moglabs

Agile RF Synthesizer & AOM driver

XRF421

Revision 1.8.3
Serials A09xxx and newer
Firmware v1.12.2

7. Digital I/O

TTL digital inputs and outputs (0–5 V) are provided on the XRF through the DE15 connector on the rear panel, and the high-speed bus (HSB). The inputs can be used as triggers and the outputs can be controlled manually or using by table mode entries (§8.3).

Note: Digital inputs are pulled *high*, meaning that a disconnected input pin is equivalent to supplying a TTL high to that input.

7.1 DE15 connector

The DE15 connector on the rear panel (Figure 7.1) provides digital inputs and outputs for monitoring and synchronisation purposes.

CHx-DOUT `Pin 4 (Ch1), Pin 9 (Ch2)`
TTL outputs that can be controlled manually or from table mode, for example to activate a mechanical optical shutter or trigger another device. This output has a rise time of 3 us.

Note: Pin 9 is internally disconnected in some commercial DE15 cables. Please check continuity on pin 9 continuity when using CH2-DOUT.

CHx-SEQ `Pin 3 (Ch1), Pin 5 (Ch2)`
Pin used for hardware triggering in table mode. When the table is armed and a falling edge is received on the associated input, the table begins executing.

CHx-ON `Pin 2 (Ch1), Pin 6 (Ch2)`
Driving this pin LOW in NSB mode instructs the FPGA to switch **ON both the RF signal and amplifiers** (if present). Has no effect if the output is already enabled. For applications that require the amplifiers to stay powered on, the CHx-OFF pin should be used instead.

Pin	Signal	Type
1	CH1 OFF	TTL in
2	CH1 ON	TTL in
3	CH1 SEQ	TTL in
4	CH1 DOUT	TTL out
5	CH2 SEQ	TTL in
6	CH2 ON	TTL in
7	CH2 OFF	TTL in
8	GND	0 V
9	CH2 DOUT	TTL out
10	GND	0 V
11	N/A	
12	GND	0 V
13	N/A	
14	GND	0 V
15	GND	0 V

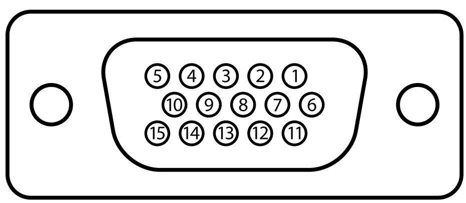


Figure 7.1: Pinout of high-density 15-pin female DE-style rear panel IO connector.

CHx-OFF `Pin 1 (Ch1), Pin 7 (Ch2)`

This input bypasses the FPGA and directly turns **the RF switch OFF unless a TTL LOW is provided**. Bypassing the FPGA provides an extremely fast method for generating externally-controlled pulses, as further discussed in §7.6.

This pin is **disabled by default** and must be enabled using the `EXTIO,ENABLE` command. If this feature is enabled and the pin is disconnected, **the RF output will not turn on**.

7.2 High-speed digital

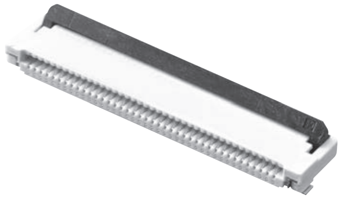
The FPGA also provides 16 high-speed digital I/O lines for use with table mode (Figure 7.2). Internal connector P1 accepts a 30-way, 0.50 mm pitch ribbon cable that can be inserted through a slot in the left-hand side of the case. The connector is an Omron XF2M-3015-1A, with example matching FFC ribbons Molex 0982660326 (150 mm length) or 0152660329 (200 mm length). Each line includes a 10 Ω series resistor and capability to sink and source 24 mA.

The high-speed lines can be configured as inputs or outputs using the `EXTIO,MODE` command, which configures groups of lines called *banks*. For example, to configure pins D1-D8 (bank 1) as inputs and pins D9-D16 (bank 2) as outputs, use the commands:

```
EXTIO,MODE,1,HSB,READ
EXTIO,MODE,2,HSB,WRITE
```

If finer control is required, the digital lines can also be configured as sub-banks of 4 lines. For example to set pins D1-D4 (sub-bank 1A) as inputs and pins D5-D8 (sub-bank 1B) as outputs, use the command:

```
EXTIO,MODE,1,HSB,READ,WRITE
```



Pin	Signal
1	3.3 V
2	3.3 V
3	3.3 V
4	GND
5	A0
6	A1
7	A2
8	A3
9	GND
10	GND

Pin	Signal
11	A4
12	A5
13	A6
14	A7
15	GND
16	GND
17	B0
18	B1
19	B2
20	B3

Pin	Signal
21	GND
22	GND
23	B4
24	B5
25	B6
26	B7
27	GND
28	GND
29	GND
30	GND

Figure 7.2: High-speed digital IO connector (internal). Note that the FFC cable can be inserted upside-down, reversing the pin ordering.

7.3 XSMA breakout board

The XSMA breakout board (Figure 7.3) is an optional additional component that provides SMA connectors for each of the digital I/O lines of both the DE15 connector (§7.1) and the high-speed bus (§7.2). The pins of the high-speed bus have matched track-lengths, to ensure consistent propagation delay for applications using advanced table mode.

The flat-flex cable (FFC) carrying the high-speed digital I/O signals can be inserted in either orientation, with contacts facing up or down. Each pin of the high-speed bus has two labels, corresponding to the purpose of the pin given the cable orientation.

