USER’S MANUAL

UKUS

INDICE DE REVISION		-1	A	B	C	D
Etabli par :	Date : Nom :	17/09/15 Stern G.				

INDICE DE REV.	DESCRIPTION DES EVOLUTIONS
-1	1st version
A	
B	

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GLOSSARY

EDFA :	Erbium Doped Fiber Amplifier
PPLN(-WG) :	Periodically-Poled Lithium Niobate (Wave Guide)
N/A:	Not applicable
Phd :	Photodiode
M, Master:	Refers to the Master laser source
^{85}Rb :	Rubidium 85
AOM:	Acousto-Optical Modulator
Autolock, autorelock	Automatic lock or relock procedure.
S0, Slave_0:	Refers to the Slave0 laser source acting as the MOT laser
S1, Slave_1:	Refers to the Slave1 laser source acting as the Raman 1
S2, Slave_2:	Refers to the Slave1 laser source acting as the Raman 2
MOT:	Magneto Optical Trap
DDS:	Direct Digital Synthesizer
PLL:	Phase Locked Loop
RaspPi:	Raspberry Pi onboard computer
MPhi:	Phase modulator
MW:	Microwave

1 WARNINGS

The following information is relative to safety. Before using the laser system, the user has to read the full document, and especially the part concerning the laser and electrical risks.

1.1 General safety instructions, liability and warranty

- All work described in this document may only be carried out by persons who have suitable technical training and the necessary experience or who have been instructed by the end-user of the product.

- Muquans assumes no liability and the warranty becomes null and void if the end-user or third parties:

  - disregard the information in this document.

  - use the product in a non-conforming manner.

  - make any kind of interventions (modifications, alterations etc.) on the product.

  - use the product with accessories and options not listed in the corresponding product documentation.

1.2 Laser risks

INVISIBLE LASER RADIATION
AVOID EXPOSURE TO BEAM
CLASS 4 LASER PRODUCT

- Laser risks and safety rules are defined according to the norm NF EN 60825-1.

- A Class 4 laser may cause severe, permanent damage to eye or skin without being magnified by optics of eye or instrumentation. Diffuse reflections of the laser beam can be hazardous to skin or eye.

- Laser system should not be operated unless all appropriate safety precautions are taken. These include, but are not limited to:
  - wearing protective safety glasses by all people in the vicinity of the laser system
  - installing warning lights, signs, safety screens and/or curtains
  - implementing a safety interlock so the amplifier shuts down if someone unexpectedly enters an area containing the laser
  - containing the beam to eliminate or minimize the possibility of exposure to the beam

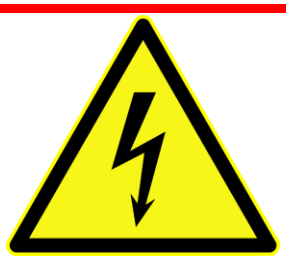
- Use of the laser system other than as specified herein may result in hazardous radiation exposure.

- Use of optical instruments with the system UKUs may increase eye hazard.

Laser risks.

Laser specifications.

1.3 Electrical risks



- Incorrectly grounded products can be extremely hazardous in the event of a fault. The power connector may only be plugged into a socket with a protective ground. The protection must not be nullified by an extension cable without protective ground.

- Hazardous voltages are present in the system. It should only be open by qualified personnel.

1.4 Other safety considerations

- The device must be located in order to keep free the fan air outlets at the rear panels of the racks.

- Do not close the cabinet containing the system.

- Switching OFF and ON the system with the key switch in a fast way can damage the fuse. Please wait for ten seconds after switching OFF the system before to switch it ON again.

