ISC-2425-25+
Industrial System Controller
Quick Start Guide

AN-50-001

www.minicircuits.com

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1. Introduction

The ISC-2425-25+ Industrial System Controller and Small Signal Generator board is a powerful device with many capabilities.

This document guides the user through the recommended steps to get a quick start with generating the output signals for an RF energy application.

First, the hardware setup will be explained, then the software setup and interactions will be covered for both a graphical user interface (GUI) and for a text-based serial terminal interface directly to the application programming interface (API) of the controller.

Note: The commands used in this manual will not be explained in detail. This information can be found in the "command set manual" available for download here:
www.xxxx.com/comand_set_manual_ISC-2425-25+

2. Quick Start (GUI)

The following instructions will enable the user to exercise a quick start with the ISC-2425-25+ signal generator and system control board.

The following load scenario will be used:

- The RF signal generator and power amplifier (the ISC-2425-25+ and the ZHL-2425-250X+, respective- ly) are connected to a suitable microwave cavity. (Note: there are many other applicator examples that could be used e.g., plasma sources etc.)
- The load inside the cavity is a material that needs to be processed with microwave energy.
- A Windows or Linux PC is used to communicate with the ISC-2425-25+ board through the Mini-Circuits GUI. The goal is to heat the chosen material, which presents a challenging load situation to the genertorsystem.

2.1 Step 1 – Assemble the hardware

The ISC-2425-25+ controller is delivered in a box with the following accessories:

- USB A – USB mini 1m cable
- I2C bus cable (Molex to Molex) assembly
- DC power supply connector

The ZHL-2425-250X+ power amplifier is connected to the ISC-2425-25+ with an SMA-to-MCX RF cable(Mini-Circuits part number XXXXXX, to be defined).

SMA-to-MCX RF cable (Mini-Circuits part number XXXXXX)

In addition to the ISC-2425-25+ controller and ZHL-2425-250X+ amplifier, the following components areneeded:

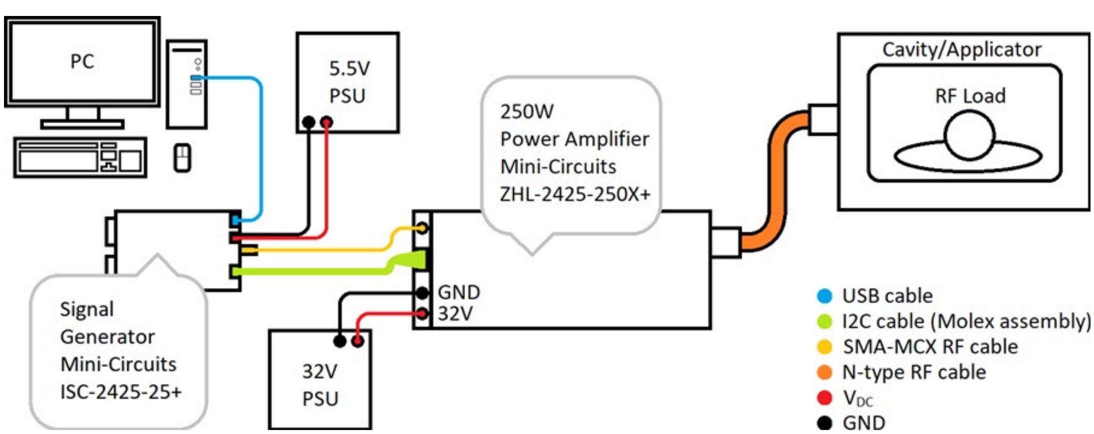
- A power supply for the ZHL-2425-250X+ power amplifier32V,
  16Amp for the power amplifier;
- Note: a power supply for the ISC-2425-25+ is optional since it is by default powered by USB. (for RF out-put power values up to 23dBm)
  For applications where the full RF output power (25dBm) of the ISC-2425-25+ is needed, a dedicated5.5V supply is required. (5.5V, 1 Amp);
- An appropriate microwave cavity with the chosen material as the load
- Additional Cables Required:
  DC supply cable (32V, 16A, wire diameter ≥2.5mm2 or ≤14AWG) to connect the main power supply to the amplifier. These are connected to the ZHL-2425-250X+ using Mating M5 screw (Mcmaster P/N92095A308), Belville washer (Mcmaster P/N 90895A027), Ring Terminal (Mcmaster P/N7113K29), please refer to the ZHL-2425-250X+ datasheet.

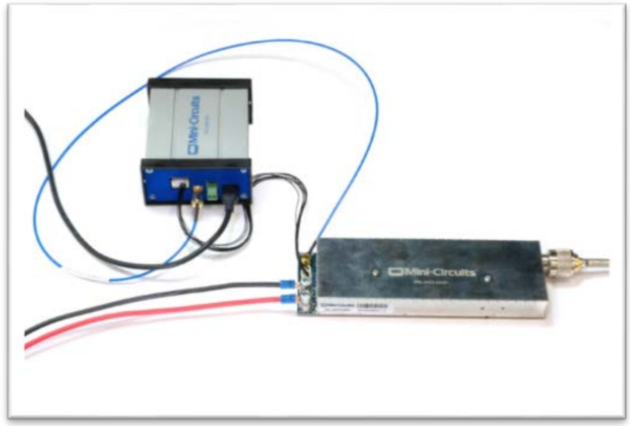
  N-type male (on amplifier side) RF cable to microwave cavity connection

- Software:
- Mini-Circuits GUI:
  Developed for integration with touch displays and with a PC and mouse. Available for

  download on Windows & Linux here: [Download link pending]

With the cables and other hardware ready, it is straightforward to connect it all together. See the diagramand photograph below:



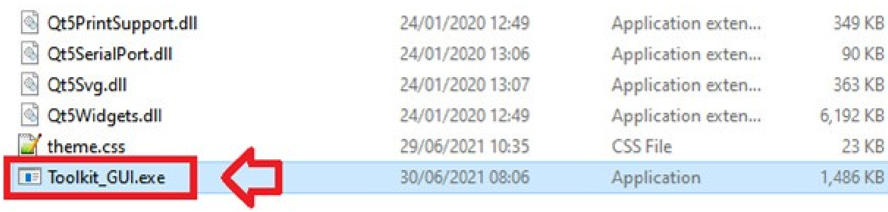


2.2 Step 2 – Set up and run software

Download the software first (see above link).