If the orientation is the same within the XRF and the XSMA board, the second set of labels apply, whereas if the cable is crossed-over,

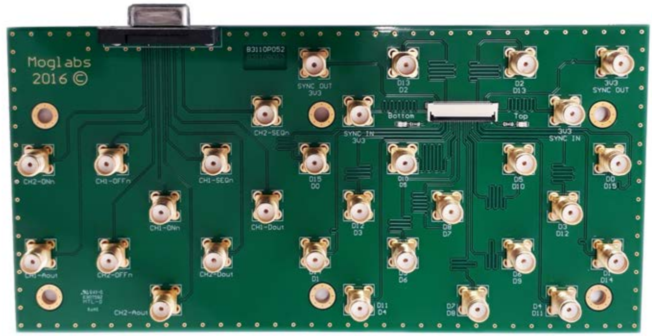


Figure 7.3: XSMA digital I/O breakout board, providing SMA connectors for the DE15 connector (left) and high-speed digital connector (right).

the first set apply. Second-generation breakout boards include LED indicators labelled *Top* and *Bottom* that identify which set of labels to use.

The board dimensions are 172x70mm (first generation) or 172x85mm (second generation).

7.4 Configuration

The `EXTIO` command is used to control the behaviour of digital I/O. Outputs can be set with `EXTIO,WRITE`, and queried with `EXTIO,READ` when set to MANUAL control, or commanded by table mode entries when set to AUTOMATIC control.

The table below shows the functionality available on the different pins. Pins in the high-speed bus can be addressed individually (HSn) or collectively as a whole bank (HSBANK) in case multiple outputs need to be changed simultaneously. HSB is short-hand for HSBANK.

Function	OFF	ON/SEQ	DOUT	HSB	HSn
Enable	✓	–	–	✓	–
Disable	✓	–	–	✓	–
Reset	✓	–	✓	✓	–
Mode	✓	–	–	✓	–
Control	–	–	✓	✓	✓
Write	–	–	✓	✓	✓
Read	✓	✓	✓	✓	✓
Counter	✓	–	–	–	✓

The different `EXTIO` commands are summarised below.

EXTIO,ENABLE

`EXTIO,ENABLE,ch,pin`

Enable the functionality of the specified `pin` on the given channel `ch`. If `pin` is HSB, the entire bank of pins is enabled.

EXTIO,DISABLE

`EXTIO,DISABLE,ch,pin`

Disable the functionality of the specified `pin`.

EXTIO,RESET

`EXTIO,RESET,ch,pin`

Resets the functionality of the specified `pin` to its default state.

EXTIO,MODE

`EXTIO,MODE,ch,pin,[mode]`

Change the mode of the specified `pin`. If `pin` is HSB, then `mode` is either READ or WRITE. If `pin` is OFF, then `mode` is either LATCH or TOGGLE. If `pin` is disabled, it is enabled first.

The sub-banks can be controlled using a second mode argument: the first `mode` argument applies to lines 1–4 of the bank, and the second applies to lines 5–8.

EXTIO,CONTROL

`EXTIO,CONTROL,ch,pin,[mode]`

Sets the control of the specified `pin`. The parameter `mode` is either MAN[UAL] or AUTO[MATIC]. Pins must be set to AUTO mode to access them in table mode. If `pin` is HSB and the (sub)bank is not in write mode, the (sub)bank is changed to write mode first.

EXTIO,WRITE `EXTIO,WRITE,ch,pin,value`
Write the specified `value` to the output `pin`. If `pin` is HSB, then `value` is an 8-bit number, whose bits correspond to the values to set on the pins of that bank. Otherwise `value` can be one of ON, OFF, 1 or 0. If the pin is not set to MANUAL control, it is changed to manual control first.

EXTIO,READ `EXTIO,READ,ch,pin`
Reads the specified `pin` and returns its current state. If `pin` is HSB, then the returned value is an 8-bit hexadecimal number where each bit corresponds to the state of the corresponding line.

EXTIO,COUNTER `EXTIO,COUNTER,ch,pin,cmd`
The FPGA provides independent digital counters which can be activated on any pin configured as an input. The counters can be individually started, stopped or queried (see §7.7).

7.5 TTL switching

A versatile feature of the XRF is the ability to switch the RF in response to an external input such as a tactile switch or a TTL trigger for device synchronisation.

Each channels has two TTL inputs on the DE15 connector, labelled CHx-OFF and CHx-ON (see 7.1), that control whether the output is enabled or disabled as described below. Both of the inputs are active LOW and have no effect if pulled HIGH.

Each input has a debouncer circuit for use with tactile switches that can be enabled or disabled using the `DEBOUNCE` command. Note that activating the debouncer will introduce a small delay to changes in the input.

CHx-ON When the output is disabled, pulling this pin LOW will switch **both** the RF signal and amplifiers ON (NSB mode only). Has no effect when disconnected.

CHx-OFF When enabled (below), the RF signal will be disabled **unless** this pin is pulled LOW. If disconnected or pulled HIGH, no output is produced. Does not affect the RF amplifiers.

This CHx-OFF functionality disables the RF output **unless** the required input is provided, so it must be explicitly enabled using software commands. There are two modes of operation for this input as described below.

`EXTIO,MODE,1,OFF,TOGGLE`
: Sets CHx-OFF to TOGGLE mode: the RF is off whenever the input is HIGH and the output is enabled whenever the input is LOW. Can be used for generating rapid externally-controlled pulses.

`EXTIO,MODE,1,OFF,LATCH`
: Sets CHx-OFF to LATCH mode: if the OFF input goes HIGH, the output will be disabled and remain disabled. The output can then only be re-enabled by taking the input LOW and **then switching on the output** via software or the front-panel. This functionality can be used as part of an interlock system.