2 LASER SYSTEM PRESENTATION

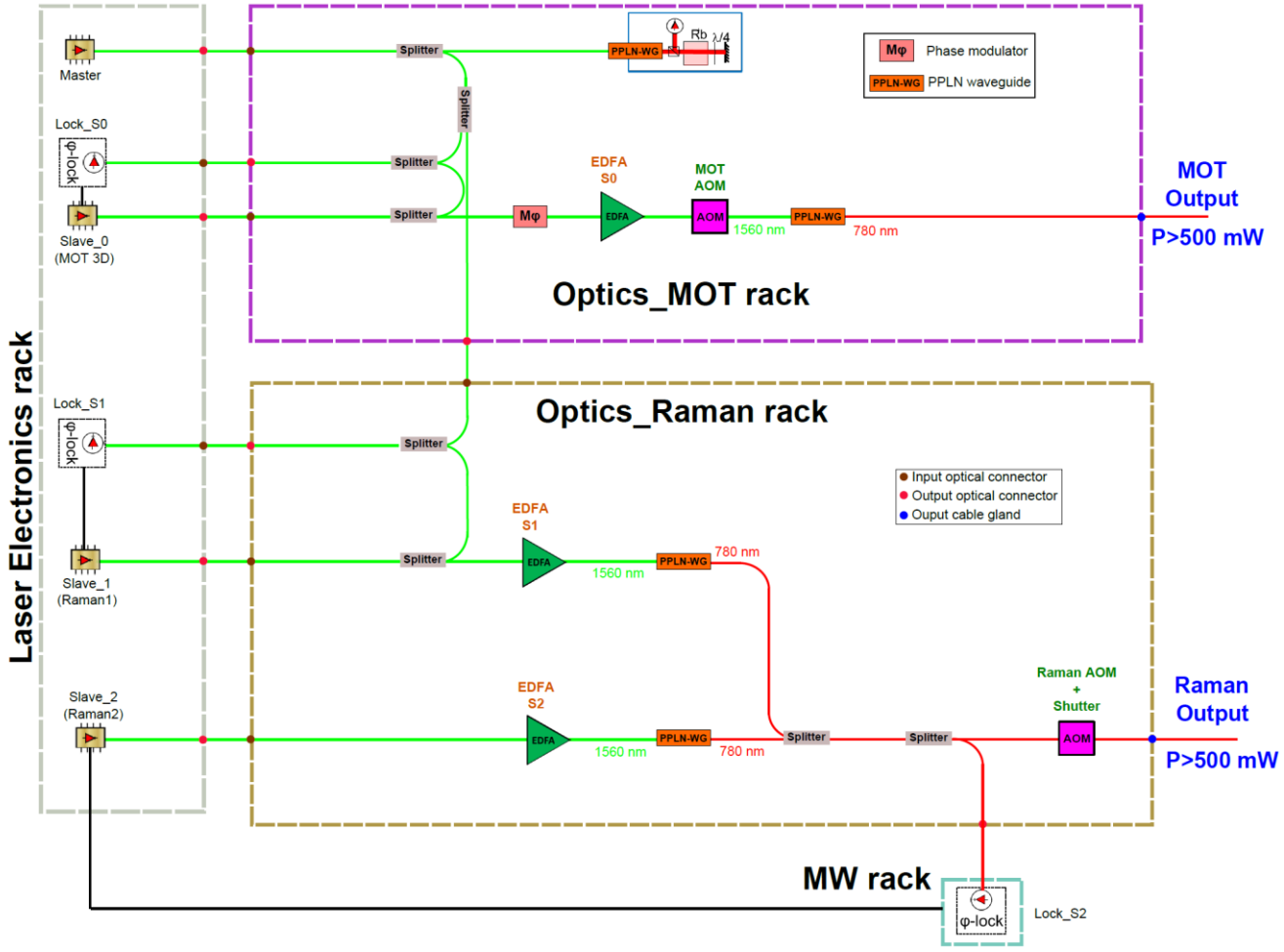
The UKUS laser system provides two laser outputs at 780 nm. The MOT output fulfills the requirements in term of frequency and power to get a MOT with the suitable experiment setup. The Raman output can be used to generate Raman pulses for atomic interferometry.

2.1 Laser diagram

All the laser diodes work at 1560 nm. The Master laser diode is locked on a ^{85}Rb absorption line (crossover 3x4 of ^{85}Rb) and acts as the optical frequency reference for the system. After a splitting/combining stage[1], two slave diodes, Slave_0 and Slave_1, are phase locked on the Master diode. The last slave diode, Slave_2, is phase locked on the Slave_1 diode after splitting and combining at 780 nm.

The S0 diode is phase modulated, amplified with an EDFA and frequency doubled. The output power can be adjusted thanks to an AOM located before the waveguide.

