moglabs

Agile RF Synthesizer & AOM driver

XRF421

Revision 1.8.3
Serials A09xxx and newer
Firmware v1.12.2

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Preface

Acousto-optic modulators (AOMs) are an integral part of many laser-based experiments. They are used for frequency shifting, amplitude modulation, and laser frequency stabilisation. Many experiments require very simple control of the RF frequency and power, but others require sophisticated sequences. The MOGLabs XRF agile RF synthesizer provides such complexity with a user-friendly interface. The extraordinary capabilities of the XRF have not previously been available from any single supplier, let alone in a single unit. Two channels, with direct output of up to 4 W per channel. Wide frequency range of 20 to 400 MHz. Arbitrary frequency, amplitude and phase with high resolution. Analogue modulation of each channel, in frequency, amplitude, and/or phase, with 10 MHz bandwidth. Ergonomic front-panel controls, and ethernet/USB interface. Table-mode operation to define complex time-dependent waveform output. All in one box which connects directly to AC mains power and to your AOMs. As you delve into this manual you will uncover more and more capability, but the powerful FPGA at the heart of the XRF allows software improvements to add new features, so please check the MOGLabs website for updates, example code, and assistance.

We hope that you enjoy using the XRF, and please let us know if you have any suggestions for improvement in the XRF or in this document, so that we can make life in the lab better for all.

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www.moglabs.com

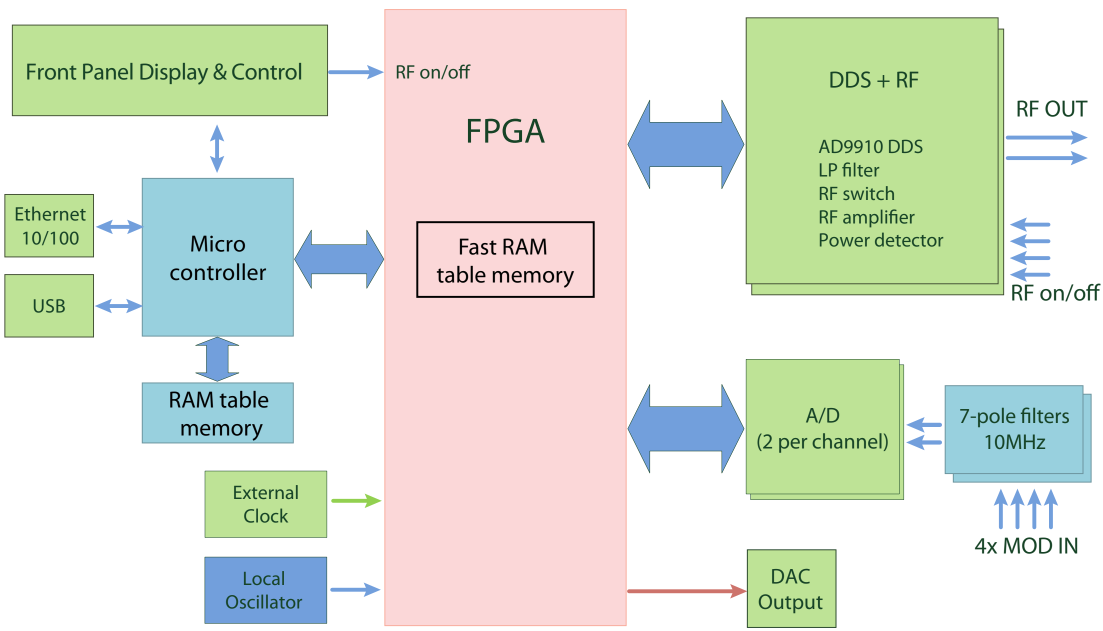
Contents

1. Introduction

The MOGLabs XRF consists of two independent AD9910 direct digital synthesizer (DDS) sources, each with 4 W amplifier. The frequency, amplitude and phase of each output is software-controlled via a microcontroller and FPGA (field programmable gate array).

This enables direct control of the frequency, amplitude and phase of the RF signals, which can be adjusted in real-time using the front-panel controls or via a scripting language over ethernet or USB. The RF parameters can be defined in a lookup table to enable complex sequences with very fast transitions.

The block diagram below shows the key components of the system.



The RF signal output from each DDS is low-pass filtered, pre-amplified, and then further amplified with a high-power output stage. The DDS chips are controlled by the FPGA. A microcontroller provides external interface with TCPIP and USB communications, and controls the front-panel display, rotary encoders (knobs) and push-buttons.

The device allows analogue modulation through two analogue-to-digital converters (ADC) with anti-aliasing filters. When modulation is enabled, the FPGA periodically reads the value of the modulation signal and uses that value to reprogram the DDS frequency, power and/or phase.

The XRF includes memory for storing complex waveform sequences, where each step in the sequence can include frequency, power, phase, time delay, and more complex definitions of ramps and other time-dependent functions. Complex capabilities can be accessed via either TCPIP or USB communications. See Chapter 3 for information on communications options and setup.

Once communications are established, the XRF can be controlled with simple text commands. The commands can be very basic, for example to define the frequency or power, or they can define complex dynamic sequences. Appendix C provides a summary of the available commands.