`EXTIO,ENABLE,1,OFF`
: Enable the CHx-OFF behaviour, as previously configured by the `EXTIO,MODE` command.

`EXTIO,DISABLE,1,OFF`
: Disable the CHx-OFF input, regular operation using the `ON` and `OFF` commands.

Please note that this setting *is* stored persistently and needs to be manually disabled when no longer desired.

7.6 Pulse generation

> **Note:** Ensure that the debouncer is disabled using the DEBOUNCE command when generating pulses with TTL inputs.

There are several approaches to generating pulses using an XRF in NSB mode (normal operation): using the TTL inputs on the DE15 connector, or using amplitude modulation (AM). Alternatively, pulses can also be generated in a preprogrammed sequence using table mode (chapter 8).

Method	Transition	Time
RF switch		25 ns
RF switch		30 ns
RF amplifier		2 s
RF amplifier		2 s
AM (fast)		500 ns
AM (slow)		< 3 us
DE15-ON		2 ms
DE15-OFF		40 ns

Table 7.1: Typical on/off time delays for switching hardware components, and for different methods of pulse generation (debouncer disabled). The time given for amplifier transitions includes time for the output to stabilise, which may vary between hardware revisions.

Note that the RF amplifiers are susceptible to thermal transients when powering on and off, causing the output power to fluctuate. Switching the amplifiers (e.g. using CHx-ON) may result in RF output within several milliseconds, but the output power may take several seconds to stabilise. Switching the RF only (e.g. using CHx-OFF) is recommended to avoid transients.

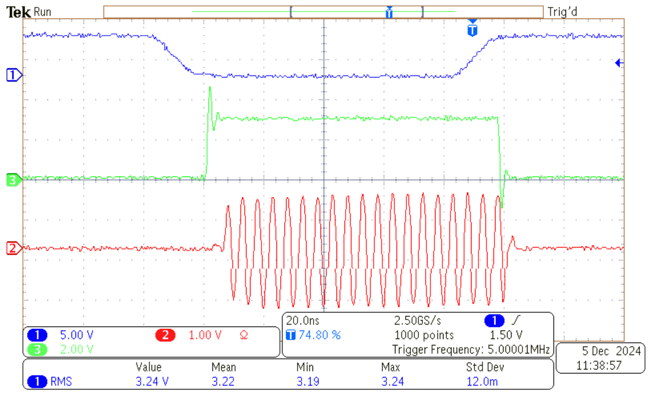


Figure 7.4: Modulation of RF output using the CHx-OFF input. Blue is TTL signal at the source; green is the TTL signal at the RF switch (internal to XRF); red is the RF signal.

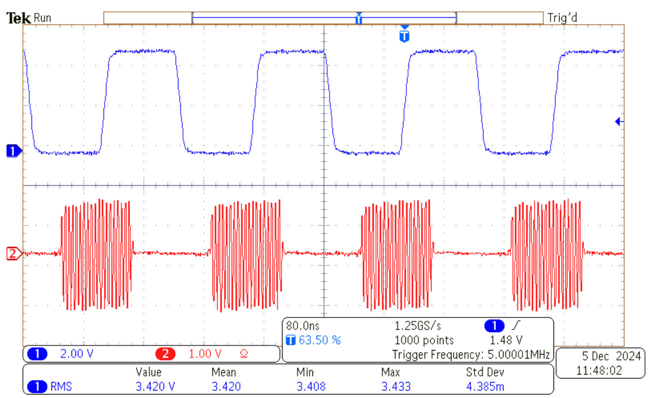


Figure 7.5: Example of pulse generation using the CHx-OFF input. Red is TTL signal; blue is the RF signal.

7.7 Counters

Fast digital counters can be accessed for each digital input pin. XRF devices can use these counters in advanced table mode (§9.4); XRF devices can only use them manually in scripts. To use a counter, the associated pin must be in READ mode and the counter function activated. The maximum edge-detection rate on the high-speed bus is 50 MHz, and level-detection (HIGH and LOW modes) accumulates 125 counts per microsecond.

The syntax to control counters is `EXTIO,COUNTER,ch,pin,command`, where `command` is one of the following:

READ, V[ALUE] Return the counter value as a 32-bit number

RESET, C[LEAR] Reset the counter value to zero

E[NABLE] Activate counter and begin accumulating count

D[ISABLE] Deactivate counter but hold count value

H[IGH] Count while input is HIGH, enables counter

L[OW] Count while input is LOW, enables counter

R[ISING] Count rising edges, enables counter

F[ALLING] Count falling edges, enables counter

B[OTH] Count both rising and falling edges, enables counter

The following NSB-mode example sets up a rising edge counter on HSB3 and counts for approximately 100 ms.[1]

```
EXTIO,MODE,2,HSB,READ
EXTIO,COUNTER,2,HS3,RISING
EXTIO,COUNTER,2,HS3,RESET
SLEEP,100 # wait approximately 100ms
EXTIO,COUNTER,2,HS3,READ # returns counts recorded
```

[1]Advanced table mode should be used for more accurate measurement (§9.4).

7.8 Examples

The following examples demonstrate how to configure and use the external I/O pins. Note that pins must be set to MANUAL using the `EXTIO,CTRL` command to be used for READ and WRITE.

These commands may be useful in executing scripts or diagnosing experiments. For any application where timing is important, table mode should be used.

`EXTIO,CTRL,1,HSB,MAN`
: Set HSB1 to MANUAL mode, for use with READ and WRITE

`EXTIO,WRITE,1,DOUT,1`
: Sets the CH1-DOut pin (DE15) to HIGH

`EXTIO,READ,2,OFF`
: Reads the current state of the CH2-OFF pin (DE15)

`EXTIO,MODE,1,HSB,WRITE`
: Set the entire first high-speed bank into write mode

`EXTIO,WRITE,1,HS7,ON`
: Sets port 7 of HSB1 to TTL HIGH

`EXTIO,WRITE,1,HSB,0x7`
: Simultaneously writes all pins in HSB1. Sets pins 0–2 HIGH and pins 3–7 LOW

`EXTIO,MODE,2,HSB,READ`
: Sets the entire second high-speed bank into read mode

`EXTIO,READ,2,HSB`
: Simultaneously read all 8-inputs of the second HSB, and return the result as an 8-bit number

`EXTIO,READ,2,HS3`
: Read only port 3 of HSB2 (returns `ON` or `OFF`)

A. Specifications

Parameter	Specification
RF characteristics	
Max output power	+34 dBm (normal operation) +36 dBm (sinc filter disabled)
Amplitude control	14-bit resolution
Frequency	20 to 400 MHz
Frequency control	32-bit resolution; 0.232831 Hz steps
Frequency stability	± 1 ppm (0 to 50°C)
Phase	0 to 2π (16-bit resolution)
Phase noise	< -110 dBc @ 1 kHz
Signal to noise	> 100 dBc @ 30 dBm
Intermodulation and spurious	< -55 dBc
Channel crosstalk	< -70 dBc (mean), < -57 dBc (max)
Power on, RF off	< -100 dBm
Extinction ratio	> 110 dB in 10 Hz RBW
Analogue input	
Inputs	2 per channel (4 total)
Function	FM, AM, ϕ or analogue sampling
Sensitivity	± 4 V
Bandwidth	10 MHz with 7th order anti-alias
Resolution	12-bit, 65 MHz sampling rate
Analog offset	± 3.5 V
VGA gain	-8 to +24 dB

Digital input/output (per channel)	
RF on/off	TTL hardwired, positive logic only
Trigger input	TTL input to continue table execution
Shutter output	TTL output on DE15 connector
High-speed I/O	16 x TTL shared
TTL input high	2.2 V
TTL input low	0.6 V
Absolute max in	7.0 V
Absolute min in	-0.5 V

Table mode	
Min. step size	1 μs (basic table), 16 ns (advanced table)
Max. table length	8191 instructions per channel
FLASH memory	Non-volatile storage of up to 4 tables
Trigger options	Software, or TTL via DE15 connector
Channel sync	Independent, shared trigger, or fully synchronised (software configurable)

Mechanical & power	
Display	320x240 pixel colour LCD with backlight
Fans	4x temperature controlled fans
IEC input	90 to 264 Vac, 47 to 63 Hz
Dimensions	W×H×D = 250 × 79 × 292 mm
Weight	2 kg
Power usage	55 W

B. Firmware upgrades

From time to time, MOGLabs will release updates to the XRF firmware, which enable new functionality or address issues in the version which shipped with your device. This section contains instructions on how to apply firmware updates to your device.

WARNING: Do not attempt to communicate with the XRF while a firmware upgrade is being applied, and do not interrupt an upgrade (or factory reset) in progress.

B.1 Installing a firmware update

The recommended way to install updates is using the `mogrf` application from the *Update firmware* menu item. Running the application will display diagnostic information about your device (Figure B.1).

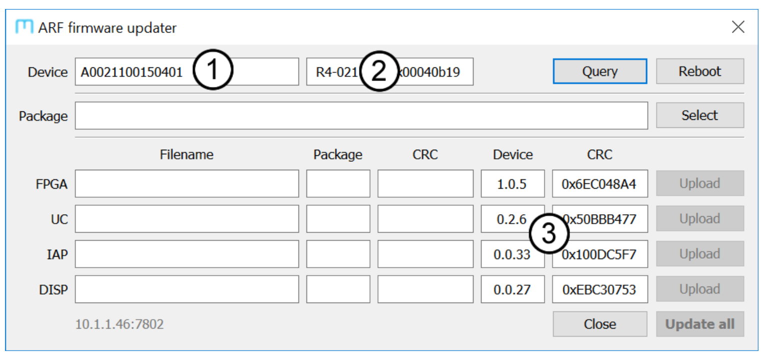


Figure B.1: The firmware update application connected to a unit, showing the serial number (1), model (2) and current firmware versions (3). Ensure that the model numbers are correct before continuing.

> **Note:** Make sure the automatically detected serial number, hardware revision and device model match the device. Uploading incorrect firmware can cause the unit to become non-operational and require return to the manufacturer to be fixed.

Update packages are available from the MOGLabs website and are loaded into the application by pressing the *Select* button. The firmware in the package is compared against the currently running version to determine which upgrades are required (Figure B.2).

Each component of the firmware is compared against the package version and colour coded as follows:

Green: Component matches package version and is up-to-date.

Yellow: Package contains an update which should be applied.

Magenta: Package contains an **older** version than currently installed. Installing this component will **downgrade** the firmware, which may be required if firmware conflict occurs.

Red: Installed version conflicts with package and may be damaged. Installation of package version is strongly recommended.

