Mini-Circuits®

ISC-2425-25+
GUI User Manual

AN-50-007

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1. Introduction

This document describes in detail how the GUI works with the Mini-Circuits system controller and signal generator, the Mini-Circuits' ISC-2425-25+ module. The Graphical User Interface (GUI) is intended for use in single channel systems.

The GUI acts as the primary Human-Machine Interface between the user and the ISC board.

The intent of the software is to offer a safe, intuitive and powerful all-in-one GUI, which can make full use ofall the ISC board's capabilities.

Below is a basic overview of the GUI's supported features.

Features	Details
Operational modes	Continuous Wave
	Pulse Width Modulation;
	Digital Locked Loop when in the modes above.
Advanced modes	Remote Command Mode
	Chain/Coherent Mode
	External Triggering Mode
Frequency range	2400 – 2500 MHz
Power range	Hardware-dependent; Varies per PA model.
Temperature readout	In degrees Celsius (°C)
Power measurement	in watt and dBm
S11 measurements	Logarithmic (dB) and linear (percentage)
S11 frequency sweepingand graphing	Logarithmic (dB) and linear (percentage)

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2. Graphical User interface

This chapter describes how the GUI works and what can be done in each menu. The GUI is built to bemodular, so that different features can be made available or hidden depending on the use-case.

2.1 Basic menu layout
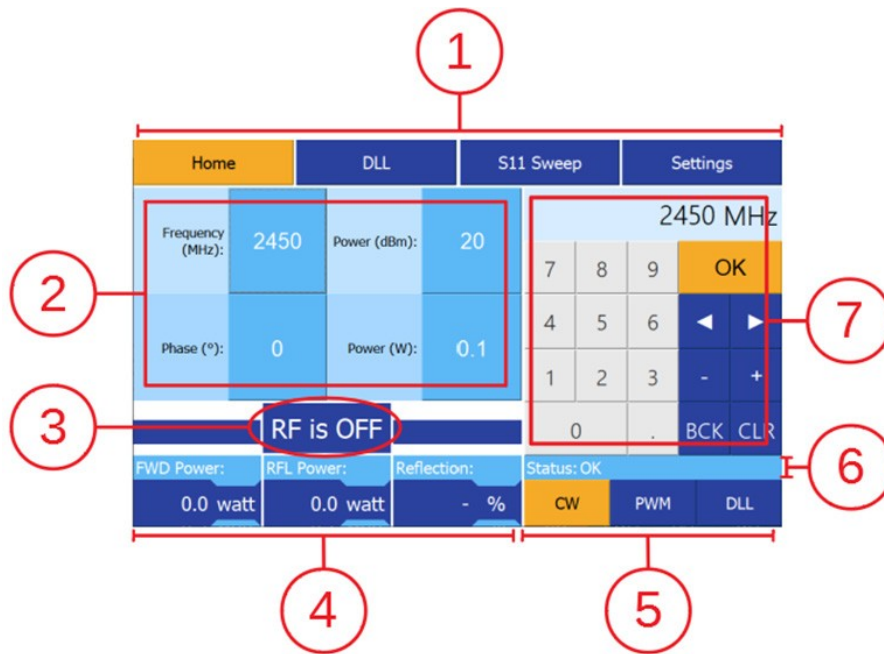
①. Menu buttons
The menu buttons are used to navigate the various tabs of the GUI. These buttons are visible at all times and on any tab. There are four menus in total:

• Home

• DLL

• S11 Sweep

• Settings

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

②. RF system parameter controls
These buttons are used to configure the parameters of the RF system. Each menu has different buttons to configure different aspects of the system. Buttons for numeric inputs will cause a numeric keypad to appear onscreen, which makes user input possible. Buttons for ON/OFF inputs, will directly switch between ON/ OFF states.

③. RF Power button
This button enables or disables the RF power output of the ISC board.

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④. Power Readings

This section is composed of indicators for forward power, reflected power and the reflection or S11. The area where watt (or dBm) is written can be pressed to change the unit of measurement between logarithmic (dBm) and linear (watt) scale.