Windows:

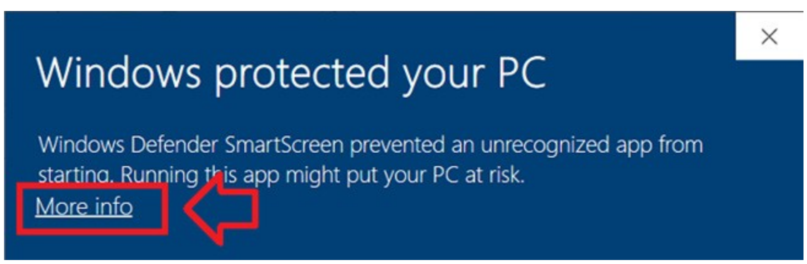
1. Simply unzip/extract the files to the desired destination folder.
2. In the extracted folder find the executable 'Toolkit_GUI' and double-click it to start the program.



Windows Defender may prevent the application from running.To grant

permission to run the application do the following:

a. Press "More Info".

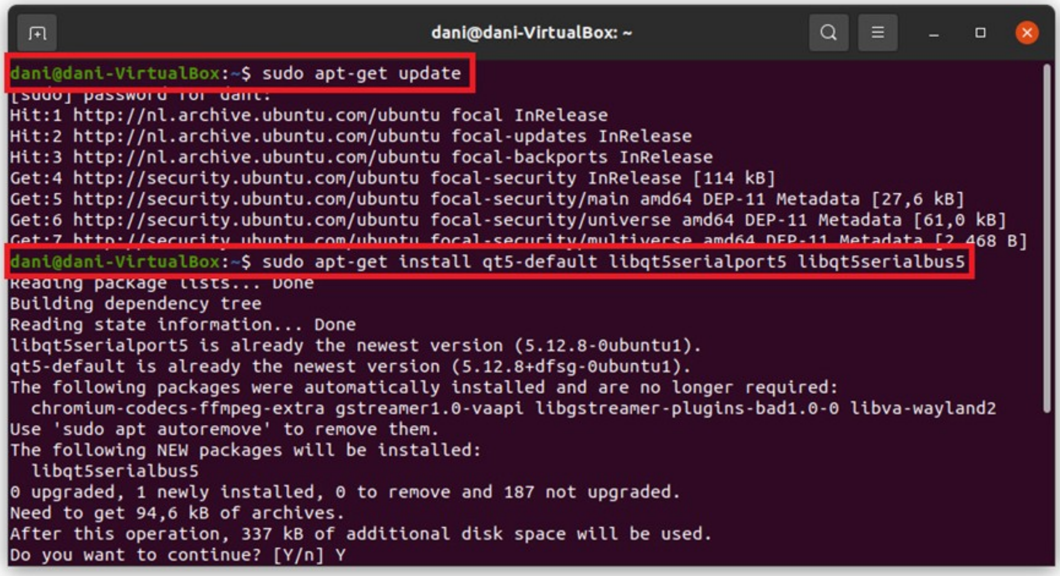


b. Press the "Run anyway" button that appears at the bottom.

Linux:

1. Simply unzip/extract the files to the desired destination folder on the Linux system.
2. Open a terminal (CTRL + ALT + T) and install the necessary dependencies.
   - Input the following lines:
     sudo apt-get update
     sudo apt-get install qt5-default libqt5serialport5 libqt5serialbus5

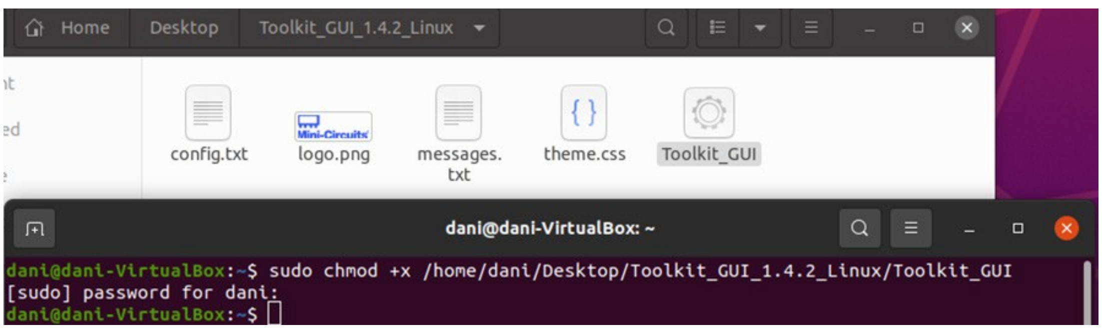
- **Note:** This step requires internet access.
- **Note:** Linux may request permission to do these actions. Provide 'Y' to approve.
- **Note:** Some Linux distributions may use a different packet manager than 'apt-get'.



3. In the extracted folder locate the file 'Toolkit_GUI'.

In the terminal application use the 'chmod' function to grant run permission to the GUI application:

- sudo chmod +x /path/to/Toolkit_GUI

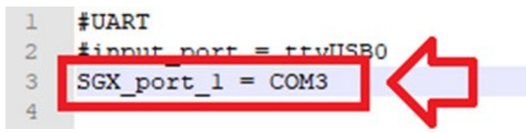


4. Double-click 'Toolkit_GUI' to start the program.

2.3 Step 2.1 – (Optional) Configure communication port

By default, the application should automatically detect the hardware communication port at which the signal generator is plugged in. If for whatever reason the application cannot find the signal generator board, it can be forced to use a specific port by editing the program's configuration file.

1. In the folder where the software was extracted find and open the file 'config.txt'.
2. Inside the config.txt file find the entry 'SGX_port_1' and uncomment it by removing the '#' in front, then provide a valid port name for the signal generator board.