1.1 Operating modes

The XRF can be used at varying levels of complexity, as either a free-running RF source or to follow pre-determined instructions defined in a table. The modes of operation are outlined below, and the current operational mode of each channel can be individually set using the `MODE` command.

NSB: Basic mode

Default state on power-up. In this mode, each channel acts as a simple single-frequency RF source, with the DDS chips controlled directly by the FPGA. The frequency and power of the signal can be controlled via the front panel, using simple instructions over the computer interface (e.g. `FREQ` or `POW`), or using the modulation inputs. Basic mode is convenient for driving AOMs and other single-frequency devices, with the flexibility of modulation and PID control.

NSA: Advanced mode

Advanced mode provides direct user-control of each DDS through its internal registers via the `DDS` command. Direct programming of each DDS is complex and not necessary for most applications; it requires careful reference to the AD9910 datasheet and manual calculation of the hardware registers.

TSB: Simple table mode

In table mode, the RF parameters are automatically sequenced by the FPGA according to a table of values pre-loaded by the micro-controller and stepped through automatically. The table entries are defined by simple text commands from the host computer which define the RF frequency, amplitude, phase and any I/O behaviour, as detailed in chapter 8. The minimum duration of a TSB entry is 1 μs and each table can comprise up to 8191 instructions.

TPA: Advanced table mode

XRF models provide a more advanced table mode with greatly improved timing resolution and single parameter updates at 16 ns intervals. Smooth pulses can be generated with precise control of the envelope through piecewise-linear interpolation. Details on advanced table mode functionality are described in chapter 9.

1.2 Feature compatibility

The XRF provides a wide range of functionality, but not all features are compatible with each other. The following table summarises which features can be used in which modes.

	NSB	NSA	TSB	TPA
Front-panel controls	✓	✗	✗	✗
External modulation (AM/FM/PM)	✓	✗	✗	✗
PID control	✓	✗	✗	✗
Direct TTL on/off control	✓	✓	✗	✗
Direct DDS control	✗	✓	✗	✗
Autonomous execution	✗	✗	✓	✓
External TTL trigger	✗	✗	✓	✓
TTL output	✓	✓	✓	✓

Table 1.1: Summary of feature compatibility

1.3 RF on/off control

The RF output can be turned on and off via software control of the DDS generators, but for many applications that is too slow and the extinction ratio is inadequate. The XRF has additional hardware-based on/off control on the output of each DDS, using an RF switch before each amplifier.

Each hardware switch terminates the RF output into an internal 50 Ω load, and is controlled via a combination of software and hardware inputs (see §7.6). In this way, the RF can be controlled using the front panel, TTL signals, software commands, or table entries.

There is additional control of the DC supplies to the high-power RF amplifiers to further improve the extinction ratio. The response time is significantly longer than just switching the RF signal, but reduces the RF noise on the output.

2. Connections and controls

2.1 Front panel controls

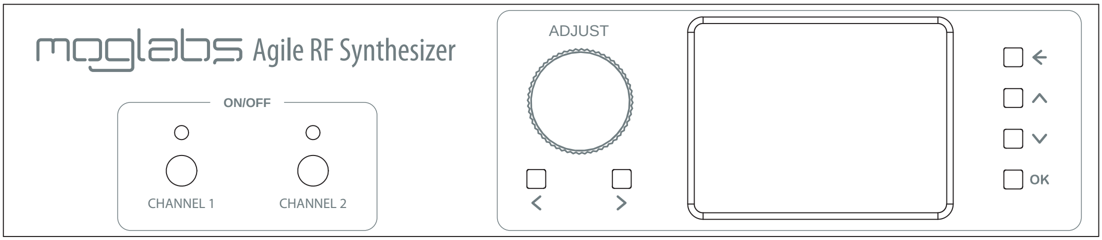


Figure 2.1: Front-panel layout of Rev9 XRF devices. Other revisions may have a different appearance.

The front-panel includes an interactive menu system for controlling the device. The buttons on the right-hand side of the display navigate through the menu structure, while the encoder wheel is used to edit values. The ∧ and ∨ keys change between menu items, ← exits to the previous menu, and OK enters the selected menu or activates the selected command.

The main menu (Figure 2.2) shows the current mode and status of each channel. In basic (NSB) mode, the current frequency and power of each channel is displayed, as well as whether modulation is currently enabled. Pressing the OK button with a channel selected will open the sub-menu to adjust settings for that channel (Figure 2.3).

The color of each menu item represents its purpose, as listed below.

White Static value, displayed for diagnostic purposes.

Yellow Adjustable value, modified using the encoder wheel.

Orange Currently selected channel.

Blue Submenu, entered with the OK button.

Green Command, executed by the OK button.