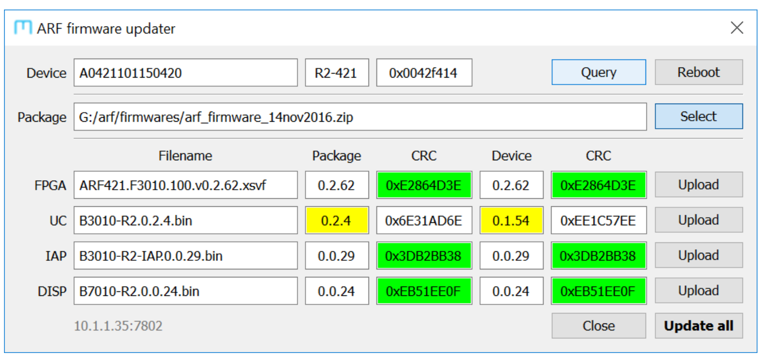


Figure B.2: The firmware update application. The versions running on the device are compared against the selected package, in this instance showing that an update is available for the UC (yellow) and the other components are already up-to-date (green).

Click on *Update all* to install all detected upgrades in sequence, otherwise individual components can be installed by clicking the *Upload* option next to each item.

The upload process proceeds through four stages:

1. The FLASH memory is erased to make room for the new image.
2. The data is uploaded to the device.
3. The device checks the data is received for consistency, to ensure the upload was successful.
4. The device is rebooted to load the new firmware.

The device will reboot after every individual component upgrade, to ensure the upload was successful before moving on to the next component.

Note: In order to upgrade the UC component, DIP3 must be set to ON, otherwise the upload will appear to succeed but the update will not be installed.

B.2 Factory reset

If a firmware upgrade fails and the device subsequently cannot boot, a factory reset (rebooting with DIP4 set to ON) must be applied. The device will then attempt to restore the configuration it was shipped with to restore operation. Once complete, the device will display a message on the front-panel LCD screen requesting that you return DIP4 to OFF and reset the device.

Note that all device settings will be overridden with factory defaults, including network settings, power limits, frequencies, calibrations, and so on. Ensure that relevant values are corrected after the reset.

Once the reset is complete, upgrade can be reattempted to gain access to newer features, or a different firmware can be applied. Please contact MOGLabs if you encounter any difficulties during firmware upgrade.

C. Command language

The protocol for communicating with an XRF is described in chapter 3, and the host software provided to interface with the unit is detailed in chapter 4.

Please note: The command language is being continuously updated across firmware releases to improve functionality and add features. When upgrading firmware, please refer to the most recent version of the manual available at `http://www.moglabs.com`

C.1 Arguments

Most commands require a channel number `ch` (either 1 or 2), and accept a comma-separated list of parameters. Parameters shown in square brackets are optional, and most commands are treated as queries when called without a value.

All commands respond with a string that begins with either OK or ERR to indicate whether it was successful. It is **strongly recommended** that commands be checked for success.

Units can be specified for values associated with frequency, power, phase and time:

Frequency Hz, kHz, MHz (default)

Power dBm (default), dB, mW, W

Phase deg (default), rad

Time ns, us (default), ms, s

Calibrations are used to convert parameters to internal discretised values. Most commands will return a message that includes the *actual* value, which may differ from the *requested* value because of discretisation and/or parameter limits.

If required, values corresponding to internal representation can be specified directly using hexadecimal format with a 0x prefix. This is potentially useful for stepping through the discrete values that the AD9910 is capable of generating.

C.2 General functions

REBOOT, RESET Initiate a soft-reset of the device, reinitialising the microcontroller, FPGA and DDS. Note that all communications links will be immediately closed so there might be no response to this command.

INFO Report information about the unit.

VERSION Report versions of firmware currently running on device. Please include this information in any correspondence with MOGLabs.

TEMP Report measured temperatures and fan speeds.

VMON Report diagnostic monitoring information about power supplies.

C.3 Basic control

MODE `MODE,ch[,type]`
Controls the operational mode of the given channel; `type` is one of NSB, NSA or TSB, corresponding to normal operation, direct DDS control, and table mode respectively (see §1.1). Some options are only available in particular modes, as specified in the commands list.

Note: this command automatically switches off the output of the specified channel.

OFF/ON `OFF,ch[,mode]` `ON,ch[,mode]`
Enable or disable the RF output of the specified channel. The signal and amplifiers can be individually controlled, which allows for more rapid switching response (see §7.6). `mode` is one of:

SIG Turn off/on the RF signal only.

POW Turn off/on the RF high-power amplifier only.
Note that the amplifiers take 2 s to completely power on.

CLOCK `CLOCK,ch`

Measures the current DDS system clock frequency for the specified channel, as measured by the FPGA over a one second window. This should return 1000 MHz, indicating that the system is correctly synchronised to the clock source. If it does not, use `CLKDIAG` to determine whether the PLL has achieved a lock to the reference.

Drift between the internal and external clocks can result in small shifts in this measurement.

CLKDIAG `CLKDIAG`

Reports diagnostic information about the status of the internal clocks. In regular operation, the Reference, System and DDS clocks should always report `OK LOCKED`.

Failure of any of the PLLs to lock can result in undefined behaviour, and is typically a result of the reference clock having incorrect amplitude or excessive phase noise.

C.8 Table mode

Table mode gives access to the powerful sequencing functionality of the XRF/XRF devices (chapter 8). XRF devices also have access to advanced table mode (chapter 9), which is controlled using the same `TABLE` commands. See section 8.2 for details on the table entry structure.

ARM `TABLE,ARM,ch`

Loads the table into the FPGA for execution, typically taking $\sim 100\,\mu s$. The table then begins execution upon receiving a software trigger (`TABLE,START`) or hardware trigger on the DE15 connector (§7.1).

Note: The table length *must* be defined before issuing `ARM` or `START`; failure to do so may result in undefined behaviour. The convenience functions (e.g. `TABLE,APPEND`) automatically update the table length.

START `TABLE,START,ch`
Provides a software trigger to initiate table execution. Calls `TABLE,ARM` if the table is not already ready for execution, which can cause a short delay before output appears.

Early 421-series models may encounter an error that the amplifiers are disabled when using this command. The recommended solution is to manually power-on the amplifiers earlier using either `ON,1,POW` or `TABLE,ARM` before the `TABLE,START` command.

STOP `TABLE,STOP,ch`
Terminates an executing table at the end of the current step. Note that the RF output will remain *on*, holding the instruction being executed when the command was received, until the table is rearmed or the output disabled with the `OFF` command.

REARM `TABLE,REARM,ch[,on/off]`
Enables/disables the automatic re-arming (loading) of the table upon completion such that it can be started again without using the `ARM` command. Table will then begin executing upon a software or hardware trigger.

RESTART `TABLE,RESTART,ch[,on/off]`
Enables/disables an automatic software-controlled restart of the table upon completion. Automatically enables `REARM`. Table will then begin executing upon a software or hardware trigger.

STATUS `TABLE,STATUS,ch`
Reports the current execution status of the table.

ENTRIES `TABLE,ENTRIES,ch[,num]`
Defines the last table entry number for the given channel. Failing to correctly set the number of entries can result in undefined behaviour.

LENGTH A synonym for `TABLE,ENTRIES`

ENTRY `TABLE,ENTRY,ch,num[,freq,ampl,phase,duration][,flags]`
Sets (or returns) the currently loaded table entry `num` of channel `ch`.

Entry numbers start at 1 and tables can contain up to 8191 entries. The structure of this command is detailed in §8.2.

Example: `TABLE,ENTRY,2,1,800MHz,0x1500,0x0000,10us`

HEXENTRY `TABLE,HEXENTRY,ch,num`
Queries the specified table entry, returning the internal hexadecimal representation of the associated frequency, amplitude and phase.

APPEND `TABLE,APPEND,ch,freq,ampl,phase,duration[,flags]`
Inserts the specified entry at the end of the table and increments the `TABLE,ENTRIES` counter.

INSERT `TABLE,INSERT,ch,num,freq,ampl,phase,duration[,flags]`
Insert the table entry at the specified index, shifts all subsequent entries down, and increments the `TABLE,ENTRIES` counter.

DELETE `TABLE,DELETE,ch,num`
Deletes the specified table entry, shifting all subsequent entries up and decrements the `TABLE,ENTRIES` counter.

RAMP `TABLE,RAMP,ch,param,start,stop,duration,count`
Creates a linear ramp in `param`, which is one of `FREQ`, `AMPL` or `PHAS`, from `start` to `stop` in `count` steps, each lasting `duration`. In simple table mode this generates `count` table entries, whereas in advanced table mode it generates up to three.

SAVE `TABLE,SAVE,ch,slot`
Save the current table in a FLASH memory slot, where `slot` is a number from 1 to 4. Uploading tables in binary format is also possible using the `mogrf` host software.

LOAD `TABLE,LOAD,ch,slot`
Loads the table from the specified slot in FLASH memory to the designated channel.

COPY `TABLE,COPY,src,dest`
Copies the table data from the `src` channel to the `dest` channel.

SYNC `TABLE,SYNC[,onoff]`
Enable or disable table synchronisation mode (see §8.8), which sets CH1 as a master table and CH2 as a slave table. Both tables then execute simultaneously when CH1 is started.

TRIGSYNC `TABLE,TRIGSYNC[,onoff]`
Enable or disable DE15 trigger synchronisation between the two channels, which causes CH2 to take its DE15 trigger from CH1. This option is a more precise equivalent of wiring the two inputs together.

NORESET `TABLE,NORESET,ch[,onoff]`
Disables table-mode phase reset for the specified channel. Normally the DDS phase accumulator is reset when the table is started, ensuring that the output waveform has the same starting phase for every execution. However, this requires switching off for a few microseconds while the DDS is reset, which is undesirable for some applications. Using `NORESET` will ensure the output stays on.

XPARAM `TABLE,XPARAM[,mode][,gain]`
TPA mode only (XRF). Set the parameter to be modified on the parallel bus in advanced table mode. The parameter `mode` is one of `FREQ`, `PHASE`, `POWER` or `AMPL`. If `mode` is `FREQ` then an optional FM-gain can be specified (§9.7), otherwise defaults to 15.

DUMP `TABLE,DUMP,ch`
Transmits the raw table data for the specified channel in binary form. The command should not be used from an interactive terminal. The first 4 bytes of the response are payload size, followed by that many bytes of data. The expected payload is $16 \times (N + 1)$ bytes, where N is the number of table entries.

Note that raw table data may be incompatible between different firmware versions.

UPLOAD `TABLE,UPLOAD,ch,nbytes`
Upload binary table data for channel `ch`. The data should first be downloaded with `TABLE,DUMP`. `nbytes` is the byte length of the table.

D. Code examples

The following simple examples demonstrate how to communicate with the XRF over ethernet in several languages, using the bindings provided by MOGLabs. Further examples are available from the MOGLabs website.