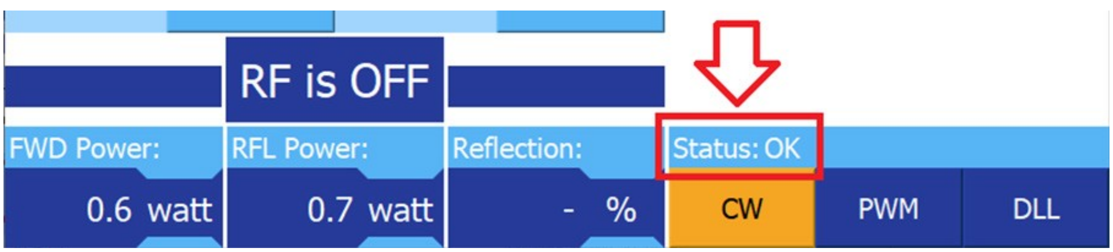


Note: The device's port name can be found using Window's Device Manager or by looking at the Linux' / dev/ directory. For detailed instructions see Chapter 3.2 Step 2 – Set up communication.
Automatic port detection can be re-enabled again by commenting out the line with a '#'.

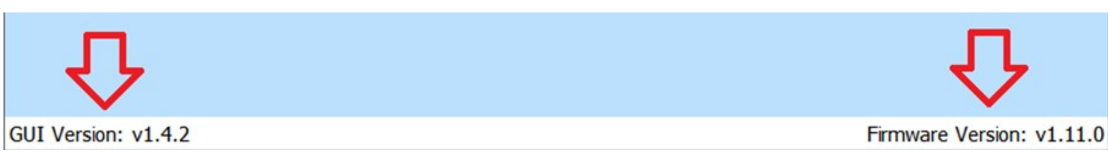
2.4 Step 3 – Check system status

Before continuing to the RF application activity, take a moment to become familiarized with some of GUI'sfeatures.

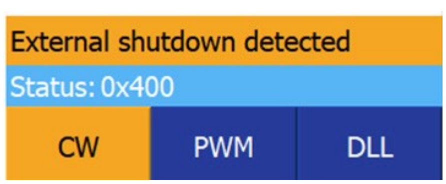
- In the 'Home' menu take a look at the status bar in the lower right area of the GUI to see if there are anyerrors.



- In the 'Settings' menu take a look at the bottom row to see the version of the signal generator board'sfirmware as well as the version of the GUI software.



In this case the firmware version on the ISC-2425-25+ is v1.11.0 and there are no pending errors.If there were an error, it would be displayed on the GUI like so:



The GUI automatically attempts to clear errors. If any errors persist, that means there is an ongoing problemwith the setup that must be resolved before continuing.

2.5 Step 4 – Find the best frequency for RF energy delivery

Now you have the GUI installed you will want to run your first application. During an RF heating process, the user wants to make sure that the available RF energy is used optimally to heat up the load (the chosen material). In a typical application, this is not a trivial thing to do: The frequency where energy is effectively transferred into the load is called the “match” and needs to be determined. A good match means most of the RF energy is absorbed by the load, whereas a bad match means a large portion of the energy is reflected back into the RF generator system.

A match can be expressed in different ways depending on the units used to measure RF power. When measuring the power using dBm, the match is expressed as ‘S11’:

$$S11 = (P_{RFL} - P_{FWD})$$

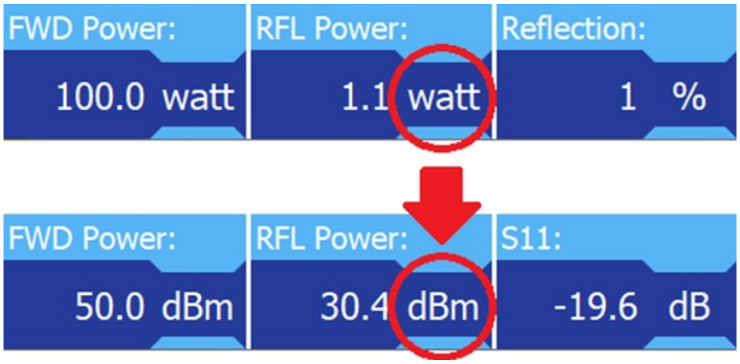
Here, S11 is expressed in dB, and the powers PFWD and PRFL are expressed in dBm.
A lower value of S11, the better. For example, a value of about -13dB would indicate that more than 95% ofthe forward RF power is used in the cavity.

When measuring the power using watts the match is expressed as “Reflection”:

$$Reflection = (P_{RFL} / P_{FWD})$$

The reflection has a value typically between 0 and 1, and is expressed as a percentage (%); The powersPFWD and PRFL are expressed in watt. The closer the reflection is to 0%, the better.

The GUI displays forward power, reflected power and reflection (%) or S11 (dB) in the lower left corner.Switching units (watt <-> dBm) is done by clicking the ‘unit’ button of any of the three displayed parameters:



Though this information is very useful, it alone is not sufficient to properly optimize the process. To find out the frequency at which to heat (i.e., the match), a frequency sweep should be performed to assess the S11 parameter across a pre-defined frequency band. This is done by briefly using low RF power and determining the S11 parameter at various frequencies over a given frequency range. The resulting data can be formatted into a graph that provides insight into the possible match within the tested frequency range.See figure 1 below.

In the example graph below, a 'minimum' S11 point can be seen around the 2450MHz range, this is the frequency where the reflection is closest to 0 and the RF energy delivery into the load/process would be the most efficient.