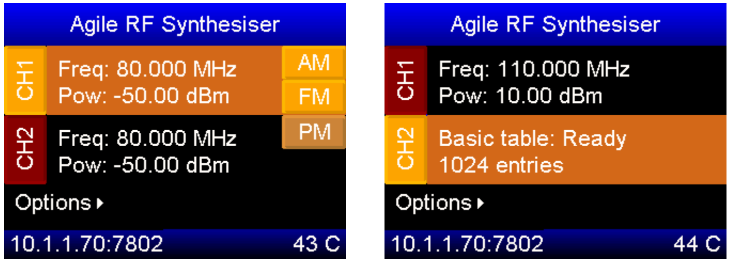


Figure 2.2: The main menu shows the current state of each channel. Left: both channels are in basic mode, with AM and FM enabled on CH1, and PM enabled on CH2. Right: CH2 is in basic table mode, with the number of entries in the table shown.

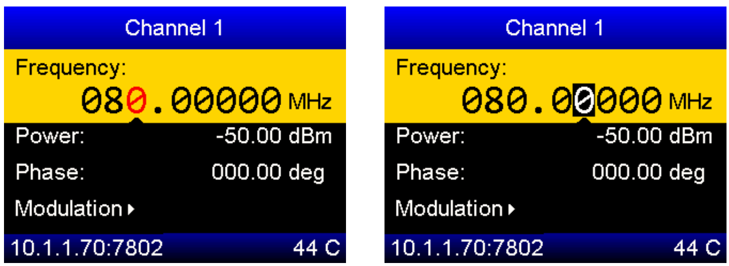


Figure 2.3: The basic parameters of each channel can be edited directly. Turning the encoder wheel modifies the selected digit of the current value (left) as indicated by the arrow. Pressing the encoder wheel changes to *digit select mode* (right), allowing the selected digit to be changed by turning the encoder.

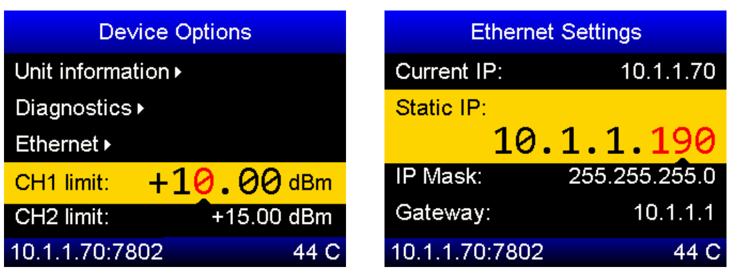


Figure 2.4: The options menu allows configuration of various settings, such as the maximum output power (left) and ethernet options (right).

When an editable (yellow) value is selected, turning the encoder wheel changes the value of the selected digit as identified by the arrow and red text. To change the digit of interest, either use the $<$ or $>$ buttons or press the encoder wheel to change to *digit selection mode*. In this mode, the currently selected digit is shown on a black background, and is changed by turning the encoder wheel. Pressing the encoder again returns to *value modification mode*.

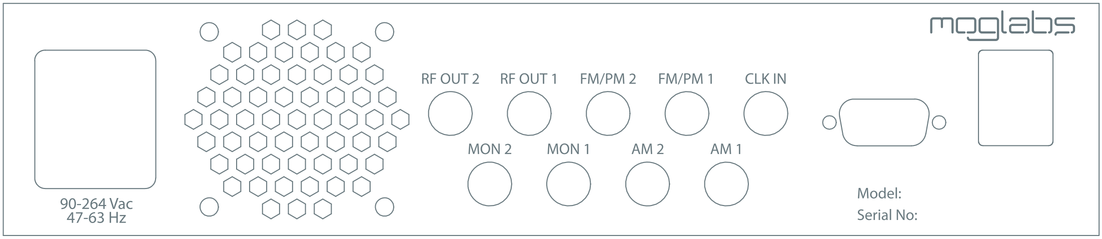
The options menu (Figure 2.4) allows the device configuration to be adjusted. In particular, the power limit applied to each channel should be set as per the desired application before use (see also the `LIM` command). The ethernet settings of the device can also be set using this interface, including whether to enable DHCP and the fall-back static IP address of the device. When in use, the network status is displayed on the display footer, and once connected displays the current IP address. Note that the *Restart ethernet* command must be used before changes in the ethernet menu will take effect.

Each channel of the device can be turned on or off using the push-buttons on the left of the front-panel. Each channel also has an associated multi-colour status LED indicator whose colour shows the current output state of the channel as follows.

Colour	DDS signal	Amplifiers
Off	✗	✗
Green	✓	✓
Yellow	✓	✗
Blue	✗	✓
Purple	Debug mode	
Red	Error state	

The overall brightness of the display can be set with the *contrast* value in the Options menu. The display also includes a *sleep* timer that dims the display if it hasn't received input in a given period of time. This feature can be disabled by setting the sleep timer value to 0.

2.2 Rear panel controls and connections



IEC power in The XRF is compatible with all standard AC power systems, from 90 to 264 V and 47 to 63 Hz.

Fan The XRF has three temperature-controlled fans directing air flow over the RF power amplifiers and the FPGA, exhausting through the rear vent. Ensure that the vent does not become blocked.

RF OUT SMA connectors for the primary RF outputs. Should be connected to a 50Ω load. Must not be short-circuited.