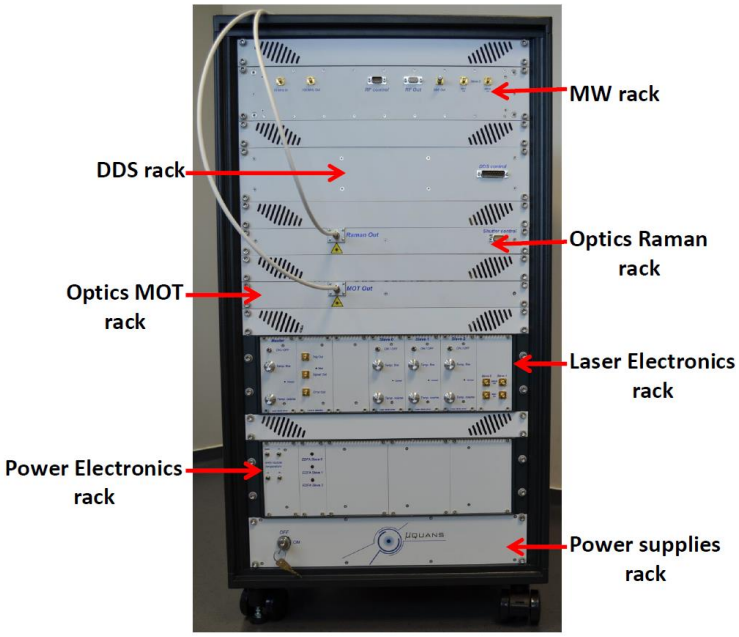
The S1 and S2 diodes are amplified with EDFA's, frequency doubled and combined in a crossed configuration (ie S2 is along the slow axis of the fiber and S1 along the fast axis). An AOM allows controlling the output power of the Raman fiber.



Laser system diagram

[1] A beat note between the Master diode and the S0 or S1 diode is obtained after combination on a fast photodiode. This beat note is then sent on a PLL whose the reference frequency is controlled with a DDS.

2.2 Laser description



Designation	Description
Power supplies rack	Contains the power supplies to generate all the voltages required by the system.
Power Electronics rack	Contains EDFA drivers.
Laser Electronics rack	Contains laser diodes, lock-in detection, S0 and S1 phase locks.
Optics MOT rack	Contains the laser components for the MOT laser.
Optics Raman rack	Contains the laser components for the Raman laser.
DDS rack	Contains DDS's and AOM drivers.
MW rack	Contains the microwave components for the Raman frequency generation.

2.3 Interconnections

All the cables are already connected. The user isn't supposed to disconnect them without recommendation from Muquans.

3 OPERATING INSTRUCTIONS

3.1 Connecting fibers

- Ensure that the device is not powered up.

- The system is delivered with fiber connectors FC/APC. To connect this system to others devices, please check the connector compatibility.

- Remove protection caps from fiber connectors.

- Clean optical connectors.

- Connect cleaned optical connectors to the suitable device.

3.2 Starting procedure

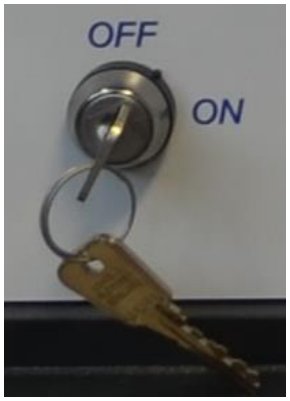
- Check that both the mains switch and the key switch are on the OFF position.

- Connect the *Shutter control*, *RF control* and DDS *control* connectors. The levels must be 0V on all inputs.

- Plug the power cable to the mains socket (230 V, 50 Hz).

- Turn the main switch on the ON position (on the rear panel of the Power Supplies rack).

- The start key (see below) is on the front panel of the Power Supplies rack. Turn the key on the ON position. The system is now ready to use.



- Connect the control computer to the laser with an RJ45 cable and open the required windows (see annex). We suppose that the Gplot server is activated. The commands are described in annex.

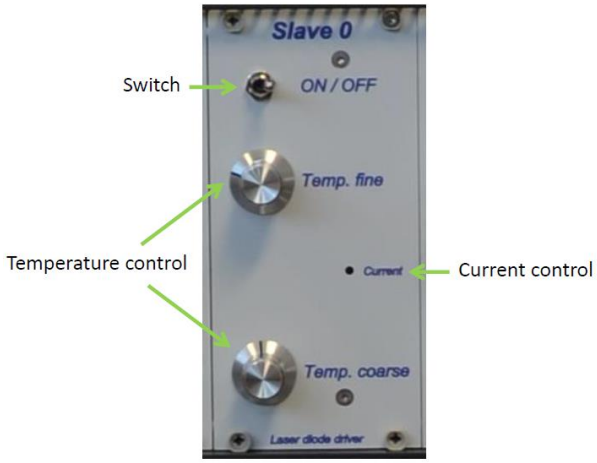
3.2.1 Power up the diodes

- All the laser diodes have the same controls. The *ON/OFF* switch allows to power up the diode. The *Temp. fine* potentiometer is a one-turn potentiometer to change slightly the diode temperature and the *Temp. coarse* potentiometer allows to change it in a coarser way. The current can be adjusted with a trimmer.

- In the Monitor_1 window[2], type the command *ukus cplot*. The most relevant parameters are now displayed in the window. You can travel with arrows from some parameters to others.