⑤. Operational Mode selection

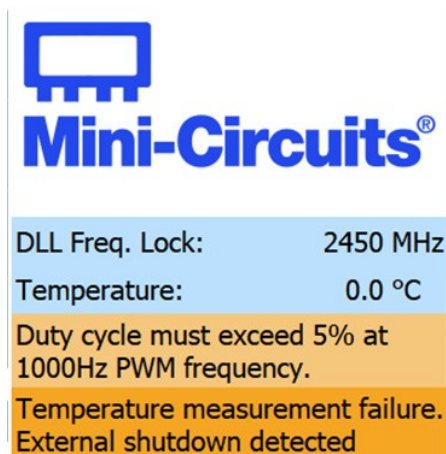These buttons determine the operational mode of the connected ISC board.

- CW / Continuous Wave – Generates a continuous wave signal with the possibility to change the fre-quency, power and phase of the wave.

- PWM / Pulse Width Modulation – Alternates the RF signal between ON and OFF state in quick succes-sion to regulate the RF output.

- DLL / Digital Locked Loop – On/off control for the DLL algorithm.

⑥. Status indicator

This indicator shows the status of the RF channel. If an issue occurs a number is displayed corresponding to an error on the ISC board. A warning message will also be displayed in the warning/notification area, explaining the details of the error.

⑦. Messages and indicators / numeric keypad

Initially the right side of the screen displays a few indicators and informative messages, but when a numeric parameter button is pressed the section changes into a numeric pad for inputting values.

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The indicators and message section can include the following:

- DLL lock-on frequency read-out
- Temperature read-out
- Notification messages
- Warning messages

The numpad has the following buttons:

- 0-9 → Input the respective number.
- . → Add a decimal point.
- OK → Apply inputs and close the numpad.
- ◀ → Move the indicator to the left.
- ▶ → Move the indicator to the right.
- \+ → Increment underlined digit by 1.
- \- → Decrement underlined digit by 1.
- BCK → Remove the last value in entry field.
- CLR → Clear the entry field.

The input is previewed in the field at the top of the numpad. When the OK button is pressed, the input is applied and the numpad is hidden from view again.

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2.2 Home menu

The home menu hosts the basic controls of the RF System. The controls on this menu are used to change the most common properties of the RF signal. By default, only the controls for continuous wave (CW) mode are visible, additional controls become available when other operational modes are selected.
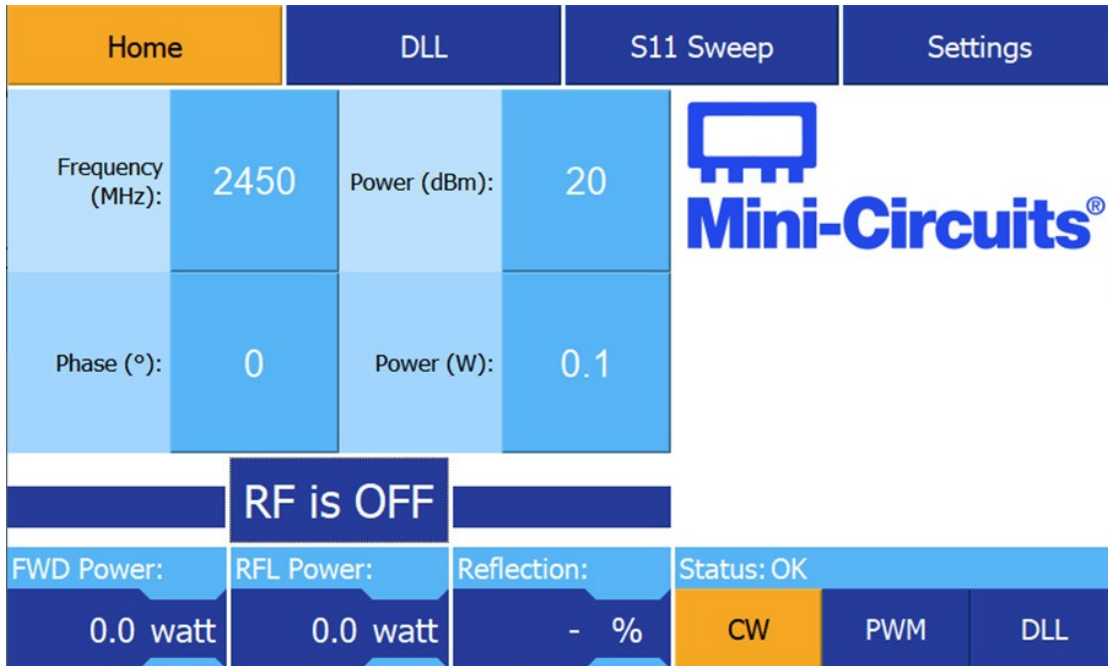
There are four basic operation modes supported by the GUI (these are explained in more detail in chapter 3 of this manual). Below are the parameters that can be configured from the home menu for each of these basic operation modes.

