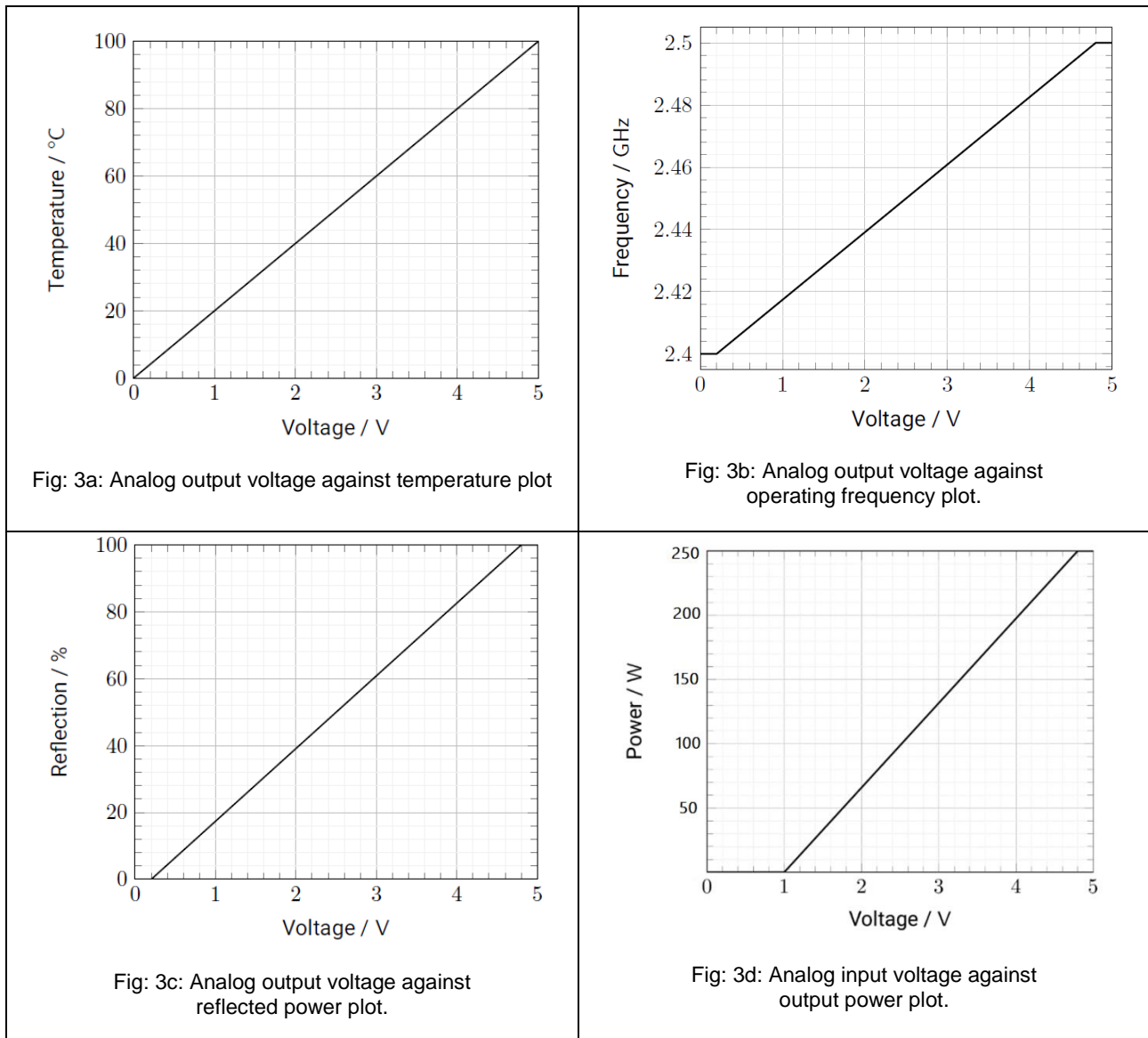


Fig. 3: Pin configuration and voltage graphs of the analog signals.

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. The GUI starts automatically when the system is booted and provides easy access to the generator's extensive features.

Fig. 4 and Fig. 5 show the front side and the rear of the generator, demonstrating the electrical and the gas connections (not C version), as well as the N-connector for the cable to the applicator.

Stand-by
switch



N-connector

Fig. 4: Front side of the PlasMaster PCU-L 250.1.

Use the main switch at the rear to power on the generator and then use the stand-by switch to start the graphical user interface (GUI). The operation of the generator is described in the following sections.



Interface

Main switch

Fig. 5: Rear view of the PlasMaster PCU-L 250.1.