MON SMA connectors for *monitor* RF outputs, which are −27 dBc copies of the main output (when terminated into 50 Ω).

FM/PM/AM SMA analog inputs, nominally for frequency, phase and amplitude modulation (see chapter 5). These inputs can also be used for laser noise-eater or frequency stabilisation applications (see chapter 6).

CLK IN The XRF can be synchronised to a high-performance external clock input via this SMA connector and software commands (see §C.7). The input is 50 Ω terminated, and the provided reference should be between +3 dBm and +10 dBm, and preferably square-wave.

DE15 The DE15 connector provides basic I/O functionality (§7.1). There are TTL inputs for quickly suppressing the RF output, and TTL outputs for controlling experimental devices such as shutters. The XSMA breakout board is available to provide convenient SMA connectors for each I/O channel (§7.3).

RJ45/USB-A Ethernet (TCP/IP 10/100 Mb/s) and USB-HS type-A communications jacks.

2.3 Internal DIP switches

Four DIP switches are provided to assist in diagnosis and recovery of the XRF units. They should be left in default configuration for regular operation.

WARNING There is potential for exposure to high voltages inside the XRF. Take care around the power supply and ensure that objects, particularly electrically conducting objects, do not enter the unit.

CAUTION The cover should be replaced before powering on to ensure proper airflow and cooling.

	OFF	ON
1	Normal operation	Firmware update mode
2	Disable FPGA	Normal operation
3	Use factory settings	Normal operation
4	Normal operation	Factory reset

DIP 1 Default OFF. If switched ON, the unit will start in firmware upload mode (see §B.1).

DIP 2 Default ON. Switch OFF to disable the FPGA for diagnostic purposes.

DIP 3 Default ON. Switch OFF to use default device and network settings.

DIP 4 Default OFF. Switch ON and reboot to restore the unit to factory version and configuration.

3. Communications

The XRF can be connected to a computer by USB or ethernet (TCPIP). The software package `mogrf` (chapter 4) provides interactive functionality, or communications can be integrated into existing control software. Examples of controlling the XRF in several languages are provided in Appendix D.

3.1 Protocol

Communication follows a query/response protocol, where the user sends an ASCII string to the unit, and the unit sends an ASCII response back. The list of possible commands is detailed in Appendix C. All messages are CRLF-terminated, requiring that any communications must end with a carriage return ('\r' = ASCII 0x0D) and new-line ('\n' = ASCII 0x0A). Most terminal applications and drivers provide the ability to automatically append these characters when configured appropriately.

Statements are either *commands* or *queries*. A command is a statement that causes some action to occur, and the unit will respond with either `OK` or `ERR` depending on whether the command succeeded or not. For example,

```
> FREQ,1,80MHz
< OK: CH1 freq now 80.00000009 MHz (0x147AE148)
> FREQ,1,10MHz
< ERR: Frequency 10.00 MHz out of range
```

The response describes the outcome of the command, such as the achieved frequency taking into account discretisation by the DDS.

Queries are statements that return a value, which respond with the value in physical units first where applicable, or an error message beginning with "`ERR`". For example,

```
> FREQ,1
< 80.00000009 MHz (0x147AE148)
> FREQ,3
< ERR: Invalid channel, 3
```

In the above example, the frequency query provides a value first in MHz as well as the internal DDS setting (called the *frequency tuning word*) as hexadecimal in brackets.

It is strongly recommended that all software should wait for this response and check whether it indicates an error before continuing. The `python` and `LabVIEW` bindings provided by MOGLabs take care of buffering and error checking automatically.

The `mogcmd` application, which is available from the MOGLabs website as a standalone application or as part of the `mogrf` package, provides a convenient interface for sending commands and receiving responses (Figure 3.1).

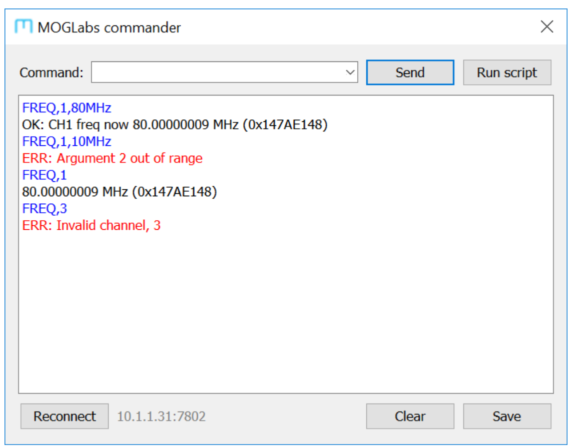


Figure 3.1: The `mogcmd` application, showing successful and unsuccessful commands and queries.

3.2 TCP/IP

The XRF can be accessed over ethernet via the IPv4 protocol. When ethernet is connected, the XRF will attempt to obtain an IP address by DHCP. If DHCP fails, an internally defined address will be used. In both cases, the address will be shown on the device display (for example, `10.1.1.190:7802`), showing the address and port number for communicating with the device.