Continuous Wave (CW):
- RF power in dBm
- RF power in watt
- Frequency of the signal in MHz
- Phase of the signal in degrees

Pulse Width Modulation (PWM):
- PWM frequency in Hz
- PWM duty cycle in percent

When PWM mode is enabled the power readings on the bottom-left report the peak power, rather than the average.

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Digital Locked Loop (DLL):

In addition to the CW & PWM operation modes a DLL algorithm can be used to track the best matching conditions during the process in both CW & PWM. (for more details on the DLL functionality, refer to the App Note: "ISC-2425-25+ appNote DLL")

- DLL step in MHz

- DLL threshold in dB

When DLL mode is enabled, a dedicated DLL frequency tracker appears in the bottom right area of the GUI, which remains across multiple menus. It shows what frequency the DLL has locked onto. The frequency parameter in the home menu will also mirror the lock-on frequency and can additionally be used to correct/ steer the DLL algorithm if it locks onto a local minimum.

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2.3 DLL Menu

The DLL menu serves as a control panel for the DLL mode.

The DLL menu has the same layout as the Home menu but hosts a new set of parameter controls relating to the DLL mode.

- The following parameters can be set from the DLL menu:
- Power in dBm (same as value in home menu)
- Power in watt (same as value in home menu)
- Upper frequency limit in MHz
- Lower frequency limit in MHz
- Start frequency in MHz
- DLL step offset in MHz
- DLL threshold in dB (same as value in home menu)
- DLL algorithm loop delay in milliseconds

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2.4   Sweep Menu

The sweep menu allows the user to configure the parameters for an S11 frequency sweep. An S11 sweep measures the forward and reflected powers across a frequency band specified by the user, calculates the S11 or reflection and generates a graph to visualize the results.
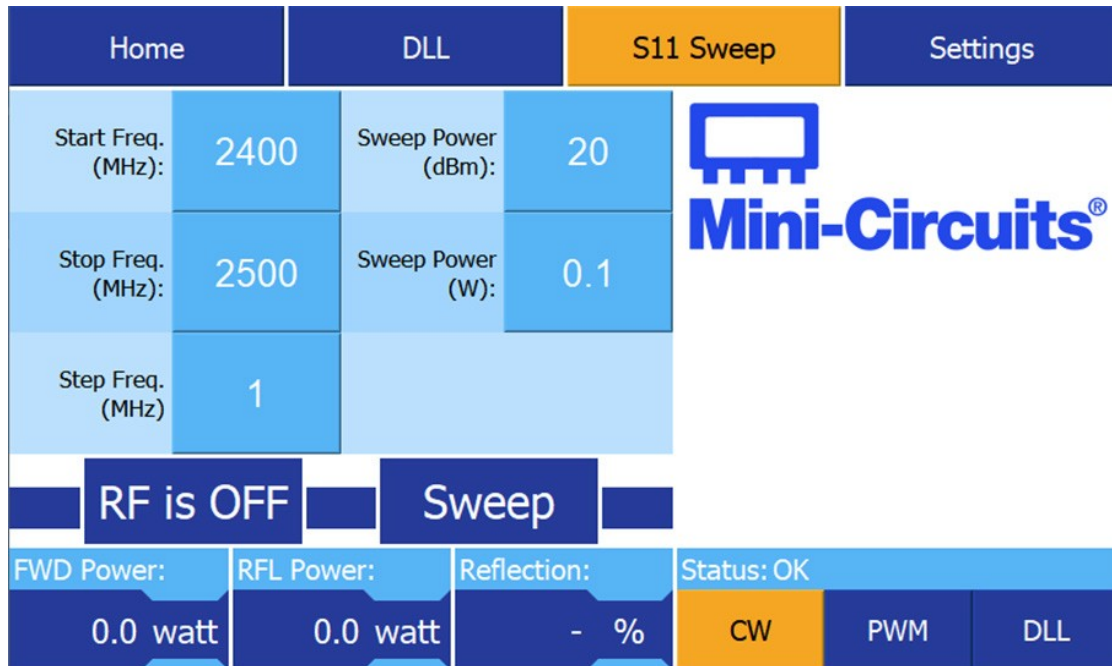
The sweep menu has almost the same layout as the Home menu but hosts a new set of parameter controls relating to the S11 Sweep. Additionally, a 'Sweep' button can be found next to the existing RF enable button. Pressing this button will execute the S11 frequency sweep with the provided parameters and lead to the second page of the sweep menu. As a safety precaution the RF output is automatically disabled after performing the S11 sweep.

The following parameters can be set for the S11 sweep:

- Sweep Power in dBm
- Sweep Power in Watt
- Start frequency in MHz
- Stop frequency in MHz
- Step frequency in MHz

The S11 sweep supports a preconfigured number of measurements (maximum of 201), meaning the minimum value of the step frequency depends on the frequency range to be measured. E.g., at 201 measurements, in a 100MHz range the step could at its lowest be 0.5MHz; In a 20MHz range the step frequency could go as low as 0.1MHz. The preconfigured number of measurements is adjusted for differing PA specifications.

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Note that the 'Sweep Power' parameters on this screen are not the same as the RF Power settings in the other menus. Altering the power values for the S11 sweep will not cause any currently active power level tochange.

The second page of the sweep menu displays a graph of the S11 or reflected power (%) across the specifiedfrequency band.
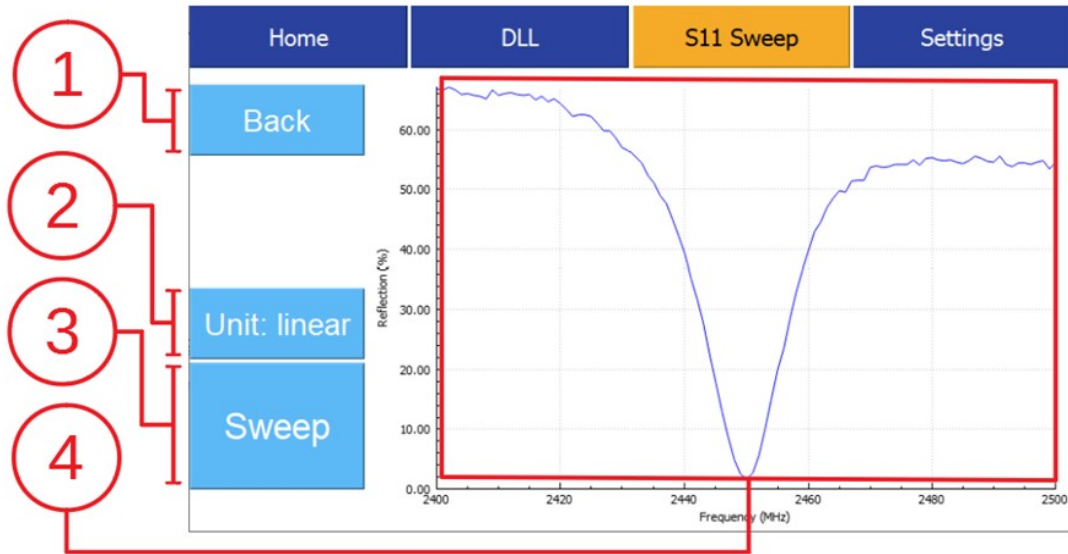
Screen elements explained:

① **Back button**
Returns the user to the first page of the Sweep menu.

② **Unit selection button**
Changes the unit / scaling of graph between logarithmic and linear.

By default, the notation of the graph is the same as the notation of the power readings on the previous page of sweep menu.

③ **Sweep button**
Run another sweep with the same sweep parameters.

④ **S11 graph**
Visualizes the S11 response of the attached RF load within the selected frequency band.

- Displays a reflection (%) for linear scale / watt notation

- Displays the S11 (dB) for logarithmic scale / dBm notation

2.5 Settings Menu

The settings menu lets the user configure the "advanced modes" of operation and view the software and firmware version of the system.

As a precaution, the RF output is automatically disabled when the settings menu is selected.

① Power Control Mode
Allows the power regulation of the generator system to be switched between automatic gain control (default operation) and manually controlled power settings.
- **[Normal]** – automatic gain control mode
- **[Feed FWD]** – manually set VGA and modulator power settings

② Chain Mode (Coherent)
Allows the ISC to be set as either a stand-alone unit or to act as a master or slave within a set of coherent controllers. Each controller can have its own GUI visible on your computer.
- **[OFF]** – ISC board uses its own low frequency clock signal.
- **[Master]** – ISC board uses its own low frequency clock signal and also provides the signal to the next slave device.
- **[Slave]** – ISC board accepts a low frequency clock signal from another device and also provides it to the next slave, allowing a chain of slave devices.

③ Remote Command Mode
Allows the user to control the RF system by sending command set compliant messages from another device such as a computer directly to the ISC board in the system.
- **[OFF]** – ISC board cannot be controlled remotely.
- **[USB]** – ISC board is controlled remotely by sending commands via the USB interface on the user's hardware. USB mode requires a 'null-modem' USB cable to work.
- **[TCP]** – ISC board is controlled remotely by sending commands via the Ethernet interface on the user's hardware. Enables control over a network.

④ Information area
Provides feedback and information regarding remote command mode.

⑤ Version indication
Shows the version of the GUI software and SG Board firmware.

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3. Basic Operational Modes

The GUI has (up to) four basic operational modes available depending on its configuration:

- Constant Wave
- Pulse Width Modulation
- Digital Locked Loop (for both CW and PWM)

This chapter will provide a description of the functionality of each of these operational modes.

3.1   Constant Wave

Constant wave (CW) mode is the most basic operational mode of the GUI. As its name implies the RF system will generate a constant RF signal. In CW mode it's possible to configure the frequency, power andphase of the signal.

3.2   Pulse Width Modulation

Pulse Width Modulation (PWM) allows the user to modulate the RF signal, and in turn the average power output of the system, by turning the signal ON and OFF at a set rate.

The following two parameters are used to achieve this:

- PWM frequency – Dictates how often the signal switches between ON and OFF.
- PWM duty cycle – Dictates the time ratio between ON and OFF of each period.

Depending on the duty cycle, the average power output of the system will decrease to a percentage of its set output. For example, 50% duty cycle at 80W results in an average RF power output of roughly 40W.

The PWM frequency and duty cycle are dependent on each other. The PWM frequency can vary between 1000 Hz – 19800Hz. To ensure accurate power readings (and therefore accurate power output), the minimum value of the duty cycle changes along with the PWM frequency according to the following formula:

$$Duty\ Cycle_{min} = ROUNDUP(f_{PWM} * T_{min\ pulse}/10,000,000)$$

Where:

- DC_{min} is the minimum duty cycle as a percentage.
- f_{PWM} is the PWM frequency between 1000 and 19800 Hz.
- $T_{min\ pulse}$ is the minimum pulse length in nanoseconds. $T_{min\ pulse}$ = 50000 ns.

This means that at 1000 Hz, the minimum duty cycle is 5% and at 19800 Hz it is 99%. Going over thisfrequency value would effectively disable PWM, as the minimum duty cycle becomes 100%.