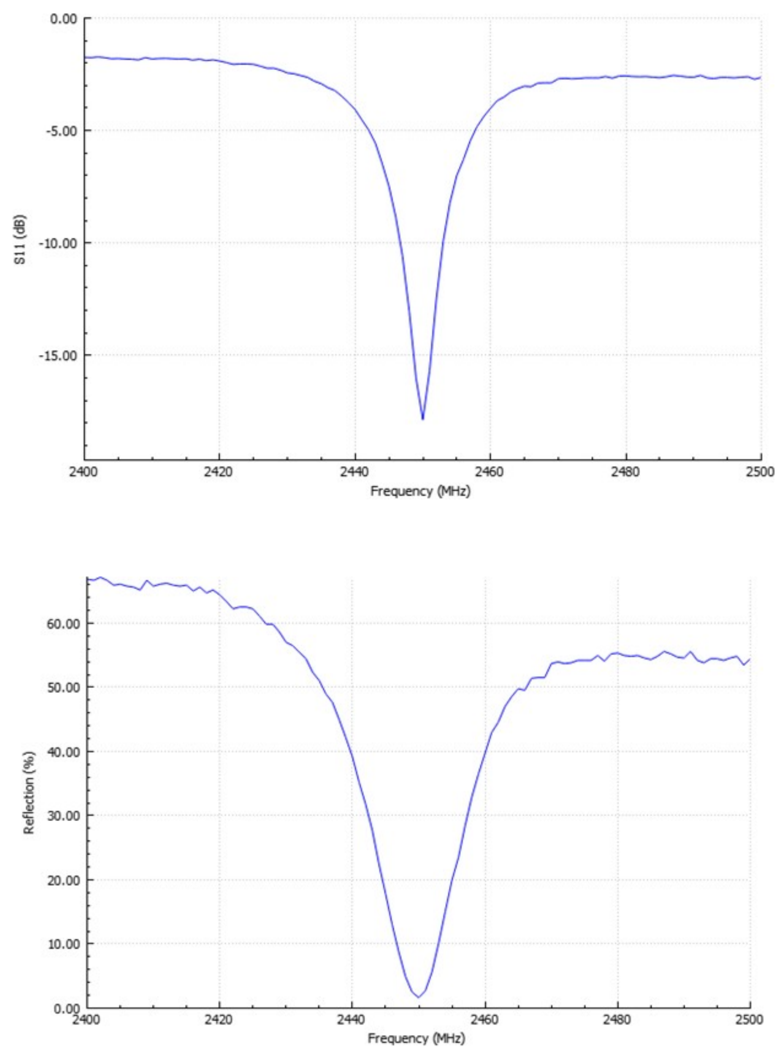


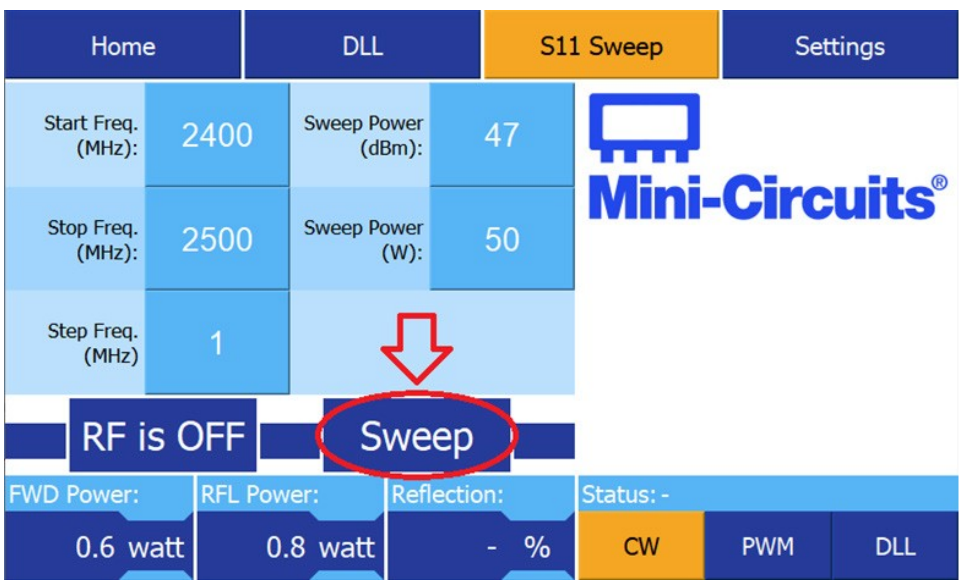
Figure 1: S11 (dB) vs frequency & Reflection (%) vs Frequency

Note: During the execution of a frequency sweep, reflected power will be generated at all mismatched frequencies; it is therefore best to perform the frequency sweep at a lower power than what is intended to be used for the actual heating process to avoid stressing the RF generator. Another reason to use low power is that the user does not want to already process the load during this characterization phase. Typical values of 5-10% of the intended processing power are recommended to be used for the characterization sweep(s).

The ISC-2425-25+ signal generator supports frequencies in the 2400 – 2500 MHz range.

In the example below, an S11 frequency sweep is performed at 50 watts, in the 2400 – 2500 MHz range, with a step size of 1MHz:

- Perform the sweep at 50 watts, in the 2400 – 2500 MHz range, with a step size of 1MHz
  1. Go to the Sweep menu.
  2. Configure the sweep parameters appropriately.
     a. Press the button for each parameter.
     b. Provide input values using the numpad that appears on the right side.
     c. Press 'OK' to confirm inputs.
  3. Press the Sweep button to perform the S11 frequency sweep.



After performing a Sweep, the GUI visualizes the sweep data as a graph (see figure 2 below). The lowest point in the graph represents the best match. In this case that is at 2470MHz, where the reflection amountsto roughly 12%.

Note: To return to previous page of the sweep menu, press the 'back' button in the top left.

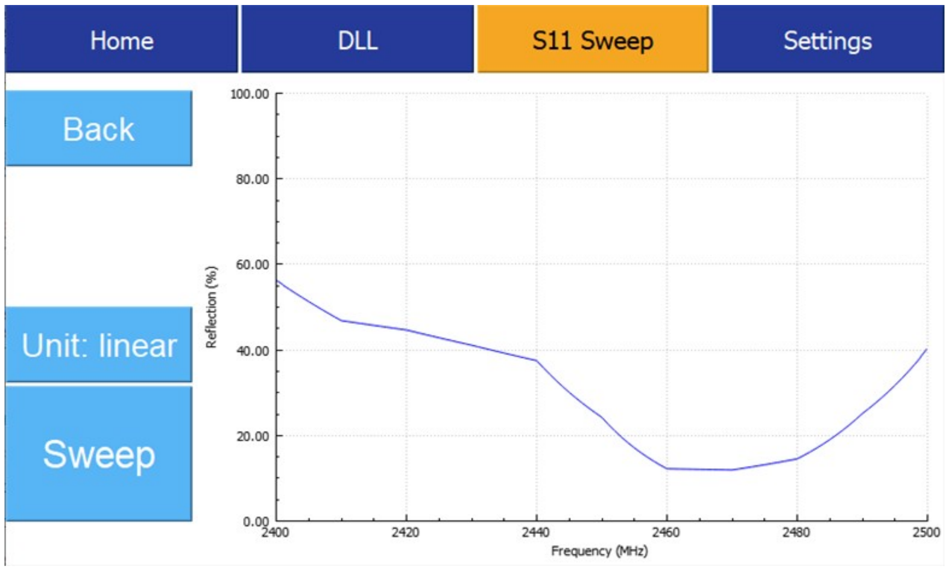
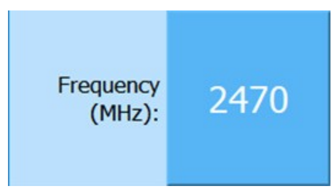


Figure 2: Resulting reflection (%) graph from the sweep just defined

Now that the best match frequency has been found, the frequency of the ISC-2425-25+ board needs to bechanged to 2470MHz.

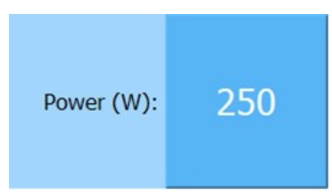
- Go to the home menu and set the frequency to 2470MHz.



2.6 Step 5 – Configure power

For this example, the chosen material will be heated with maximum available power. The Mini-CircuitsZHL-2425-250X+ PA is a 250W model, so 250W output power will be used.

- Set the power to 250W.



2.7 Step 6 – Start heating

With the right frequency and power configured, the RF output may now be switched on.

Note: Before turning on the RF output, ensure the RF cannot leak from the cavity.Press the

RF ON/OFF button to enable RF.

2.8 Step 7 – Use the digital locked loop (DLL) to track the best match frequency real time

With the right frequency and power configured, the RF output may now be switched on.

Note: Before turning on the RF output, ensure the RF cannot leak from the cavity.Press the RF ON/OFF button to enable RF.

The material in the cavity is now being heated at the optimized frequency.

The GUI displays a forward power of 250W, a reflected power of 30W and a reflection value of 12%, meaning the material is absorbing some 220W of RF energy. This is in line with the earlier sweep measurement.

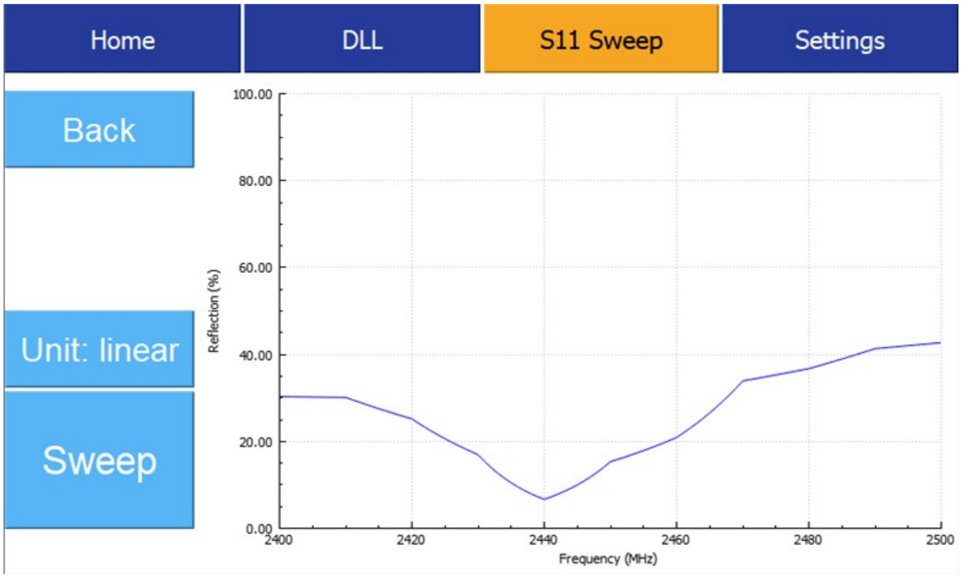
2.9 Step 7 – Use the digital locked loop (DLL) to track the best match frequency

As the material continues to heat, its physical properties may start changing. Changes to the load can affect the quality of the match: the best match frequency will shift to a different value. It is more than likely that after a while the match is no longer optimal, and the load reflects too much energy back into the system. Obviously, this is not a desirable situation.

- To avoid straining the system with a poor match, turn off RF output for the time being.

Conveniently, the ISC-2425-25+ board provides a method that tracks the processing frequency as the match changes over time: this is called the “digital locked loop” (DLL). The next few paragraphs describe the usage of this DLL feature. (see Apps Note: “appsNote DLL”)

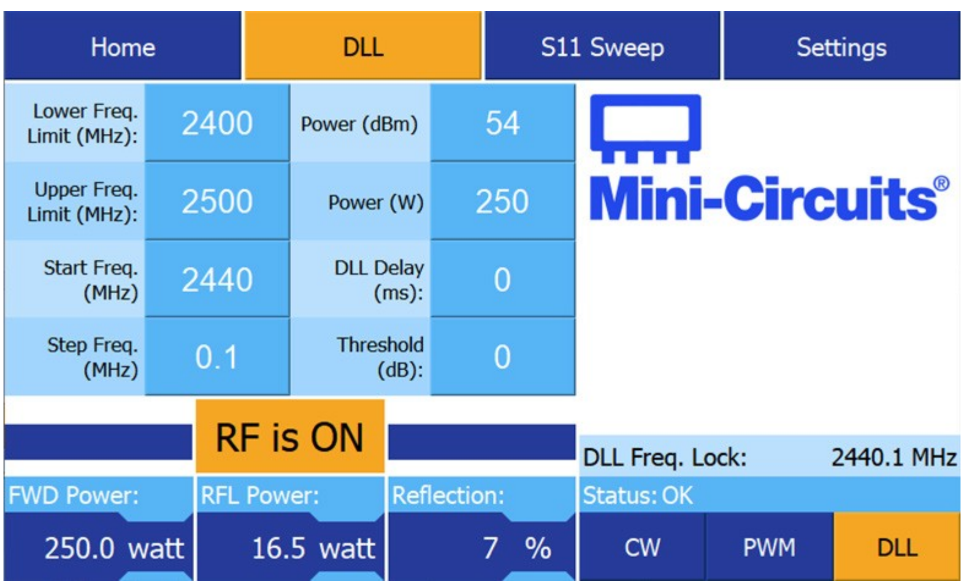
- Perform an S11 frequency sweep to determine the starting frequency for the DLL algorithm



The sweep indicates the best match frequency has shifted towards 2440MHz, where the reflection value is a mere 6.6%. Please note that the reflection at the previously configured 2470 MHz has increased to almost34% in the meantime.

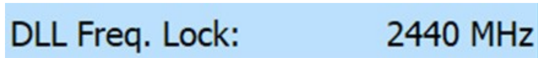
To enable the real time tracking, we will enable the DLL algorithm to do the frequency tracking for us.

- Go to the DLL menu
- Configure the start frequency to 2440 MHz
- Press the DLL enable button in the bottom right corner of the GUI to turn on the DLL.
- Enable RF output.



The DLL is now enabled and is tracking the optimum S11 frequency as the material heats.

The currently used (locked-) frequency for the DLL can be viewed live on the right side of the GUI in the ‘DLL Frequency Lock’ bar (or alternatively at the frequency parameter in the home menu).



Finish:
With the frequency optimized, the chosen material will be processed as per the user requirements. Of course, the exact timing of this process depends on the size of the material and the RF power used and needs to be determined in by the user.

3. Quick Start (Serial Terminal Interface)

The entire process of the quick start will be repeated now, but this time using the terminal emulator program 'PuTTY' instead. The scenario is the same as before (See chapter "2 Quick Start (GUI)") except forthe software used.

When using the command language to control the ISC-2425-25+ the user has the option to create and save their own individual recipes to support their specific applications.

3.1 Step 1 – Assemble the hardware

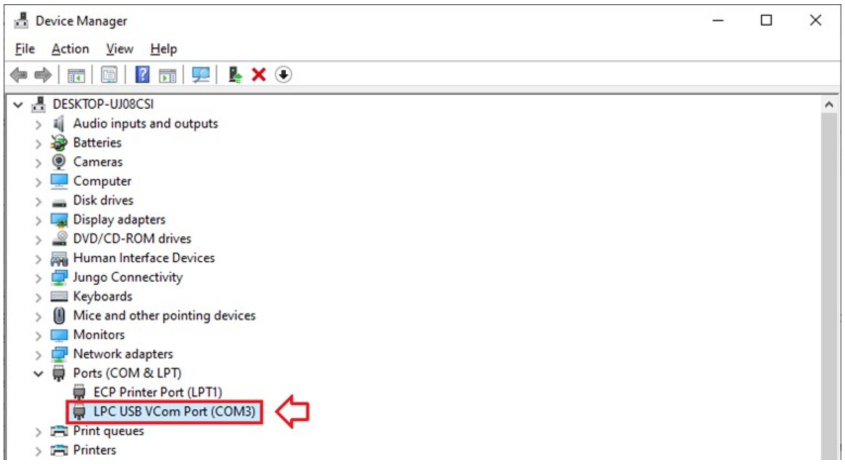
The physical requirements and the assembly of the components are the same as before (See chapter "2.1 Step 1 – Assemble the hardware"), however instead of the Mini-Circuits GUI, the ISC's command set is used to operate the generator. This is achieved by using the terminal emulator program PuTTY.

- PuTTY SSH and telnet client free
  open-source software
  Windows download available here: https://www.chiark.greenend.org.uk/~sgtatham/putty/latest.html Linux variants available through the package manager.
- Download example (Debian):
  sudo aptitude install putty
  Additional information available here: https://www.ssh.com/academy/ssh/putty/linux

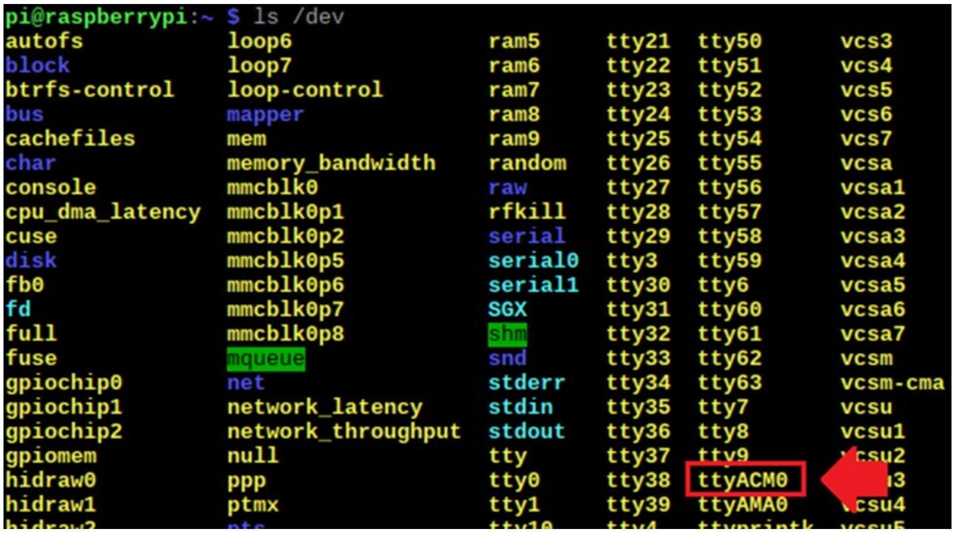
3.2 Step 2 – Set up communication

1. Plug the ISC-2425-25+ board into the PC using a mini-USB cable.
2. Find the port name of the device

- **Windows:**
  Open the 'Device Manager' in Windows and find the port name of your device.It will show up as an 'LPC USB VCOM Port', followed by the port name.

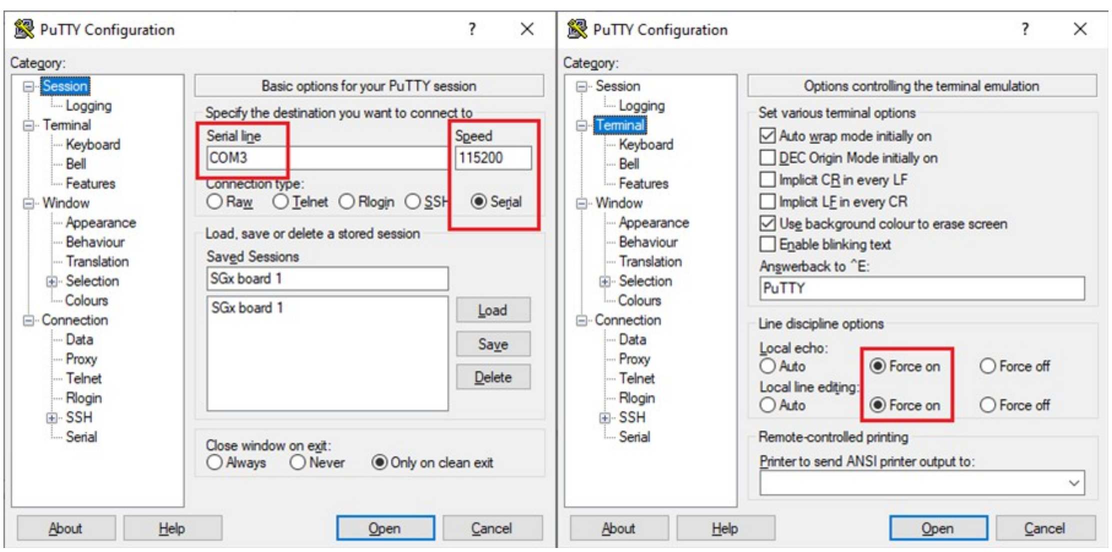


- **Linux:**
  Open a terminal (CTRL + ALT + T) and use the “ls /dev” command to view available devices. The signalgenerator board should appear as a ‘ttyACM’ device followed by a number.



3. Open PuTTY on your PC and provide the necessary information for the connection with the device. It ishighly recommended to configure the settings ‘Local echo’ and ‘Local line editing’ to ‘Force on’.

Note: Linux requires the full path to the port (e.g., “/dev/ttyACM0”).



Save the session, so that it won’t need to be reconfigured again in the future and press ‘Open’ to start aconnection with the ISC-2425-25+ board.

A blank terminal window will pop up.

3.3 Step 3 – Check system status

Before applying RF, take a moment to gather some data about the system to verify proper functioning:

- Send the $VER command to view the firmware version of the ISC-2425-25+ board.
- Send the $ST command to check if there are any errors.

```
$VER,1
$VER,1,PRF,1,10,4,SVN_REV,Feb 23 2021,14:47:38
$ST,1
$ST,1,0,0
```

In this case, the firmware version is v1.10.4 and there are no errors pending.

If the $ST command were to return an error value (for example "$ST,1,0,400"), use the $ERRC command to reset errors, then send $ST again to see if the errors did not reappear.

```
$ST,1
$ST,1,0,400
$ERRC,1
$ERRC,1,OK
$ST,1
$ST,1,0,0
```

If any errors persist, that means there is an ongoing problem with the setup that must be resolved before continuing. All error/warning codes are explained in the "Command set manual".

3.4 Step 4 – Find the best frequency for RF energy delivery

During an RF heating process, the user wants to make sure that the available RF energy is used optimally to heat up the load (the chosen material). The frequency where energy is effectively transferred into the load is called a "match" and needs to be determined. A good match means most of the RF energy is absorbed by the load, whereas a bad match means a large portion of the energy is reflected back into the RF generatorsystem.

To find out the best frequency at which to heat (i.e. a good match), a frequency sweep should be performed to assess the S11 parameter across a pre-defined frequency band.

The ISC-2425-25+ small signal generator supports frequencies in the 2400 – 2500 MHz range.

In the example below, an S11 frequency sweep is performed at 50 watts, in the 2400 – 2500 MHz range, with a step size of 10MHz:

- Use the $SWP command to perform an S11 frequency sweep in watts.

```
$SWP,1,2400,2500,10,50,0
$SWP,1,2400.00,49.95,28.08
$SWP,1,2410.00,49.96,23.40
$SWP,1,2420.00,49.98,22.32
$SWP,1,2430.00,49.97,20.54
$SWP,1,2440.00,50.01,18.75
$SWP,1,2450.00,50.00,12.12
$SWP,1,2460.00,50.02,6.11
 SWP,1,2470.00,50.04,5.92
$SWP,1,2480.00,50.03,7.27
$SWP,1,2490.00,50.00,12.56
$SWP,1,2500.00,49.99,20.12
$SWP,1,OK
```

Input

Response

The command ($SWP,1,2400,2500,10,50,0) returns forward and reflected RF powers in watts at 10MHz intervals, which show that the match is best around 2470MHz. At that frequency the reflection is only around 12% of the forward power (5.92W / 50.04W = 0.118 → 12%).