3.2.1 Changing IP address

Depending on your network settings, you may need to manually set the IP address. This is most easily done via the front-panel menu system as described below. Once configured, these settings are stored in the non-volatile memory of the unit and will be recalled in future. However, automatic address acquisition via DHCP is a simpler solution where available.

1. From the main menu, open Options > Ethernet Settings.
2. Select *Static IP* and use the encoder wheel to set the IP address of the device as required. Note that pressing the encoder wheel changes between octets of the address.
3. Select *Gateway* and set the gateway address as required.
4. Select *DHCP* and set to OFF by turning the encoder anti-clockwise.
5. Select *Restart ethernet* and press the OK button.
6. The new IP address will be displayed in the display footer.

In some situations it may be necessary to power-cycle the device to propagate ethernet changes.

3.3 USB

The XRF can be directly connected to a host computer using a USB cable (type A-male). The device will appear as a Virtual COM port – a fast serial port that behaves like an RS232 connection.

The required STM32 Virtual COM Port Driver (VCP) device driver is available from the MOGLabs website for the Windows™ operating system. After installation, the XRF will appear as a new COM port on the machine.

To determine the port number of the device, go to Device Manager (Start, then type `Device Manager` into the Search box). You should see a list of devices including *Ports* (Figure 3.2).

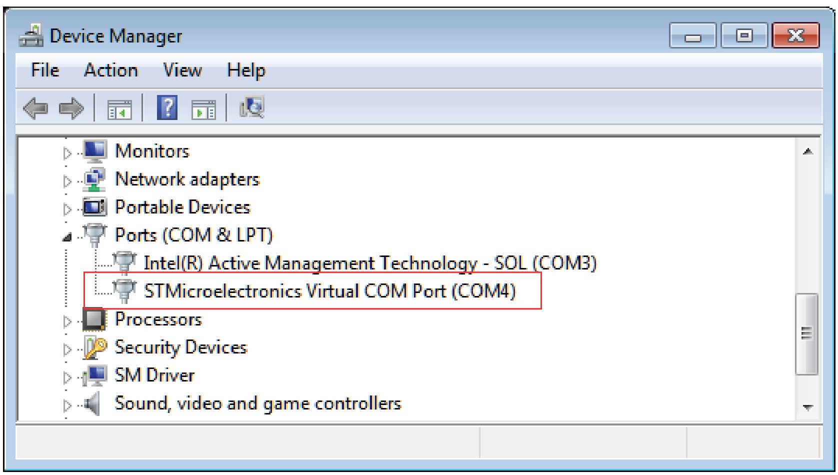


Figure 3.2: Screenshot of Device Manager, showing that the XRF can be communicated with using COM4. The port number might change when plugging into a different USB port, or after applying a firmware update.

The device can be identified as a COM port with the following name,

`STMicroelectronics Virtual COM Port (COMxx)`

where `xx` is a number (typically between 4 and 15). In the example above, the device was installed as COM4.

Note that if the port appears in Device Manager with a different name, then the driver was not successfully installed. If this occurs, disconnect the device from the host computer, reinstall the VCP driver, then reconnect the USB cable.

The `mogrf` host software (§4) automatically enumerates the available COM ports when started, making device identification simpler.

4. MOGRF host software

The `mogrf` software package provides a simple user interface to the basic behaviour of XRF devices, with the ability to issue commands, run scripts, control tables, and apply firmware updates.

Please note: It may be necessary to install a firmware update (see Appendix B) to use the software described in this section.

4.1 Device discovery

Upon starting the application, a device discoverer (Figure 4.1) is initiated. This program scans the COM ports of the host computer looking for an XRF device, and then scans the local network subnet. Starting the application is then as simple as selecting the device and clicking *Connect*. If your device is not listed, recheck your connection and network settings.

If the network and/or firewall blocks device discovery, enter the IP address of the unit in the *Device address* box directly.

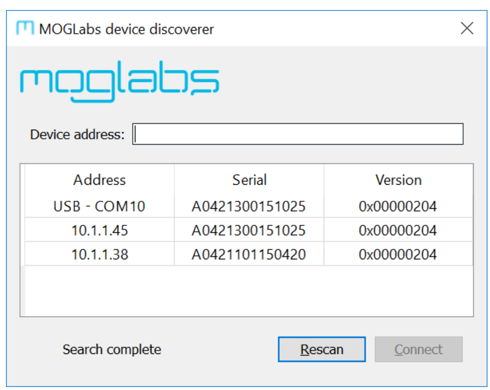


Figure 4.1: Example of the *Device discoverer* window, showing that one USB device and two networked devices were detected.

4.2 Device commander

The *Device commander* is an interactive terminal for issuing commands and queries to your XRF device and displaying the result (Figure 4.2). The accepted commands and their functions are listed in Appendix C. Type statements into the *Command* box and execute them by pressing the ENTER key or clicking Send. The window contains a history of recently executed commands.