3.1 Gas Connection and Operation

The PlasMaster 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 (except for C versions). The generator has a built-in magnetic valve to enable the gas flow, which can be either enabled manually over the gas enable switch or over pin 5 of the DSUB connector at the back (in this case, both gas connections are enabled simultaneously).

- Gas 1: Generally used for cooling (air). Nitrogen can alternatively be used here, which can be advantageous in certain applications, where oxidization can be an issue. The level of activation is also generally higher when nitrogen is used. The flow rate should be in the range between 15 – 30 sl/min (depending on the jet) and can be set using the flowmeter 1.
- Gas 2: Process gas, generally argon with a much lower gas flow of up to 3 sl/min. Also this flow can be activated and regulated similar to gas 1.

4. The Graphical User Interface

The PlasMaster generator is operated through the graphical user interface (GUI) visible on its touch display. The GUI starts automatically when the system is booted and provides easy access to the generator's extensive features. 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 Control Mode*) by the setting voltages described in Fig. 3. Switching off the Remote Control Mode activate the GUI described as follows.

This chapter describes in detail how the GUI works and what you can do in each menu (Fig. 6).

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 any 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:

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 phase³ of the wave.
- DLL Mode – Digital Locked Loop

Digital frequency matching and energy delivery optimization for fast applications (system reaction is below 1 second, recommended in all general applications).

³ Optional feature for applications with multiple generators, where the respective phases needs to be determined, e.g. in heating applications.



Fig. 6: 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 on screen when one of parameter configuration buttons has been pressed. It is used to set the value of the parameters. 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 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.

4.2 Home Menu

The first screen you will see after your generator has started up is the Home menu. This is where the most important controls are present. The controls on this page are used to change the basic properties 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.

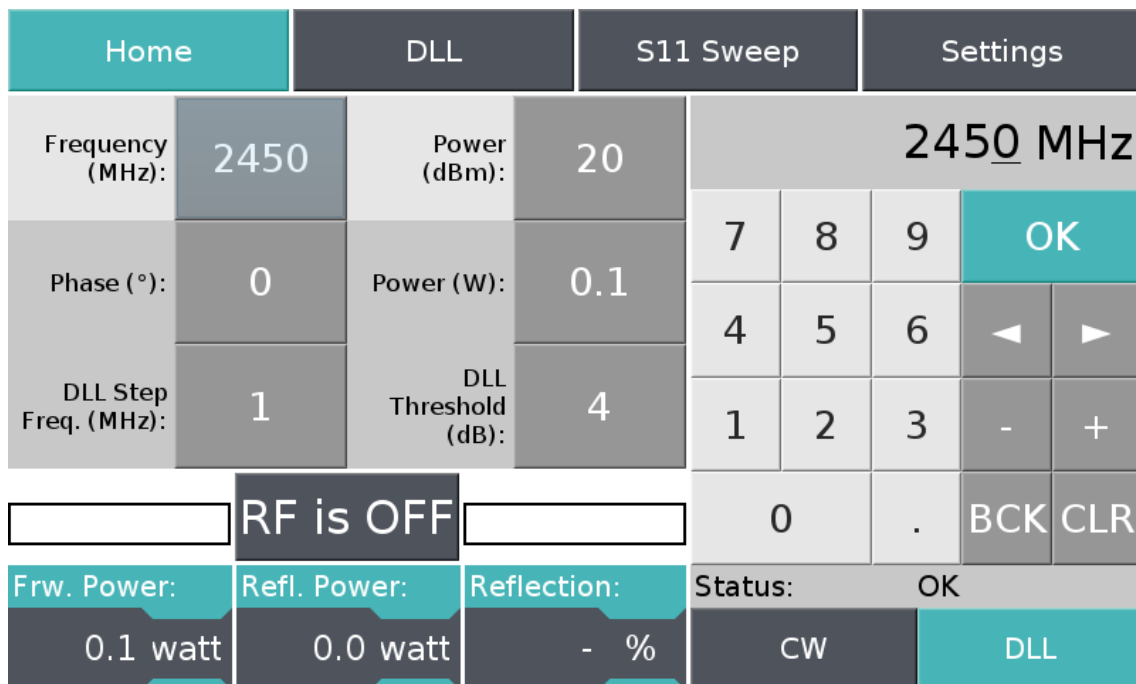


Fig. 7: The home menu of the GUI.

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

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 make sure that the ventilation path is free before contacting us.
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. In applications without airflow, please contact us to turn off this feature.
3. DLL Frequency: Displays the current frequency optimized by the DLL.

1.1 DLL Menu: Energy Delivery Optimization

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

The DLL mode attempts to find the best working frequency (i.e. minimum in reflected power or minimum in reflection value S11, and thus maximum the energy transport 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, standard value is 1 MHz) to the right and left of the current “center” frequency, measuring the reflected power for each frequency and moving into either direction if the S11 value is better than a certain “threshold” set in the control panel. This way it can dynamically follow changing impedance conditions of the applications and yet retain the best energy delivery efficiency for the process.

The technology reacts within milliseconds and is fast enough to drive most applications with changing impedances, such as plasma torches and plasma lamps.

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)
- Optimization interval upper frequency limit in MHz
- Optimization interval lower frequency limit in MHz
- Optimization search start frequency in MHz (preferably close to the ignition frequency for plasma applications)
- DLL step offset in MHz
- DLL threshold in dB
- DLL algorithm loop delay in milliseconds

Home		DLL		S11 Sweep		Settings	
Lower Freq. Limit (MHz):	2400	Power (dBm)	20	20 dBm			
Upper Freq. Limit (MHz):	2500	Power (W)	0.1	7	8	9	OK
Start Freq. (MHz)	2450	DLL Delay (ms):	0	4	5	6	◀ ▶
Step Freq. (MHz)	1	Threshold (dB):	4	1	2	3	- +
	RF is OFF			0	.	BCK	CLR
Frw. Power:	Refl. Power:	S11:	Status: OK				
18.2 dBm	14.1 dBm	- dB	CW		DLL		

Fig. 8: 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. The S11 sweep menu allows the user to configure the parameters for an S11 sweep. An S11 sweep 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 for a scalar network analyzer.

Home		DLL		S11 Sweep		Settings	
Start Freq. (MHz):	2400	Sweep Power (dBm):	20	20 dBm			
Stop Freq. (MHz):	2500	Sweep Power (W):	0.1	7	8	9	OK
Step Freq. (MHz):	1			4	5	6	◀ ▶
				1	2	3	- +
<input type="checkbox"/> RF is OFF		<input type="checkbox"/> Sweep		0	.	BCK	CLR
Frw. Power:	Refl. Power:	Reflection:	Status: OK				
0.1 watt	0.0 watt	- %	CW		DLL		

Fig. 9: 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
- Measurement interval start frequency in MHz
- Measurement interval stop frequency in MHz
- Step offset in MHz

Note that 'Sweep 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 your ongoing RF signal to change.

Additionally, this menu differs from the norm in that 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, seen below.

The second page of the sweep menu shows a graph of the S11 ratio across the specified frequency band.

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. Using a minimum of about 5 Watt ensures a reliable measurement.

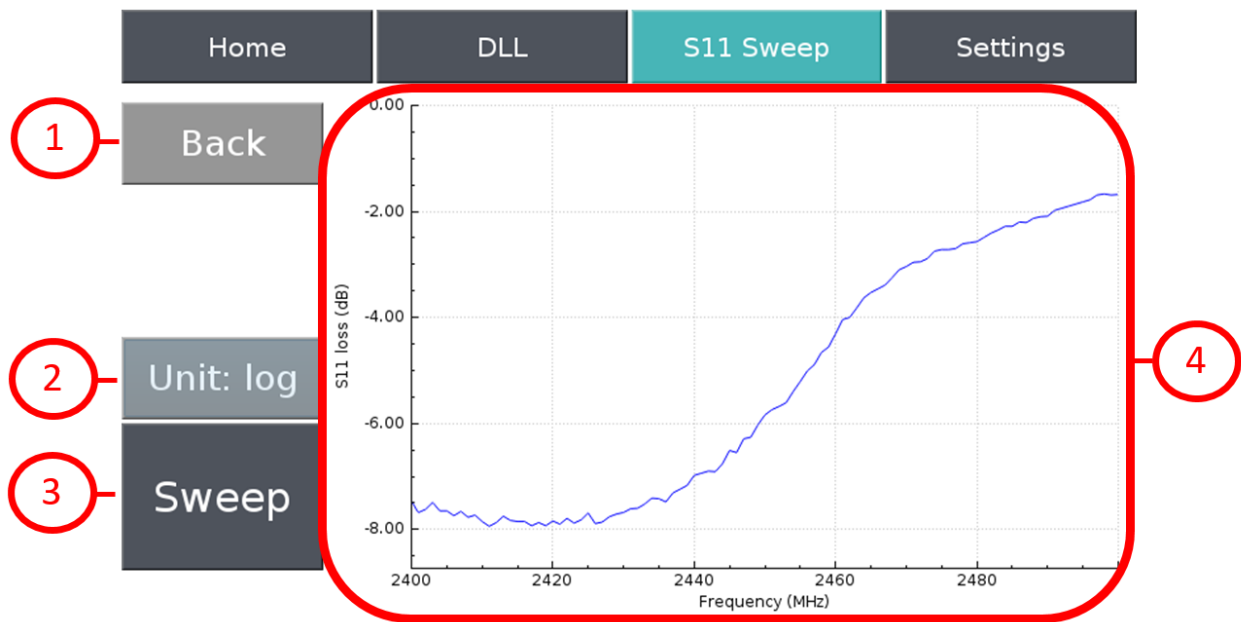


Fig. 10: S11 sweep of a microwave plasma jet in operation.