- Push the switch to the ON position for the Master, Slave 1 and Slave 2 diodes. In the Monitor_1 window, the Idiode and Back Facet parameters now indicate the operating values of the diodes.

[2] See annex for window description.



Laser diode driver front panel

```
UKUS_MASTER_SLAVE0_DIODES_ANALOG_IN

Error DS : 1.267090 V
Slave 0 RIO Back facet : 4.035000 V
Slave 0 RIO LM35 : 0.367000 V 36.700000 degC
Slave 0 RIO TEMP : 3.226000 V 23.711884 degC
Slave 0 RIO IDIODE : 0.177000 V 177.000000 mA
Master RIO Back facet : 2.261000 V
Master RIO LM35 : 0.412000 V 41.200000 degC
Master RIO TEMP : 3.332000 V 22.106366 degC
Master RIO IDIODE : 0.132000 V 132.000000 mA
```

Monitor_1 window: the current value (IDIODE) and the Back Facet value (related to the diode output power) change when the diode are ON. The diode temperature is also indicated.

3.2.2 DDS programming

First program the DDS frequencies used for the phase locks, AOM's, antenna and phase modulator. In the DDS_Slave window, type the following commands[3]:

ukus dds_slave0_set 80e6 0 0

ukus dds_slave1_set 70 e6 0

ukus dds_slave2_set 95e6 0

ukus dds_raman_set 65e6 0

In the DDS_AOM window, type the following commands:

ukus dds_mphi_set 104.25e6 0

ukus dds_antenna_set 165e6 0

ukus dds_aom_raman_set 110e6 0

ukus dds_aom_mot_set 110e6 0

- With these values, the beat note frequency M/S0 @ 1560 nm when the S0 laser is locked will be 8*80 MHz=640 MHz. The beat note frequency M/S1 @ 1560 will be 32*70MHz=2240 MHz and the beat note S1/S2 will be 6.835 GHz. The beat notes can be visualized on the *BEAT note* outputs.

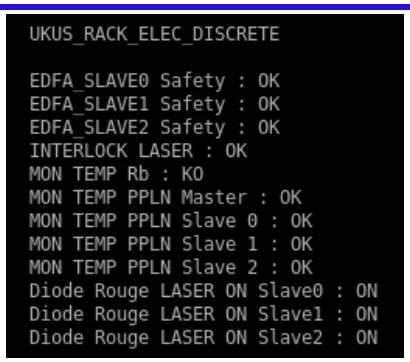
- The drive frequency is 110 MHz for both AOM's.

- The real-time control of DDS is in a read_me on the computer.

3.2.3 EDFA control

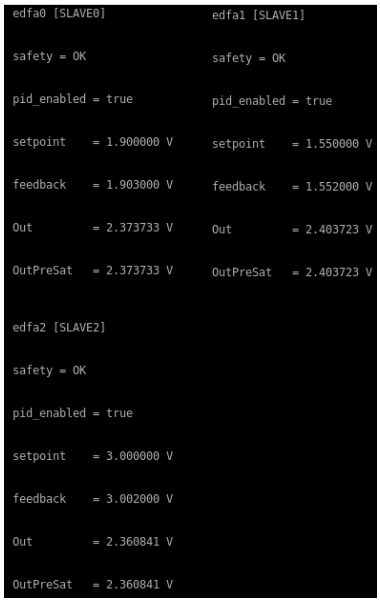
- Wait for the PPLN temperature being OK in the Monitoring_2 window to get the phase matching temperature and so frequency doubling. You can get this information by typing *ukus cplot* in the Monitoring_2 window.

[3] See annex for the link between the DDS value and the laser/mphi/antenna output frequency. Values here are for example purpose.

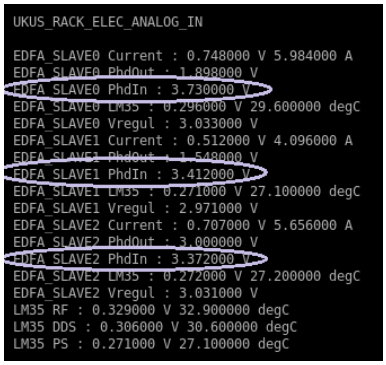


Temperature control in EDFA_monitoring window

- In the EDFA_monitor window, type the command *driver_edfa_tool plot_all*. The EDFA control parameters are now displayed in the window.



- In the Monitor_2 window, check the PhdIn level. It must be more than 2.5 V for all the EDFA's to rearm them.