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3.3   Digital Locked Loop
(see App Note: "ISC-2425-25+ appNote DLL")

The Digital Locked Loop (DLL) is an algorithm on the ISC board's microcontroller. It tunes the RF signal towards the best matched frequency within a user-defined frequency range. The DLL is suitable for driving applications with changing impedance conditions. The algorithm utilizes a feedback loop, based around the forward and reflected powers of the RF channel. The DLL operates in in two stages:

First stage: Acquisition

During the acquisition stage, the DLL probes frequencies across the user-defined frequency range, seeking the first frequency that meets the user-defined return loss threshold (dB). The algorithm moves from high to low frequency beginning at the user-defined starting frequency and will loop around indefinitely if no suitable match is found. When a suitable frequency is found that meets the threshold (i.e., local minimum), the DLL will immediately proceed to the second stage.

Second stage: Tracking & Finetuning

During the tracking stage the DLL's goal is two-fold:

1. Fine-tune the frequency towards the best-matched frequency around the local minimum.

2. Remain locked to a frequency which meets the threshold for return loss.

During this stage the frequency will be referred to as the 'locked' frequency and the frequencies directly adjacent to the "locked freq" will be called its 'neighbour' frequencies.

The DLL algorithm probes the neighbouring frequencies to check if any of them measure a better match than the locked frequency; f this is the case, the DLL algorithm shifts the locked frequency towards the new 'sweet spot'. In this way DLL quickly adjusts towards the best-matched frequency.

Certain RF loads may have changing impedance conditions which will cause the best-matched frequency of the RF system to shift along the frequency band. By continuously comparing the "locked" frequencies' S11 value to the S11 conditions of its neighbours, the DLL algorithm can dynamically follow the changing impedance conditions of its load, while retaining the best energy delivery efficiency for the process.

If the locked frequency's match can no longer satisfy the S11 threshold, the DLL algorithm reverts to the Acquisition stage.

Note: Leaving the device running in the acquisition stage (for example by having too demanding a threshold value) results in the RF System looping across the defined frequency band. This may strain the RF system and can have adverse effects on both the system and the attached load.

Tip: The above behaviour can be avoided by configuring the threshold value to 0. Then virtually any match will meet the DLL's threshold and the algorithm will immediately proceeds to the 2nd stage. It will shift towards the best match frequency it can find, but with the downside that it may lock onto a non-ideal local minimum. This latter problem can be mitigated by performing periodic frequency sweeps to keep track of the overall system status.

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4. Advanced modes explained in more detail

The GUI supports a few advanced operational modes depending on its configuration:

- Remote Command Mode
- Chain/coherent Mode
- Forward Control Mode
- External Triggering Mode

These modes allow the system to be used in additional ways. This chapter provides a description of thefunctionality of each of these advanced modes.

4.1 Remote command mode

In remote command mode (RCM) the user can communicate directly with the ISC board connected to the computer running the GUI using the DMC command set (please refer to the 'DMC Command Set' that is described in the Command Program Manual. The GUI simply passes all outside communication directly along to the connected ISC board.

This functionality is useful for experimentation, testing and automation purposes, especially when the ISC board is integrated in a system without easy physical access.

When RCM mode is enabled, the GUI becomes temporarily locked to the settings menu, and all non-RCM buttons are made unavailable.

RCM supports two interfaces: TCP and USB.

TCP

In TCP mode, a device can be directly connected to the user's hardware e.g. RPi, with a regular ethernet cable. It's also possible to connect the user's hardware to a network and reach it from other devices on thesame network.

When TCP RCM mode is enabled from the GUI's settings menu, the software will display the IP and port number of the user's hardware. This information is necessary to connect a device to the GUI. The user must provide the information to the external device they wish to use (e.g., a laptop with PuTTY, see GUI download info). If an external device has successfully connected to the GUI, its IP address will be displayed in the settings menu.