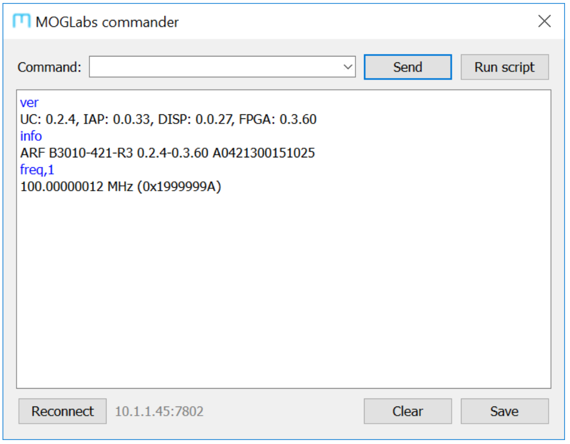


Figure 4.2: The *Device commander* window, which permits the execution of individual instructions or of text files containing scripts.

Scripts are ASCII text files where each line corresponds to a command to be executed (see Appendix D). Clicking *Run script* triggers stepwise execution of such a script, where the success of each statement is checked before executing the subsequent line. If an error occurs, execution of the script is aborted and an error message is displayed.

If the device is restarted or the connection is lost, clicking *Reconnect* will attempt to reestablish communication.

4.3 MOGRF main window

The main window of `mogrf` is shown below. The two channels are displayed side-by-side, with information and controls that depend on the current operational mode of each channel.

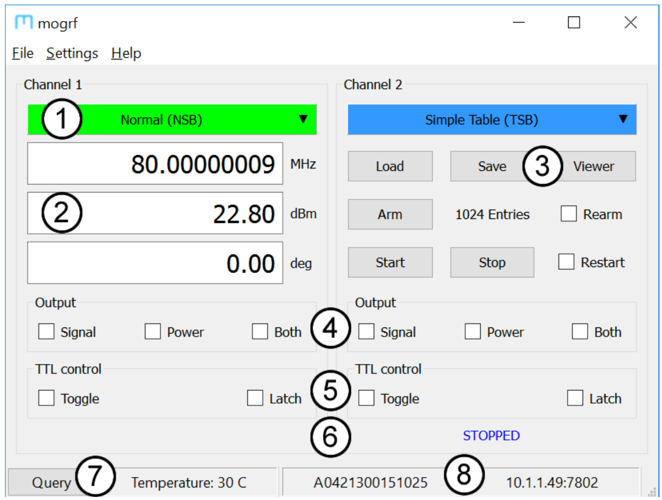


Figure 4.3: The main window of `mogrf`, showing Channel 1 in normal (NSB) mode and Channel 2 in simple table (TSB) mode.

The main features of the application are as follows:

1. Current operational mode of the channel. Click to change mode by selecting from a list. Note that *advanced table mode* will only appear on XRF units.
2. Current frequency, amplitude and phase in NSB mode. Changing the value immediately updates the output.
3. Controls are provided for specific table-mode functionality. Tables can be exchanged with internal FLASH memory, or uploaded/downloaded from the host machine in binary or CSV format (§8.5). Table execution can be started or stopped, auto-restart configured (§8.6), and a graphical viewer is provided for table visualisation in TSB mode (§4.4).

4. Channel output can be controlled by enabling only the RF switch (signal), RF amplifiers (power) or both (421-series only).
5. Options to enable external TTL control of the channel output using the OFF input on the DE15 connector (see §7.6).
6. Current channel status. Includes whether any modulation options are enabled (both frequency and amplitude modulation are enabled in this example) and the current execution status in table mode.
7. Click *Query* to manually update the displayed status information. Useful for reflecting changes caused by device commands or front-panel input.
8. The status bar contains diagnostic information about the unit and connection.

4.3.1 File menu

Device command Starts the *Device commander* (§4.2) for interactive execution of instructions to control the device.

Upload firmware Starts the firmware update application to upload and install updates on the device. The procedure for applying firmware updates is described in detail in Appendix B. It is strongly recommended to make a backup of device settings (Settings→ Download settings) before commencing an update.

Upload table Upload a previously downloaded binary table to FLASH memory, which can be subsequently loaded into either channel. Note that binary compatibility between firmware revisions is not guaranteed, and it is recommended that all tables be generated and stored in ASCII (human-readable) form.

4.3.2 Settings menu

Ethernet Allows configuration of network connection settings (IP address, mask, gateway and port). Particularly useful for configuring the network settings over USB. Note that changing the *Static IP* only has an effect if DHCP is disabled, or if DHCP name resolution fails.

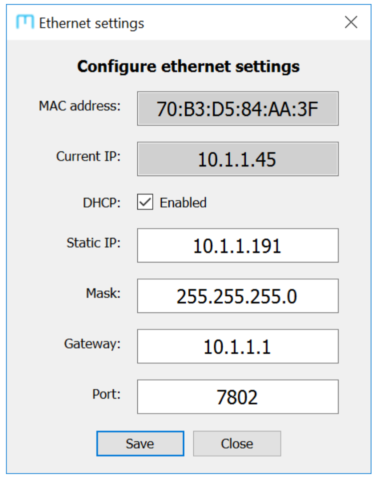


Figure 4.4: Ethernet configuration interface.

Note that changing the ethernet settings will require the application to be restarted, and may also require the device to be rebooted. The port should be unchanged at 7802 to ensure that the `mogrf` suite of programs can continue to communicate with the device.