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 graph between logarithmic and linear.

By default, the notation of the graph is consistent with the notation of the power readings.

③ **Sweep Button**

Run another sweep with the same sweep parameters.

④ **S11 Reflection Graph**

The S11 reflection graph visualizes the efficiency of the RF signal in the attached RF load within the selected frequency band. S11 is the ratio between reflected and incident wave:

- Displays an S11 ratio for linear scale
- Displays an S11 loss (dB) for logarithmic scale / dB notation

Using this sweep, you can determine the threshold for the DLL settings. In this example from Fig. 10, a threshold of 6 dB would be recommendable.

4.5 Setting: Remote Control 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 unit is enabled when gas flow is activated on pin 5 (high, standard version). The output power can now be set over pin 15 of the DSUB 15 connector at the rear according to Fig. 2.d.

“TCP” is currently inactive.

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

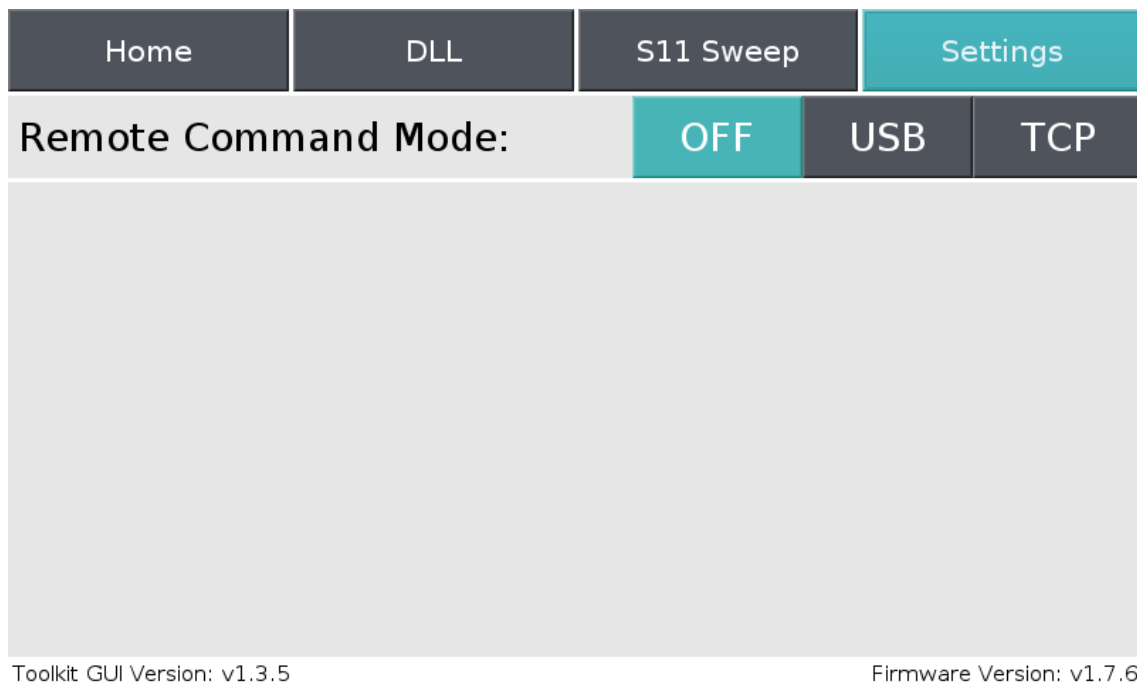


Fig. 11: The settings for the external trigger mode.

5. Quick Start for External Control with a Coupler

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 Control Mode:

- A. Connect the coupler to the generator with the corresponding cable. Make use both sides of the cable are firmly connected.
- B. Use pin 15 to set the output power (Fig. 2.d) 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). 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

To control the unit over 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. 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 the frequency of ignition and operation.

The THRESHOLD value should be set to about 1 dB lower than the matching at ignition and operation⁴. These frequencies are available in the datasheet of the applicator.

- C. Set the required power for ignition.
- D. Switch the power on.
- E. Eventually change the power setting according to the application.

7. 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. The plasma can be very bright. Refrain from looking at it directly.

8. Contact

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