USB

To use remote communication over USB, the user's hardware running the GUI software must see the connected device as a COM port interface. For this reason, most setups require the use of a USB 'null modem' cable between the user hardware and the remote host to work correctly.

An 'FTDI-chip USB NMC-2.5m' null-modem cable is commonly used for this purpose:
https://www.ftdichip.com/Support/Documents/DataSheets/Cables/DS_USBNMC.pdf

It can be purchased here: https://www.ftdichip.com/Products/Cables/USBtoUSB.htm

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4.2 Chain/Coherent mode

Chain/coherent mode allows an ISC board to be configured as stand-alone or master or slave in a chain of ISC controllers. This is useful for specific use-cases such as phase-coherent heating.

In chain mode, one system must be configured as a master, and the others as slaves. The master system provides a low frequency clock signal to the first connected slave. The slave accepts the clock signal, and also shares it with the next in line slave. This continues until the end of the chain is reached. See the Application Note on coherence for more detail.
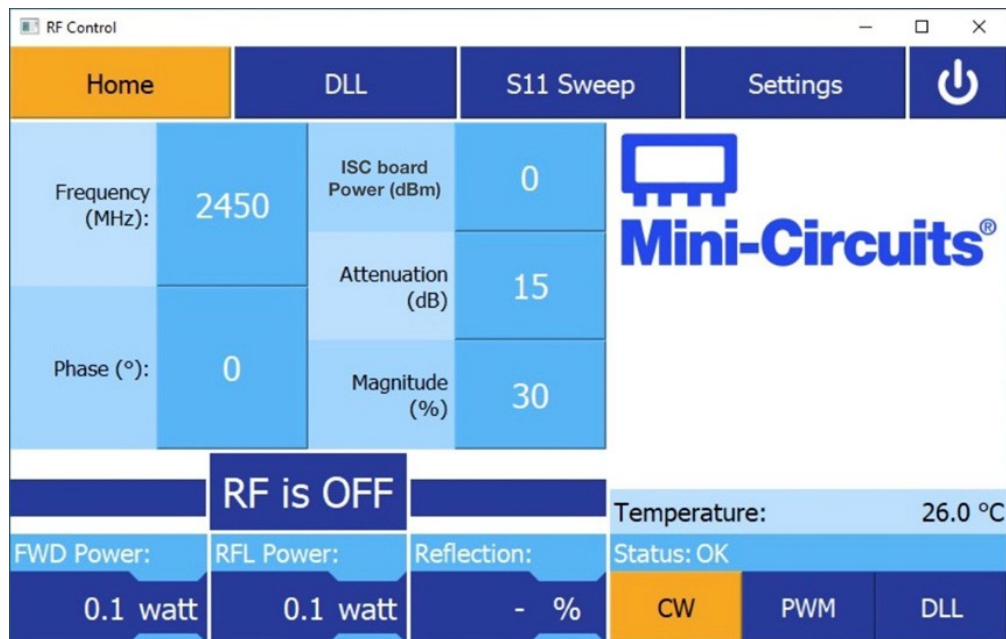
Forward control mode

In this mode, the autogain feature of the controller is switched off, and the user must determine the output power manually.

The GUI offers a changed "Home" tab that is show below:

The power buttons have changed into "Attenuation" and "Magnitude". These buttons program the VGA and modulator via the $GCS and $MCS commands, respectively, these are described in the datasheet with typical output power values for the ISC-2425-25+.

Alternatively, the button "SGx board Power" can be used to program the ISC output power in dBm's, the attenuation and magnitude will be adjusted accordingly. This button acts through the $PWRSGDS command.

Alternatively, the button "ISC board Power" can be used to program the ISC output power in dBm's, Note: the attenuation and magnitude will be adjusted accordingly. This button acts through the $PWRSGDS command.

External trigger mode

This mode puts the ISC into a state where it accepts external trigger pulses through pin 8 of the DSUB-9 connectors to switch the RF output signal according to the pulses provided. The RF output is on when the input is high and vice versa.

In this mode, the autogain feature of the controller is switched off, and the user must determine the output power via the $GCS and $MCS commands, respectively.

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