Synchronisation Configures the channel synchronisation feature, detailed in §8.8.

Download settings Downloads configuration and calibration data from the device and stores it in a file for backup purposes.

Upload settings Restore previously downloaded settings to the unit.

4.3.3 Modulation

The XRF supports a wide variety of modulation options (see chapter 5) which can be controlled using this window. Individual modulation types can be enabled/disabled using the checkboxes on the left, and their associated gains adjusted using the sliders (Figure 4.5).

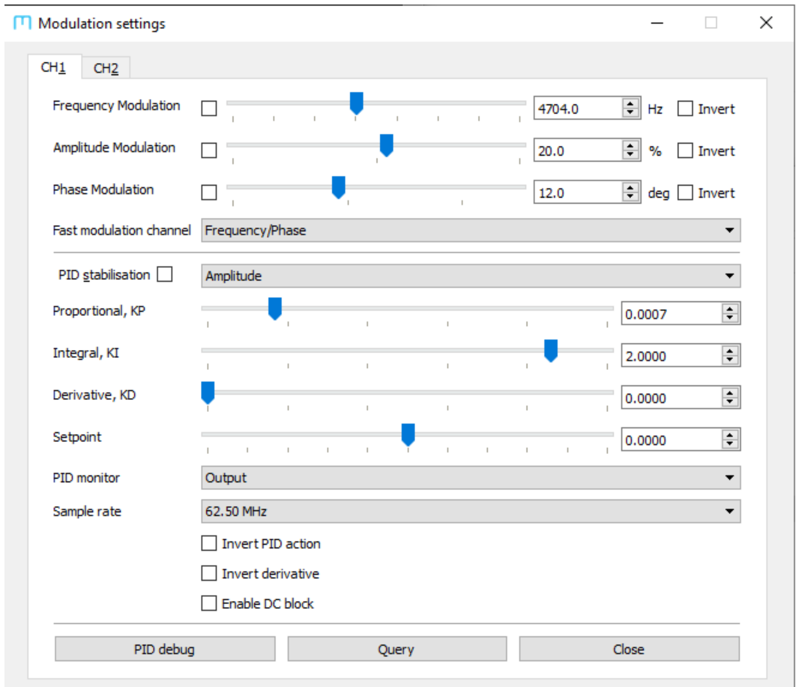


Figure 4.5: Use the Modulation dialog in the `mogrf` application to change the modulation settings for each channel

4.3.4 PID debug

The `mogrf` software contains a diagnostic capture viewer that displays the error signal input and servo output signals from the PID controller, which can be beneficial in checking the operation of the PID loop and optimising the gain coefficients.

In particular, it is recommended for performing the following checks:

- Adjust the offset voltage to give zero input at the lock point.
- Confirm the PID action polarity by checking the error signal converges *towards zero* when the controller is engaged.
- Adjust the VGA gain to increase noise suppression ADC.
- Detect oscillation when the gain is too high.

The indicator LED shows green when the PID is locked and red when the controller has saturated. Clicking this indicator toggles whether the PID is engaged. Clicking the *Single* button momentarily disables and re-enables the PID, allowing the initial transient to be observed.

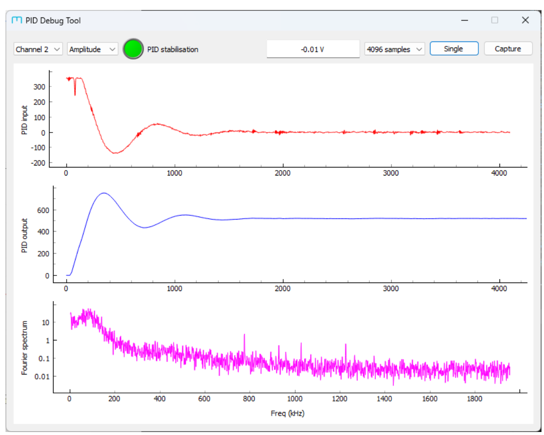


Figure 4.6: Demonstration of the PID debug capture when engaging the lock showing the error signal rapidly converging to zero. The overshoot implies the gain is slightly too high.

4.3.5 Help

Diagnostics Queries the unit for diagnostic information, which may be useful in assessing issues with the functionality of the XRF (Figure 4.7). When encountering a problem with the device, please run the diagnostics and click *save results*, then send the resulting text file and a description of the problem to MOGLabs for analysis.

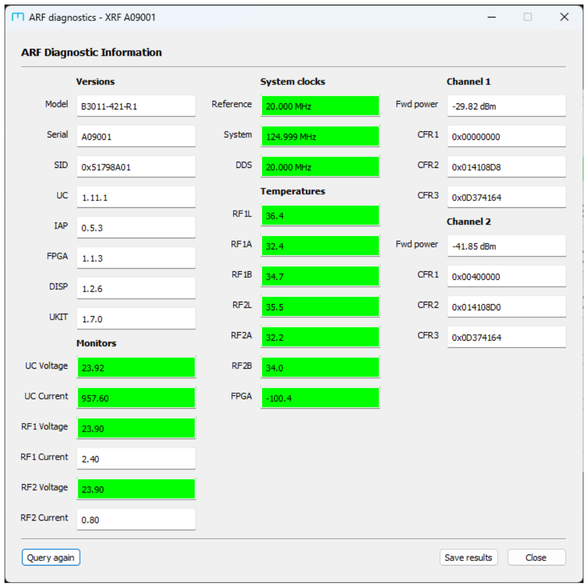


Figure 4.7: Diagnostic information about the connected XRF unit, which should be sent to MOGLabs for analysis if there is a problem with the device.

About Displays version information about the `mogrf` toolkit and connected XRF device, for support purposes.

4.4 Table viewer

In simple table mode (TSB mode), `mogrf` provides a viewer for inspecting both the table instructions currently loaded into each channel, as well as the instructions stored in FLASH memory (Figure 4.8). This is beneficial for cataloguing the sequences in memory, as well as for debugging sequences which have been generated by scripts and uploaded to the device.

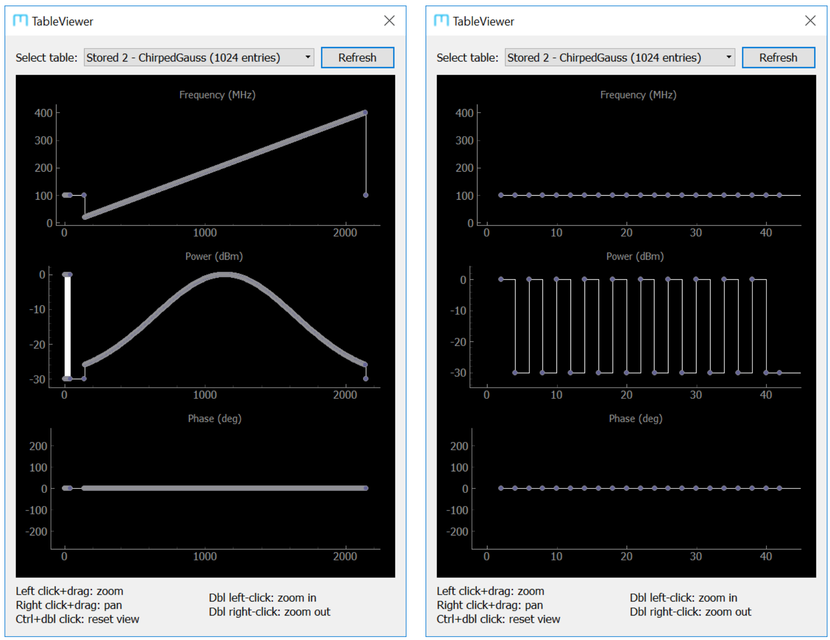


Figure 4.8: *Table viewer* showing how the frequency, power and phase of a table stored in FLASH memory change across the sequence (left). The example shown is a chirped Gaussian pulse, with a number of rapid on/off pulses at the beginning. Mouse controls allow zooming in on areas of interest, such as the rapid pulses at the start of the sequence (right).

At present, the table viewer is only available for simple tables, but may be extended in future to provide visualisation of advanced tables.

4.5 External I/O settings

The XRF provides extensive digital I/O capability through the EXTIO command and configuration window (Figure 4.9). It displays the instantaneous input and output state of the I/O pins on both the DE15 connector (§7.1) and the high-speed banks (§7.2).

This is provided to assist diagnosing the I/O state, and to ensure that any settings are correct for the desired application. In particular, note that associated pins must be set to AUTO control to be used in combination with table mode.

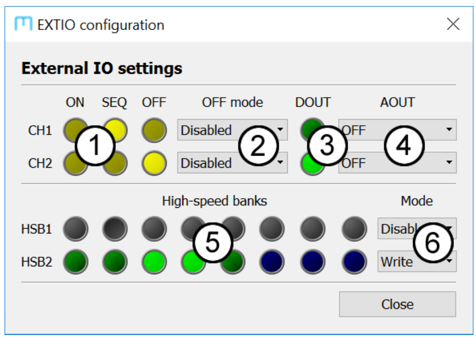


Figure 4.9: External I/O configuration window, showing the current state of inputs (yellow), outputs (green), table-mode outputs (blue) and disabled outputs (black). Left-clicking on an output changes its state, and right-clicking brings up a menu of options.

Features of the EXTIO configuration window are:

1. Current state of the input pins of the DE15 connector.
2. Configure the CHx-OFF input on the DE15 connector as an interlock (*Latch* mode) or for direct control of the RF switch (*Toggle* mode), see §7.6.
3. Current state of the DE15 digital output (shutter) pin, which can be set manually or placed in AUTO mode to use in table mode.

4. Analog monitoring signal currently output on the analog output pin of the DE15 connector (not supported on all units).

5. Current state of the two high-speed banks. The banks are disabled (black) on boot, and must be set to either read (yellow) or write (green) mode on a per-bank level. Once in write mode, individual output pins can be set as AUTO (blue) for use in table mode.

6. Overall I/O mode to apply to the associated high-speed digital bank.