- Rearm the S0, S1 and S2 EDFA with the commands in the EDFA_control window:

driver_edfa_tool rearm edfa0

driver_edfa_tool rearm edfa1

driver_edfa_tool rearm edfa2

- The safety status turns to OK in the EDFA_monitoring window.

- The ouput power of the EDFA is regulated at a fixed set point determined by the output photodiode. Set the power setpoints with the commands:

driver_edfa_tool ctrl_phd_out edfa0 1.9

driver_edfa_tool ctrl_phd_out edfa1 1.55

driver_edfa_tool ctrl_phd_out edfa2 3

- The maximum setpoint is 1.9 V for S0 and 3 V for S1 and S2. However, the phase lock S1/S2 has been optimized for the S1 EDFA working at 1.55 V (see annex).

- **As soon as the *driver edfa tool ctrl phd out* command is used, power at 780 nm is potentially available at the fibers outputs depending on the AOM and shutters status. Be sure that the fibers are connected to the right optical device.**

3.2.4 Locking the lasers

- Let the system warm for 20-30 minutes before locking the diodes.

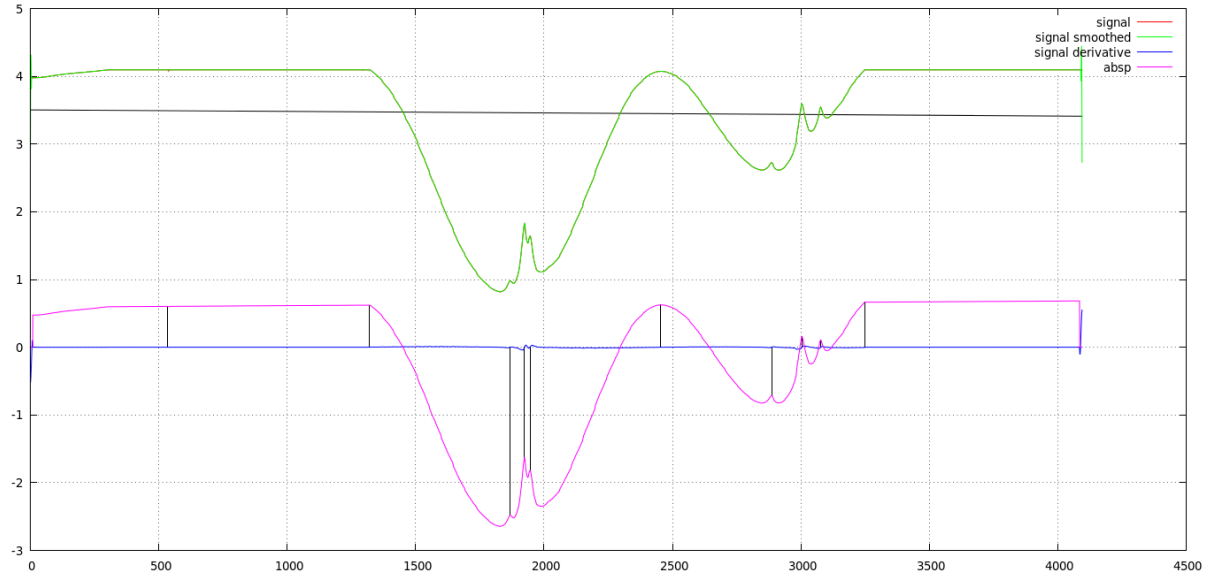
- In the Autolock_Monitor window, type the command *ukus autolock_monitor*. The lock parameters are now displayed in the window.

- Type the commands below in the Autolock_control window:

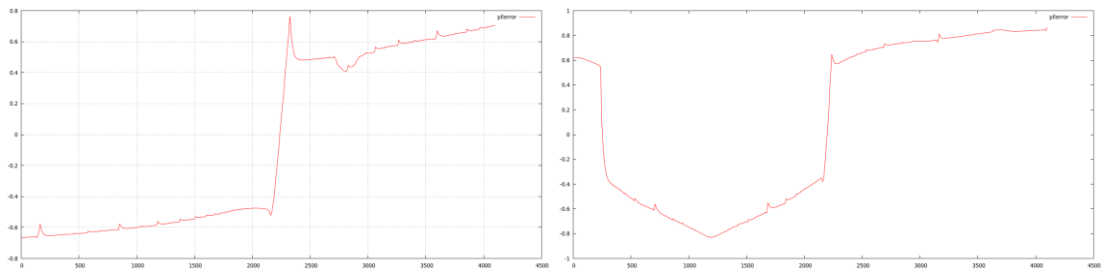
ukus all_lockout

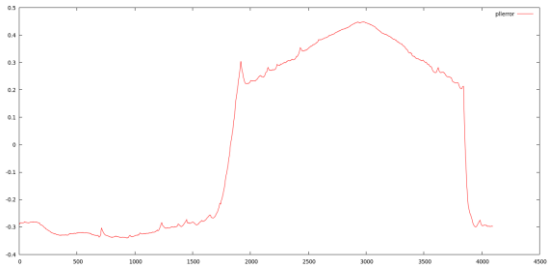
ukus all_lock

- The *all_lockout* command initializes the lock system. The *all_lock* command makes the Master laser lock first, then the S0 laser, the S1 laser and finally the Slave2 laser. The full procedure lasts about 1 minute. If the GPlot Server is activated, the following windows appear:



Saturated absorption window: this is the absorption signal used to lock the Master laser diode. The absorption dips must be near the middle of the scan range.

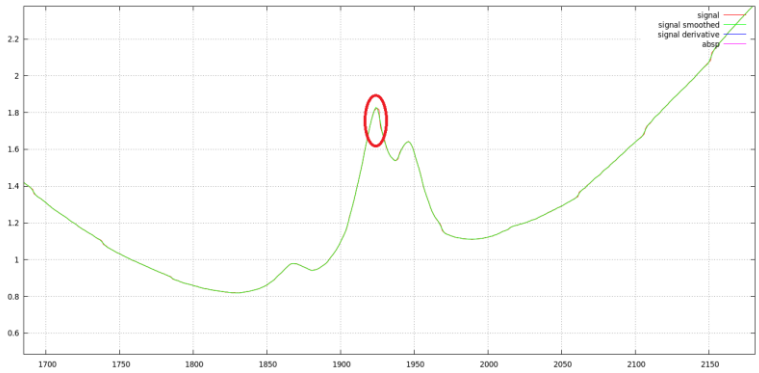




Error signals for S0, S1 and S2; the 0-crossing from negative to positive must be near the middle of the scan range.

- At the end of the lock procedure, the statuses are displayed in the Autolock_monitor window with the command *ukus autolock_monitor*:

Autolock monitor parameters; the Master laser is locked on the right absorption dip if the *absp* parameter (here 1.756513 V) is near the value of the crossover 3x4 of ^{85}Rb where the laser is supposed to lock (see below)



- It's possible that the diode setpoints changed after a travel or with a different room temperature. In this case, the diode temperature[4] must be adjusted in order to get the above signal in the middle of the scan range (please refer to the previous pictures). For the Master laser, the command *ukus autolock_scan_only* activates a periodic frequency sweep on the diode which makes easier the absorption signal search. For the slave diodes, the *BEAT Out* outputs are useful to bring the slave lasers to the expected frequency once the Master laser is locked[5].

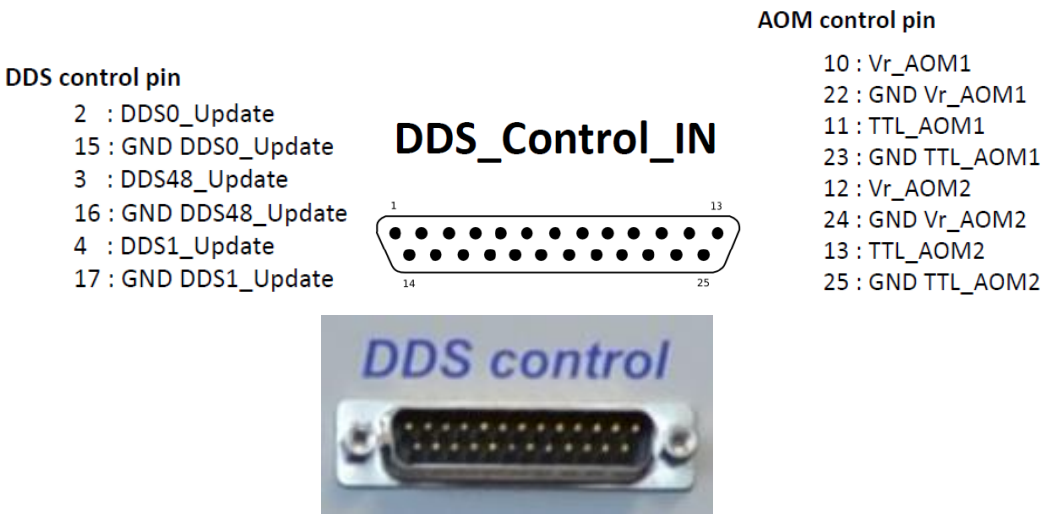
3.2.5 AOM

- AOM's are driven at 110 MHz. We strongly recommend switching on the RF frequency as soon as possible, especially for the Raman AOM, because the warm up time is quite long (30 minutes).