D.1 `python`

Communication is handled by a "device" class, which provides convenience functions for sending commands and queries.

```python
#-----------------------------------------------------------
# XRF python example, (c) MOGLabs 2016
#-----------------------------------------------------------
from mogdevice import MOGDevice

# connect to the device
dev = MOGDevice('10.1.1.23')
# print some information
print('Device info:', dev.ask('info'))

# example command: set frequency
dev.cmd('FREQ,1,100MHz')
# example query: check frequency
print('CH1 Freq:', dev.ask('FREQ,1'))
# some queries can return dictionaries
print('Temperatures:', dev.ask_dict('TEMP'))
# other queries respond with binary data
tbl = dev.ask_bin('TABLE,DUMP,1')
print('Binary table:', len(tbl))
# close the connection
dev.close()
```

The next example shows how to construct a Gaussian pulse using `numpy` and the `MOGDevice` class, showing how easy it is to generate arbitrary waveforms. The resulting waveform is shown in Figure D.1.

```
#-----------------------------------------------------------
# XRF Gaussian pulse example, (c) MOGLabs 2016
#-----------------------------------------------------------
from mogdevice import MOGDevice
import numpy as np
# connect to the device
dev = MOGDevice('10.1.1.45')
print('Device info:', dev.ask('info'))

# construct the pulse
N = 200
X = np.linspace(-2,2,N)
Y = 30*(np.exp(-X**2)-1) # -30 to 0dBm

dev.cmd('MODE,1,TSB') # set CH1 into table mode
dev.cmd('TABLE,ENTRIES,1,0') # clear existing table
for y in Y: # upload the entries
    dev.cmd('TABLE,APPEND,1,100,%.2f,0,5'%y)
print(dev.cmd('TABLE,ARM,1')) # ready for execution
```

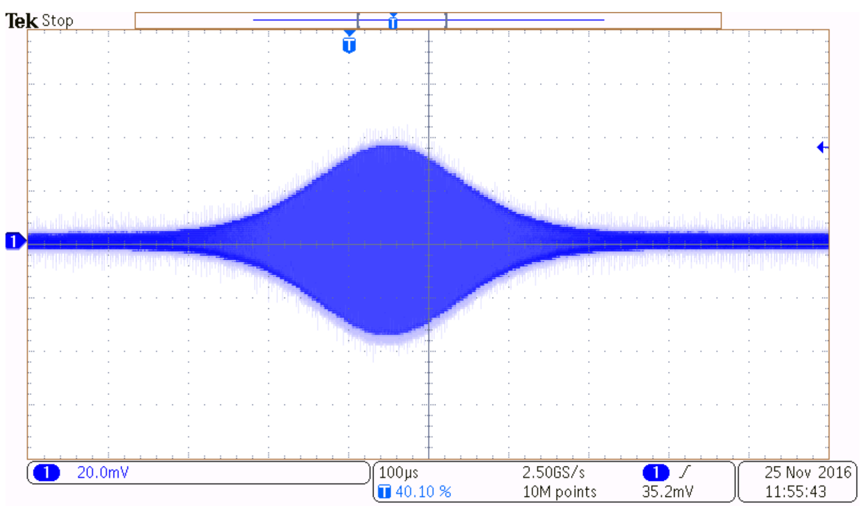


Figure D.1: Pulse with a Gaussian envelope, created in table mode using the example python code.

D.2 matlab

Similar to the python bindings, a class is provided to make controlling the XRF easy using matlab. The listing below demonstrates how to create a simple table that produces a pulse with a Gaussian envelope.

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% XRF MATLAB example, (c) MOGLabs 2017
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% create a device instance
dev = mogdevice();
% example: connecting by ethernet
dev.connect('10.1.1.31');
% print some information about the device
disp(dev.ask('INFO'));

% create a gaussian envelope
N = 500;
pulse = exp(-(8*((0:N)/N - 0.5)).^2);
plot(pulse)
% convert mW to dBm
pulse = 10*log10(pulse);

% upload gaussian pulse in simple table mode
dev.cmd('MODE,1,TSB');
dev.cmd('TABLE,CLEAR,1');
disp('Uploading␣table...')
for i=1:length(pulse)
    % we can use printf notation when sending commands
    dev.cmd('TABLE,APPEND,1,100MHz,%f␣dBm,0,1us',pulse(i));
end
disp('Done')
dev.cmd('TABLE,ARM,1')
dev.cmd('TABLE,START,1')

% close the connection
delete(dev);
```

D.3 `LabVIEW`

The `LabVIEW` drivers provided make use of `NI-VISA` to provide a unified interface over both ethernet and USB. They perform automatic error checking, and are compatible with `LabVIEW`-2009 and later editions.

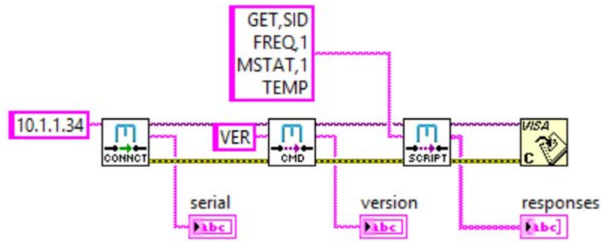


Figure D.2: Example `LabVIEW` program that connects to an XRF unit, and performs a number of queries

When using these drivers, it is strongly recommended that the automatic session close option be enabled, to prevent communications problems if the VI aborts or is interrupted. The option is found in Tools→Options→Environment→Automatically close VISA sessions.

E. Troubleshooting

The following is general troubleshooting advice for unexpected behaviour. Please contact MOGLabs (support@moglabs.com) for further assistance

The command `ADC,ch,F` provides a useful diagnostic for checking the output power from the device without needing to connect test equipment. The power out of the specified channel is measured using a directional coupler after the switch and amplifiers. The true output power should be within a few dB of the reading.

E.1 Computer interface

Advice for resolving common issues is contained in the *Drivers and Connection Guide* available from the *Support* section of our website at `www.moglabs.com`. The guide provides instructions for connecting the XRF to a computer by Ethernet or USB.

E.2 Unexpectedly high output power

This may occur when AM is enabled but the AM input port is left disconnected, which causes the amplitude to rise by the AM gain. Ensure that modulation is disabled when the input port is disconnected. Note that the output power will be less than the limit power (see `LIM` command) even when modulation is enabled, but may be circumvented in advanced modes (NSA or TPA).

E.3 Incorrect output frequency

This typically only arises when FM is enabled or the reference clock provided to CLK IN connector is not supported. Note that a disconnected modulation input is not the same as providing a 0 V input signal.

Confirm that FM is disabled and check that CLKSRC is set to INTERNAL. If synchronisation to an external clock is desired, confirm that the clock satisfies the requirements in §C.7.

E.4 Fan stall error

The XRF contains several fans to manage the thermal load of the high-power RF amplifiers. The fan speeds are temperature-controlled, and they will only turn on if required. Failure of the fans will disable the RF outputs to prevent thermal damage to the unit, and an error message will be displayed. If that occurs, check for obstruction of the fans and for anything that could restrict airflow.

E.5 Unsupported load error

The XRF is designed to drive a 50 Ω load, but is capable of driving mismatched loads without damage. However, driving a (near) short-circuit will draw significantly more power and reduce the lifetime of the amplifiers, so the RF output will be shutdown in this situation. Check the resistance of the load and confirm it is not damaged or accidentally shorted.

Note that when the sinc filter is disabled (see §C.4) this error may occur when driving high power at low frequency ($<$ 25 MHz).

E.6 No RF output power

There are a number of interlock and safety features that can cause the output to be disabled. These scenarios should result in error messages being produced, either on the display or as a response to the command instructing the output to be activated.

The front-panel LEDs indicate whether the device expects that output should be generated. If the LEDs do not light up as expected, there is likely an error condition. Check for errors by connecting with the `mogrf` software and turning on the output through the application.

If there is no error, verify that the CHx-OFF functionality is disabled. In particular, the LATCH feature may cause the output to be turned off immediately after enabling it if the TTL input is left floating.

If the LEDs are lit but no output is observed, verify that AM and CHx-OFF are disabled, as these can cause the output power to be zero despite the apparent requested power being nonzero.

In the case where modulation is disabled, or the output power is $\sim 30\,\text{dB}$ lower than expected, verify that the power amplifiers are enabled by checking the supply current with the VMON command or opening the Diagnostics window in `mogrf`. Contact MOGLabs for further assistance

E.7 CHx-OFF has no effect

The CHx-OFF functionality for generating pulses is disabled by default (§7.4) and must be enabled through the interactive menu system, the host software, or via a relevant EXTIO command.

E.8 FPGA PROGRAM or VERSION error

This error can occur if a firmware update is aborted, or a factory reset is performed. Please complete a firmware upgrade to the latest version to resolve the issue.

F. Low-frequency output

The XRF provides RF generation across the range 20–400 MHz, but some applications may require frequencies outside this range. It is possible (but not recommended) to access the full range of the integrated DDS by *unlocking* the frequency limits.

The behaviour of the integrated RF power amplifiers is not specified outside the intended operating frequency range, and the **device performance specifications no longer apply**. In particular, the power calibration, maximum output power, distortion, current draw, and monitor outputs will be adversely affected.

WARNING: MOGLabs is not responsible for device behaviour when operated outside the specifications. Calibrate performance on a 50 Ω load before use.

The output power of the device drops rapidly below 20 MHz, and device calibration should not be relied upon. Typical variation in output power is shown in Figure F.1. The amplifier current draw can also increase, which can result in a "load error" shutdown, implying the output power must be reduced at that frequency.

F.1 Unlocking low-frequency output

Due to the variation in behaviour, operation outside the specified frequency range must be explicitly unlocked using the `UNLOCKFREQ` command on a **per-channel** basis. The command can be issued using the *Device Commander* as part of the `mogrf` application.

The `UNLOCKFREQ,ch[,mode]` command can query or set the operational mode of the specified channel `ch`, where `mode` is one of `NORMAL`, `UNLOCKED` or `LF-TAP`, as shown in the example below.

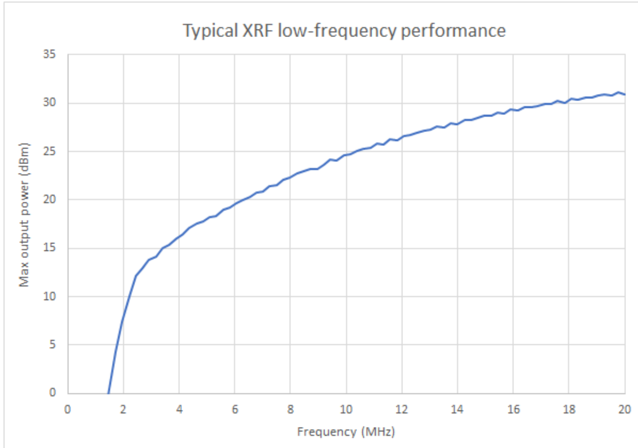


Figure F.1: Example frequency sweep showing variation in output power below 20 MHz at +33 dBm requested power.

```
UNLOCKFREQ,1,UNLOCKED
UNLOCKFREQ,2,NORMAL
```

Listing F.1: Demonstration of using the UNLOCKFREQ command to set CH1 to unlocked mode and CH2 to normal mode.

F.2 Low-frequency tap

An alternative option is to bypass the power amplifiers and tap the RF output directly out of the DDS. This avoids the behaviours related to the amplifier performance at the expense of much lower output power (typically up to -5 dBm) and no output monitoring.

The RF tap is provided on an SMA connector internal to the unit (Figure F.2), which can provide low-frequency generation down to near DC. In this mode the associated external rear-panel SMA outputs cannot be used, and the user must attach cables as appropriate to route the RF from each of the tap outputs to external connections outside the unit.