Note: For the sake of this guide, a large step size is used in the sweep to keep the resulting data easy to work with. Under normal circumstances a smaller step size like 1 MHz is recommended as it would yield a better resolution along the frequency axis.

Tip: In general, large loads will generate "broad", generally well-matched S11 sweeps, whereas small loadswill generate a more structured S11 spectrum with only few frequencies allowing efficient energy delivery.

Now that the best match frequency has been found, the frequency of the ISC-2425-25+ board needs to bechanged to 2470MHz.

- Use the $FCS command to set the frequency to 2470MHz.

```
$FCS,1,2470
$FCS,1,OK
```

3.5 Step 5 – Configure power

For this example, the material will be heated with the maximum available power. The Mini-Circuits ZHL-2425-250X+ PA is a 250W model, so 250W output power will be used.

- Use the $PWRS command to set the power to 250W.

```
$PWRS,1,250
$PWRS,1,OK
```

3.6 Step 6 – Start heating

With the right frequency and power configured, the RF output may now be switched on.Note:
Before turning on the RF output, ensure the RF cannot leak from the cavity.

- Use the $ECS command to turn on RF output.

```
$ECS,1,1
$ECS,1,OK
```

The material is now being heated. According to the 12% reflection value calculated in the earlier step, the load is absorbing some 220W of RF energy and reflecting around 30W back into the RF system. This can be monitored on the fly using the $PPG command:

- Use the $PPG command to get live power measurements.

```
$PPG,1
$PPG,1,249.89000,29.76000
$PPG,1
$PPG,1,250.02000,29.92000
$PPG,1
$PPG,1,250.10000,30.32000
$PPG,1
$PPG,1,249.79000,29.78000
```

The measurements align with expectations: 250W forward power is emitted, 30W is reflected back,220W is absorbed by the load.

3.7 Step 7 – Use the digital locked loop to track the best match frequency

As the material continues to heat, its physical properties will start changing. Changes to the load can affect the matching conditions: the best match frequency will shift to a different value. It is more than likelythat after a while the match is no longer optimal, and the load reflects too much energy back into the RF generator. Obviously, this is not a desirable situation.

- To avoid straining the system with a poor match, turn off the RF output for the time being.

```
$ECS,1,0
$ECS,1,OK
```

The available DLL tracking algorithm resolves the issue.

- Perform an S11 frequency sweep to determine the starting frequency for the DLL algorithm.

```
$SWP,1,2400,2500,10,50,0
$SWP,1,2400.00,49.88,15.11
$SWP,1,2410.00,49.95,15.04
$SWP,1,2420.00,50.00,12.59
$SWP,1,2430.00,49.99,8.47
$SWP,1,2440.00,49.97,3.32
$SWP,1,2450.00,49.94,7.65
$SWP,1,2460.00,50.01,10.45
$SWP,1,2470.00,49.80,16.88
$SWP,1,2480.00,49.99,18.36
$SWP,1,2490.00,50.00,20.67
$SWP,1,2500.00,49.99,21.35
$SWP,1,OK
```

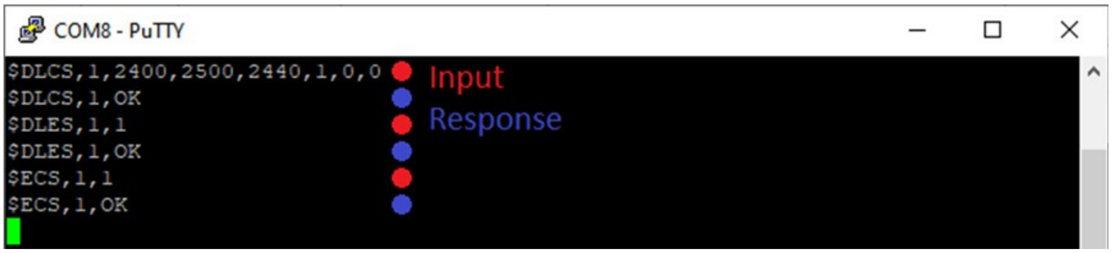
Input

Response

The sweep indicates the best match frequency has shifted towards 2440MHz, where the reflection valueis a mere 6.6% (3.32W / 49.97W = 0.066 → 6.6%). Please note that the reflection at the previously config-ured 2470 MHz has increased to almost 34% in the meantime.

Going forward, the DLL algorithm will do the frequency tracking:

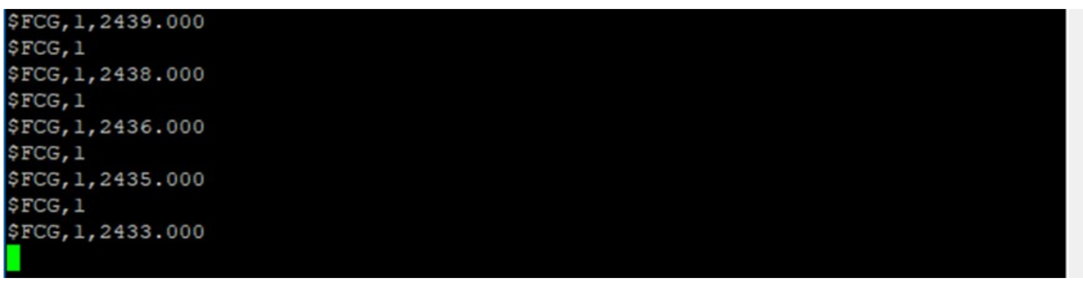
- Use the $DLCS command to configure DLL to start tracking at 2440 MHz (at the best-known match).
- Use the $DLES command to turn on DLL.
- Use the $ECS command to turn on RF output again.



The DLL is now enabled and is tracking the optimum S11 frequency as the material heats.

The momentarily used (locked-) frequency for DLL can be viewed using the frequency get command.

- Use the $FCG command to view the frequency as it changes over time.



This shows the DLL is tracking the match downward in frequency as the best match frequency continuesto shift over time.

Finish:

With the frequency optimized, the material will be processed as per the user requirements. Of course, theexact timing of this process depends on the size of the material and the RF power used and needs to be determined by the user.