[4] We strongly recommend not touching the diode current unless asked by Muquans.

[5] Be careful with the sign: once the Master locked, the beat note M/S0 must increase if the S0 laser temperature increases and the beat note M/S1 must decrease if the S1 laser temperature increases. When S1 is locked, the beat note S1/S2 must increase if the S2 laser temperature increases.

- The applied microwave power is controlled through external analog and digital signals applied on the *DDS control* connector. The analog signals must be in the range [0V-5V] and the digital level no more than 5V. Here is the pinout of the *DDS control* connector:



DDS control connector. AOM1 refers to Raman AOM and AOM2 to MOT AOM.

3.2.6 Shutter

- A shutter is located just before the Raman AOM to improve the extinction ratio.

- In the Shutters window, initialize the shutters state with the command:

shutters reinit

- After initialization, the shutter is open.

- With the command *shutters enable*, it can be controlled with external digital signals (<5V) applied on the *Shutter control* connector. Here is the pinout:

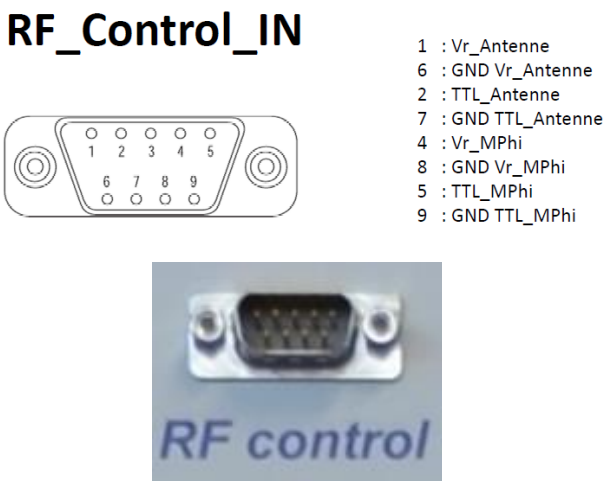
Shutter control connector.

- With the external control, shutters are open when the digital signal is high and closed when low.

- The command *shutters shutdown* inhibits the external control. Use the initialization command before enabling the external control again.

3.2.7 Phase modulator and MW antenna

The phase modulator allows the generation of sidebands around the S0 optical frequency to get a repumping laser when the right frequency is applied on it. The relation between the DDS value and the sideband frequencies is given in annex. The sideband power is controlled through external analog and digital signals applied on the *RF control* connector (see pinout below). The analog signal must be in the range [0V-5V] and the digital level no more than 5V.



RF control connector (Antenne is for antenna and MPhi for the phase modulator)

The RF control connector also allows the control of the MW Out power used to drive MW transition during the experimental sequence. The power is controlled through external analog and digital signals applied on the *RF control* connector (see pinout above). The analog signal must be in the range [0V-5V] and the digital level no more than 5V.

3.2.8 Interlock

The system is provided with an interlock safety. The connector is on the rear panel of the Power rack. The 2 poles of the connector must be shortened to enable the laser. The user can connect it to an external circuit.

3.3 Switching off the system

- Set all the external signals to 0V.
- Inhibit the shutter external control.
- Unlock the 4 lasers with the command *Ukus all_lockout*.
- Stop the EDFA's with the commands:

    driver_edfa_tool shutdown edfa0

    driver_edfa_tool shutdown edfa1

    driver_edfa_tool shutdown edfa2

- Switch off the diodes.
- Turn the key switch on the OFF position.
- Turn the main switch on the OFF position.

3.4 Assistance

Should a problem occur, please contact Muquans before operating the system in a debug mode.

SOFTWARE ANNEX

- In the folder /home/user/, click on startUkus.sh.

- 9 windows will open (description below). Open 2 new tabs (File→Open tab).

- In the first new tab, open a Gplot server with the command:

gplot_server tcp 2000

- In the other one, type the command:

user@ukus:~$ sudo su

pwd: user

cd ukus_dds_dist/prod

./test_ukus_dds set_all_gpios_to_gnd

- The 9 windows are dedicated to specific tasks provided that the right command is used as explained in the manual:

- Monitor_1: display of diode parameters.

- Autolock_monitor: display of lock parameters.

- Autolock_control: control of laser locks.

- Shutter: shutter control.

- Monitor_2: display of global analog and digital parameters.

- EDFA_monitor: display of EDFA parameters.

- EDFA_control: control of EDFA.

- DDS_Slave: DDS programming for laser locks.

- DDS_AOM: DDS programming for AOM's, antenna and phase modulator.

- Typing *ukus* gives you the list of the available commands for each window. Some of them are only for debug purpose. We describe below only the useful ones (examples for syntax are in the manual):

ukus autolock_scan_only: to sweep the Master laser frequency to look for the absorption lines for example.

ukus autolock_lock: to lock only the Master laser.

ukus autolock_slave0: to lock only the S0 laser.

ukus autolock_slave1: to lock only the S1 laser.

ukus autolock_slave2: to lock only the S2 laser.

ukus all_lock: to lock all the three lasers one after another (Master, S1 then S2).

ukus all_lockout: to unlock all the lasers at the same time.

ukus dds_slaves_reset: to reset the DDS used for laser locks.

ukus dds_slave0_set <freq Hz> <phase rad>: to set the DDS used for the S0 lock at the suitable frequency.

ukus dds_slave1_set <freq Hz> <phase rad>: to set the DDS used for the S1 lock at the suitable frequency.

ukus dds_slave2_set <freq Hz> <phase rad>: to set the DDS used for the S2 lock at the suitable frequency.

ukus dds_raman_set <freq Hz> <phase rad>: to set the Raman DDS used for the S2 lock at the suitable frequency.

ukus dds_mphi_set <freq Hz> <phase rad>: to set the DDS used for the MPhi at the suitable frequency.

ukus dds_antenna_set <freq Hz> <phase rad>: to set the DDS used for the antenna at the suitable frequency.

ukus dds_aom_raman_set <freq Hz> <phase rad>: to set the DDS used for the AOM Raman at the suitable frequency.

ukus dds_aom_mot_set <freq Hz> <phase rad: to set the DDS used for the MOT Raman at the suitable frequency.

ukus cplot: to display the relevant parameters in the current window.

ukus autolock_monitor: to plot the absorption signal for the Master laser and the error signals for the slave lasers during the lock procedure.

- Typing *driver_edfa_tool* in the EDFA windows gives you the list of the available commands for the EDFA control. Some of them are only for debug purpose. We describe below only the useful one (the parameter <edfa> is either *edfa0* for EDFA S0, *edfa1* for EDFA S1 or *edfa2* for EDFA S2):

driver_edfa_tool rearm <edfa>: to rearm the EDFA designed by <*edfa*>

driver_edfa_tool ctrl_phd_out <edfa> <setpoint V>: to control the output power of the EDFA. <*setpoint V*> must not exceed 3V for S1 and S2 and 1.9 for S0.

driver_edfa_tool shutdown <edfa>: to switch off the EDFA.

driver_edfa_tool plot_all: to plot the relevant EDFA parameters.

- Typing *shutters* in the Shutter window gives you the list of the available commands for the shutter control. Here is the list of commands and their description:

shutters reinit: to initialize the shutters state (open or close).

shutters enable: to control the shutters state with an external digital signal.

shutters shutdown: to disable the external control of the shutters state.

DDS ANNEX

We give here the link between the DDS values and the output frequencies of beat notes, antenna and phase modulator sidebands. Be careful at which wavelength the value is given and don't forget to consider the AOM frequency to get the absolute frequency at the output fiber. The DDS frequency is F_{ref}.

DDS	What	Wavelength	Frequency	Comments
Slave0	Beat note M/S0	1560 nm	8* F_{ref}	
Slave1	Beat note M/S1	1560 nm	32* F_{ref}	
Slave2			95 MHz	Fixed value
Raman	Beat note S1/S2	780 nm	7.095 GHz- 4*F_{ref}	
MPhi	Sideband	780 nm	(3.5 GHz-2* F_{ref})*2	From S0
Antenna			7 GHz- F_{ref}	

Quick MOT setpoint (tested with success):

DDS S0: 81.312 MHz gives a beat note M/S0 at 650.5 MHz. The S0 absolute value is then 15 MHz on the red of the ^{87}Rb 2→3 transition.

DDS MPhi: 104.25 MHz gives sidebands @ 6.583 GHz apart from the S0 frequency. This gives a repumping frequency close to the ^{87}Rb 1→2 transition.

RAMAN PHASE LOCK ANNEX

The Raman phase lock has been optimized for a detuning for the S1 laser 750 MHz on the red of the ^{87}Rb F=1→F'=1 transition. Around this value, the ratio to compensate the light shift I_2/I_1 is about 1.7. We can have this ratio for the setpoint 1.55 V for the EDFA S1 and 3V for the EDFA S2. The estimation of the phase noise is given below: