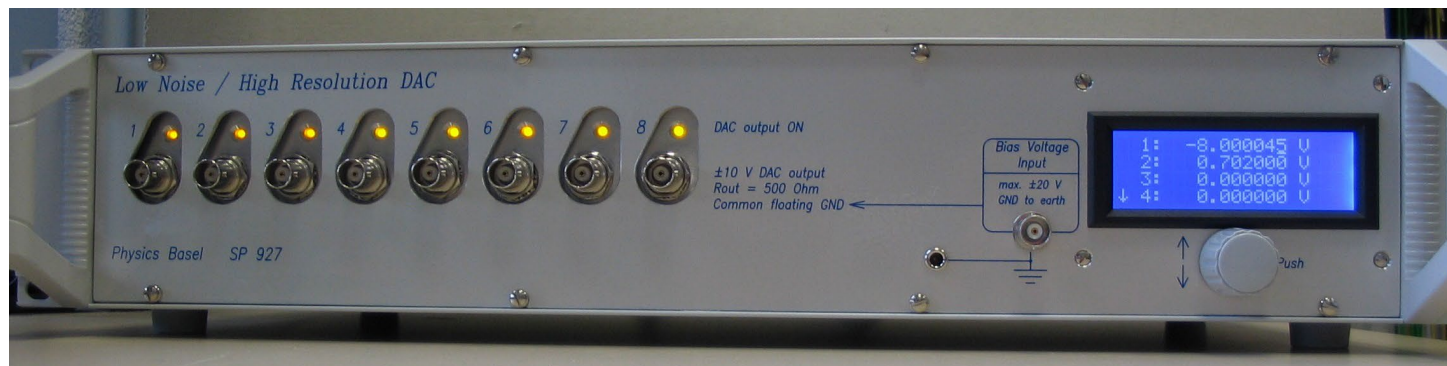


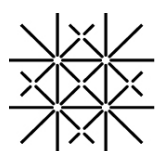
Physics Basel

Low Noise / High Resolution DAC SP 927

User's Manual
Revision 2.6.2



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University
of Basel

THIS USER'S MANUAL IS ONLY VALID FOR LNHR DAC SOFTWARE REVISION 2.6.2

Features

- Eight DAC voltages with a range of ± 10 V
- Low noise (0.1-100 Hz): Typical $0.5 \mu\text{V}_{\text{RMS}} = 3.3 \mu\text{V}_{\text{PP}}$
- 24-bit resolution corresponds to a voltage step size of $1.2 \mu\text{V}$
- Independent DAC channels with a crosstalk isolation of >140 dB
- Output ground is isolated from housing and computer interface
- LC-display for status/voltage display and manual control
- Remote controllable via RS-232 or Ethernet (Telnet or web-browser)
- LabVIEW 2013 drivers and sample programs included (for RS-232 and TCP/IP Telnet remote control)
- Power supply box can be separated from the LNHR DAC
- Compact and robust 19" desktop and rack mount housing (2U Height)



Safety Precautions

- The Low Noise / High Resolution DAC (LNHR DAC) is designed for indoors dry laboratory use by qualified and authorized persons only.
- Read this manual carefully before installing and use the LNHR DAC; all the safety precautions must be respected.
- Before connecting the device to the mains voltage makes sure that you have properly set the mains section switch ($115 \text{ V}_{\text{AC}} / 230 \text{ V}_{\text{AC}}$) on the rear of the device.
- Only use a mains power cable with a protection ground (earth). Make sure that the device is always properly grounded.
- Always disconnect the mains cable before replacing the mains fuse on the rear side of the device.
- Do not remove any cover. Since the internal parts are precisely adjusted, do not try to adjust or modify any part of the LNHR DAC.
- The external bias voltage must not exceed ± 20 V with respect to ground; it is internally restricted to ± 25 V by Zener-Diodes.
- When the device is powered on or off, small ($100 \text{ mV}_{\text{peak-peak}}$) and short ($10 \mu\text{s}$) spike-voltages can occur at the DAC outputs (measured at a bandwidth of 20 MHz). Normally such short and small spikes are not harmful to samples attached directly to the LNHR DAC.

Disclaimer

Physics Basel hereby disclaims all responsibility for personal injury, property damage and fine of penalty which results from misuse, not respecting the safety precautions, improper maintenance or improper application of this product.

Compliance with all applicable environment and personnel safety regulations is the sole responsibility of the user.

1. Description and Applications

The Low Noise / High Resolution DAC (LNHR DAC) generates eight independent, low noise and ultra-stable voltages. The output range of ± 10 V, combined with the 24-bit resolution, allows adjusting the voltages with a step size of only $1.2 \mu\text{V}$. The output voltage noise is well below $1 \mu\text{V}_{\text{RMS}}$ (typically $0.5 \mu\text{V}_{\text{RMS}}$), measured in a frequency range of 0.1 Hz to 100 Hz. Each channel can be independently switched ON (active driven) or OFF (grounded by 100 kOhm).

The device has an alpha numeric display and can be locally as well as remotely controlled. Remote control works with simple ASCII commands which can be sent and received either via the serial port (RS-232) or via the Ethernet port (TCP/IP Telnet). Further the LNHR DAC can be controlled remotely by using a web-browser.

Such low noise and ultra-fine tunable voltages are often needed for fundamental physics experiments at very low-temperatures. For those experiments constant DC bias-voltages and high resolution sweep-voltages with very low fluctuations (noise) are mandatory; e.g. for driving gate voltages. Since the typical load resistances of such gates are very high, the output current of the device is relatively small (maximum ± 1 mA) and the output source resistance is relatively high (500 Ohm).

With a bandwidth of DC...75 Hz the LNHR DAC is designed for DC-voltage biasing, for ramping/sweeping and for low frequency waveform generation at high impedance loads.

2. Front-Panel

On the left the eight DAC voltages are fed to the front-panel via eight BNC connectors. A yellow LED above the BNC connector indicates the status of the DAC channel (ON/OFF = 100 kOhm to GND). The large front-panel recesses for the BNC connectors make sure that the outer conductor doesn't make an electrical connection to the housing (earth). Make sure that the outer conductors of your attached BNC cables do not contact the front-panel since this would result in a ground loop.



Photo 1: The front-panel of the LNHR DAC with all DAC channels switched on.

The common floating ground of the DAC voltages can be shifted up to ± 20 V, with respect to the housing (earth), by applying an external bias voltage. This bias voltage has to be connected to the BNC connector (Bias Voltage Input) on the right. Note, when using this feature the common ground of the DAC outputs is no longer floating and ground loops may degrade the performance of the device.

On the rightmost part of the front-panel the LC-display and the rotary/push knob (encoder) can be found.

3. Rear-Panel

To minimize the electromagnetic interference from the mains power supply to the DAC outputs, the transformers and rectifiers are enclosed in an external box attached to the rear of the LNHR DAC. On the back of this Transformer & Rectifier Housing the mains AC voltage has to be connected via a standard mains connector plug. Before connecting the mains voltage makes sure that you have properly set the mains voltage selection switch (115 V_{AC} / 230 V_{AC}).

If necessary, the power supply box can be separated easily from the LNHR DAC by unscrewing the four bolts at the bottom. Then power supply box has to be connected to the device by a shielded 15-pole D-sub cable (1:1) with a maximum length of 4 meters.



Photo 2: The rear-panel of the LNHR DAC with the attached Transformer & Rectifier Housing on the left. If necessary, this box can be separated from the LNHR DAC up to 4 meters.

The mains fuses are installed just to the left of the mains connector. The mains cable must be disconnected before one can open and replace the mains fuses. The following slow-blow fuses (d=5 mm, l=20 mm) are needed:

When operating at 115 V_{AC}: 2 x 400 mA; and at 230 V_{AC}: 2 x 200 mA – both slow-blow.

One can find the mains power switch between the mains voltage selector switch and the slot for the fuses. When the power is switched on or off, small (100 mV_{peak-peak}) and short (10 μs) spike-voltages can occur at the DAC outputs. Since the energy of such short and small spikes are very low, normally they aren't harmful to samples attached to the device.

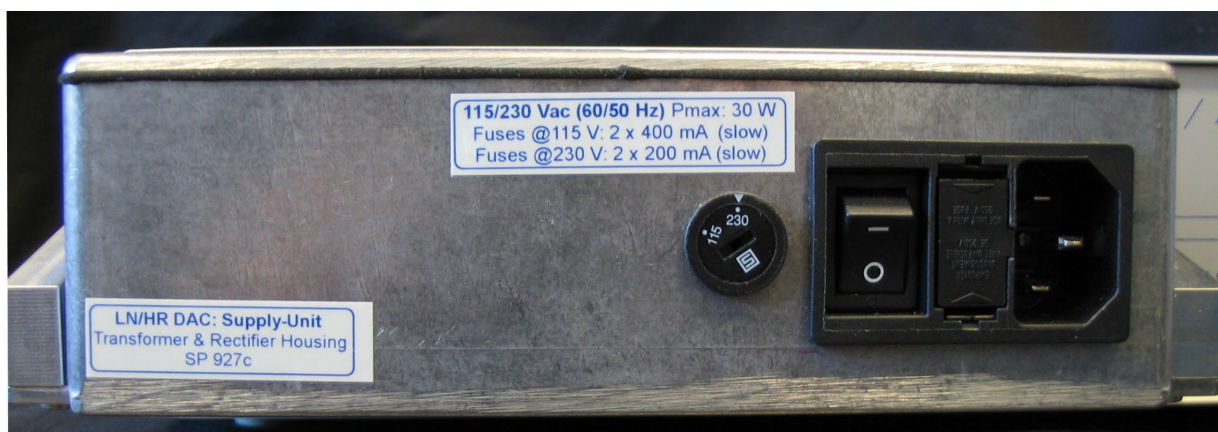


Photo 3: The external and well shielded Transformer & Rectifier Housing on the rear-panel of the LNHR DAC prevents from mains-disturbances.

In the middle of the rear-panel, green LEDs indicate when the power is switched on and when remote writing (DAC values/status) is enabled. Remote reading DAC values/status is always allowed. During editing DAC values locally, remote writing (via RS-232 or Ethernet) gets disabled.

The connectors for the remote control (RS-232 or Ethernet) are located on the right. When the LNHR DAC is directly connected to a computer, crossover cables are recommended. For the serial interface (RS-232) a so called “AT link data cable, female-female” has to be used; such a RS-232 cable with a length of 1.8 meters is supplied with the device.

At the top right, a rocker switch allows to select between floating computer interface and the ground of the interface hard connected to the housing (earth); for more details see the chapter **Grounding**.

4. Startup

After the mains power cable is connected and the power switch is turned on (rear side of the power supply) the device starts up and the following message is displayed on the LCD:

```

W E L C O M E
Now starting the
LN/HR DAC software!
(takes about 45 sec)

```

After about 45 seconds the device is booted and the following startup information is shown:

```

8 Channel Low Noise
High Resolution DAC
Physics Basel
SP 927

```

During the boot-process up all DAC channels are switched OFF and preset to 0 V. After 10 seconds (or shortened by pressing the push-button) the device switches to the main menu where you can select different display formats and make settings.

5. Main Menu

Within the following main menu, several settings can be made locally by using the LC-display and the rotary/push knob:

```

Show/Edit: V/mV
Show/Edit: V/mV/ $\mu$ V
Show/Edit: DEC val.
Show/Edit: HEX val.
HELP
RS-232 Settings
IP Settings
Software Release
Hardware Version
Power Supply Status
Specifications
Restart the device
Contact Information

```

The main menu can be scrolled up and down by using the rotary knob; a menu item can be selected by pressing the push-button. Leaving a sub-menu is done by long (> 1 sec) pressing the push-button.

6. Local Show/Edit DAC Values

By using the four top menu items, the DAC output voltages can be shown and edited in different number formats. During editing a DAC value locally, remote writing DAC values or status (ON/OFF) gets disabled.

In the **Show/Edit: V/mV** menu all DAC voltages can be displayed and modified on a single page with a resolution of 1 mV. On the left (separated by a colon) the corresponding channel number is indicated; the DAC channel 1 and 2 is displayed on the first line, the DAC channel 3 and 4 on the second line and so on:

12:	10.000V	10.000V
34:	<OFF> V	<OFF> V
56:	-8.000V	3.300V
78:	-10.000V	-10.000V

The displayed voltages are not measured; they are calculated from the set DAC values. Since the DAC output voltages can have a maximum voltage error of up to ± 1 mV, the shown voltages may be slightly different to the real DAC output voltages.

In the **Show/Edit: V/ μ V** menu the DAC voltages can be edited with a resolution of 1 μ V. Since only four channels can be displayed simultaneously, one has to scroll the display with the rotary knob:

^ 5:	-8.000000 V
6:	3.300000 V
7:	-10.000000 V
8:	-10.000000 V

Because the DAC output voltages can have a maximum voltage error of up to ± 1 mV, the shown voltages may be slightly different to the real DAC output voltages. Due to the intrinsic DAC resolution of 1.2 μ V the last digit (μ V) may skip some values due to rounding to the nearest possible output voltage.

In the **Show/Edit: DEC val.** menu the decimal DAC values, in a range from 0 (-10 V) to 16'776'960 (+10 V), can be displayed and modified on a single page. The resolution of the last digit corresponds to a voltage step of 1.2 μ V:

12:	16776960	16776960
34:	<OFF>	<OFF>
56:	1677696	11156678
78:	-	0

In the **Show/Edit: HEX val.** menu the hexadecimal DAC values, in a range from 0x000000 (-10 V) to 0xFFFF00 (+10 V), can be displayed and modified on a single page. The resolution of the last digit corresponds to a voltage step of 1.2 μ V:

12:	xFFFF00	xFFFF00
34:	x <OFF>	x <OFF>
56:	x199980	xAA3CC6
78:	x000000	x000000

In all the display formats, a DAC channel is switched ON/OFF by double-click the push-button; a switched OFF DAC channel is indicated by the text <OFF>.

Editing a DAC value is performed manually in this way: First press the push-button, then a blinking cursor occurs in the left part of the LCD where the DAC channel numbers are shown. With the rotary knob select the DAC channel to be modified by pressing the push-button again. Then the blinking cursor jumps to the last digit of the selected DAC value. Now, select the digit to be in- or decremented with the rotary knob. By pressing the push-button again the editing-mode gets active.

In the editing-mode the blinking-cursor is replaced by an underline-cursor and the DAC value is immediately modified by turning the rotary knob left or right. One can toggle between the digit-selection and the editing-mode just by pressing the button.

Ten seconds after the last user interaction or by long pressing the push-button, the former selection is retained. The system remains in the editing-mode until the user presses and holds the push-button long (> 1 sec).

7. Local System Settings

The Baud rate of the serial connection can be set in the **RS-232 Settings** menu item. Baud rates from 300 up to 115'200 can be selected by turning the rotary knob. At delivery a Baud rate of 9600 is programmed. The data length (8 bit), the number of stop-bits (1 stop) and the parity (none) are fixed and cannot be changed:

Baud rate:	9600
	(300-115200 bits/s)
Fix:	8 data, 1 stop
	no parity, XON/XOFF

When the Baud rate has been changed by the user and the button is pressed, the device asks what to do. With the rotary knob one can chose between two options: **Escape to MAIN MENU** makes no changes and the old Baud rate remains valid. When choosing **Use/Save Baud Rate!** the new Baud rate gets activated and it is saved permanently:

WHAT TO DO NOW?
Escape to MAIN MENU
Use/Save Baud Rate!

Under the menu item **IP Settings** the IP-address and the subnet-mask of the device can be programmed. At delivery the private IP-address 192.168.000.005 with a subnet-mask of 255.255.255.000 is programmed. Setting a different IP-address or a subnet-mask can be done in the same way as editing a DAC value:

```
IP-Address:
    192.168.000.005
Subnet-Mask:
    255.255.255.000
```

After setting new IP-values and long pressing the push-button the device asks what to do. With the rotary knob one can select between two options: **Escape to MAIN MENU** makes no changes and the old IP-address and subnet-mask remains valid. When selecting **Save IP & Restart!** the modified values are saved permanently and the LNHR DAC is restarted (takes about 45 seconds). Thereafter the new IP-settings are active. During restarting the device, all DAC channels are switched OFF and they are reset to an output voltage of 0 V:

```
WHAT TO DO NOW?
Escape to MAIN MENU
Save IP & Restart!
```

Under the menu item **Restart the device**, the device can be restarted without using the power ON/OFF switch on the back panel. In addition, the TCP/IP-Telnet connection can be restarted. An open Telnet connection is forced to closed; this can be useful if the host computer has crashed.

Under this menu item you can choose between “Escape to MAIN MENU”, “Restart device now!” and “Restart Telnet now!”:

```
WHAT TO DO NOW?
Escape to MAIN MENU
Restart device now!
Restart Telnet now!
```

If “Escape to MAIN MENU” is selected, nothing will be restarted and the software returns to the main menu.

If “Restart device now!” is selected, the following message will pop up and after a while (several seconds) the reboot process will be started:

```
Restarting now...

Please wait!
```

Note: During the restart of the device, all DAC channels are switched OFF and they are reset to an output voltage of zero (0 V).

If “Restart Telnet now!” is chosen, an open TCP/IP-Telnet connection is closed immediately and the software returns to the main menu; the process is very fast and no further information is displayed.

Note: The status of the device is not affected by closing the Telnet connection and all the DAC output voltages are unaffected.

If a TCP/IP-Telnet connection isn't properly closed by the host computer due to a crash or by an interrupted Ethernet connection, the Telnet connection on the LNHR DAC may still be open. Since only one Telnet connection can be open on the device, the previous one must be closed first, otherwise no new Telnet communication can be established. In this case, the user must manually close the TCP/IP-Telnet connection via this "Restart Telnet now!" menu item.

8. Local Information

Different text information can be accessed via the following main menu items (use the rotary knob to scroll through the long texts):

- **HELP:** General information about the LNHR DAC and the possibilities to control the device locally and remotely.
- **Software Release:** Shows the installed firmware release and date.
- **Hardware Version:** Displays the serial number of the device and the revisions of the installed hardware modules.
- **Power Supply Status:** The status of the different power supply voltages is shown (normally all should be OK):

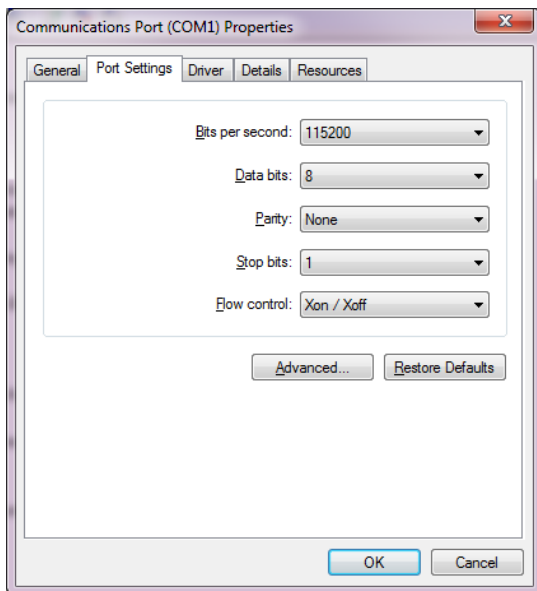
Line Voltage: OK
+15Va Supply: OK
-15Va Supply: OK
μ C Supply : OK

- **Specifications:** Shows the typical specifications of the LNHR DAC.
- **Contact Information:** Displays the contact information of the manufacturer.

9. Remote Control via Serial Port

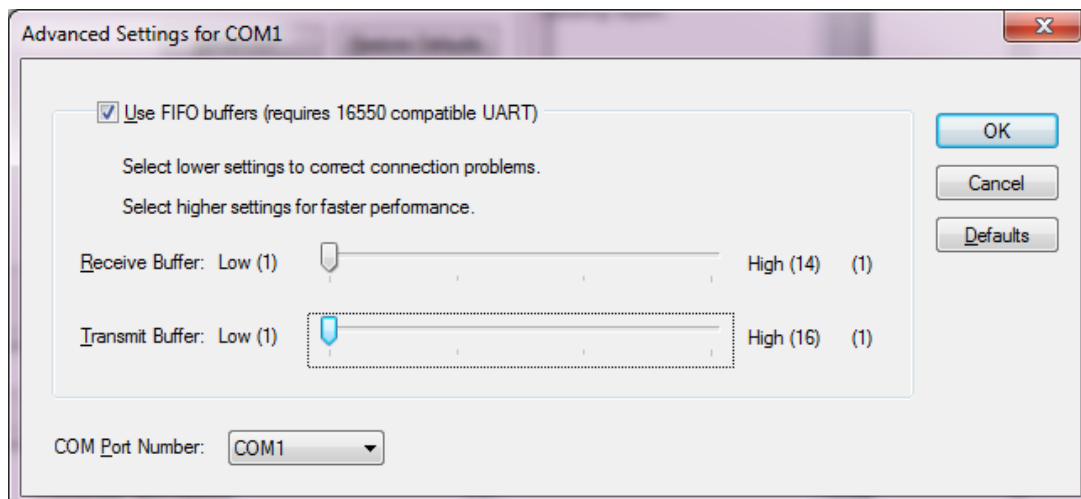
The device can be controlled remotely via the serial port (RS-232) by using simple ASCII commands. A crossed null modem AT link data cable (included) has to be used to connect the device directly to a computer. The Baud rate can be set in a range from 300 Baud up to 115 kBaud via the main menu item **RS-232 Settings**. At delivery the Baud rate is set to 9'600 bits/sec. The number of data bits is fixed to eight with one stop bit and the parity is not used. The data flow is controlled via the XON/XOFF protocol.

To reach a fast update rate, use a Baud rate as high as possible. For a reliable data transfer via RS-232 handshaking between the LNHR DAC and the control software running on the host computer is mandatory. Proper handshaking is implemented in the serial-port LabVIEW drivers, which are included on the USB-stick. When operating at the highest Baud rate (115.2 kbit/sec), typical 125 DAC values per second can be transferred to the LNHR DAC with proper handshaking. In this case use the following COM-port settings on the host computer:



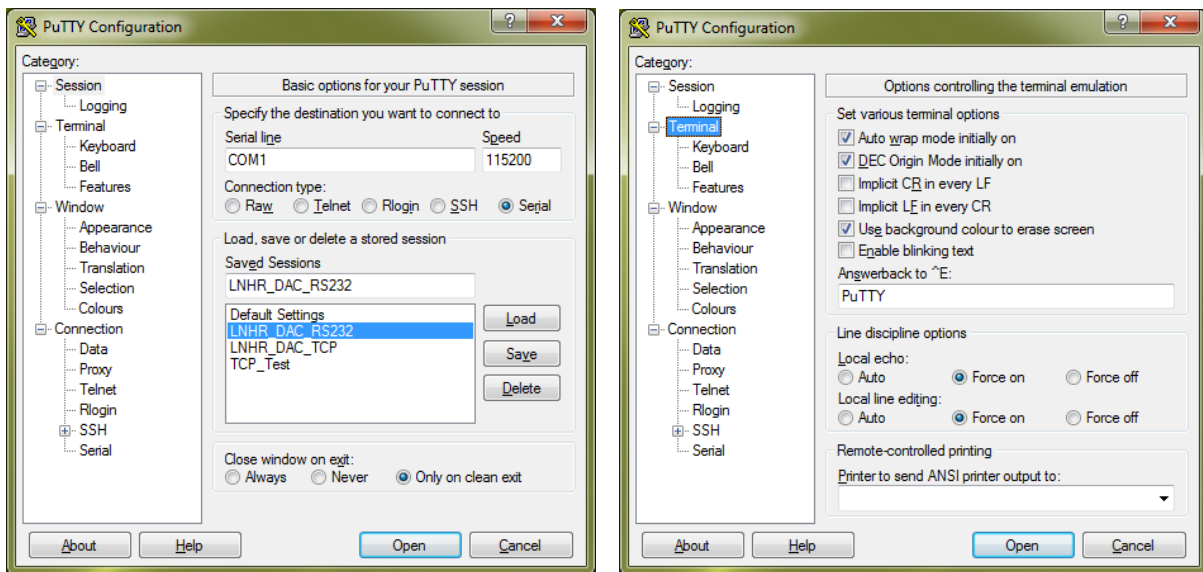
Make sure that the speed of the serial port (Baud rate) on the host computer is always the same as configured on the LNHR DAC (see chapter **Local System Settings**).

To prevent from “Buffer Overrun Error” when using the serial-port LabVIEW drivers in combination with the maximum Baud rate, use the following Advanced Settings of your COM-port installed in the host-computer:



All commands must be terminated with a Line-Feed <LF>. With a terminal-program send a "?" followed by a <LF> to the device and you will receive a text with an overview of all the ASCII commands to control and monitor the LNHR DAC.

All the ASCII commands can be tested by using a standard terminal-program (e.g. PuTTY on Windows systems). The commands are not sensitive to UPPER and lower case typing. The terminal-program must be configured so that a send line is terminated with a Line-Feed <LF>. To generate a <LF> with the PuTTY terminal-program type a CTRL-J and then press the ENTER key. To see the typed-in commands on the computer monitor, the local echo of the terminal-program must be turned on. See below the PuTTY Configuration when testing the RS-232 communication with the LNHR DAC at its maximum speed of 115.2 kbit/sec:



Here is a typical RS-232 PuTTY window with some SET- and some QUERY-commands. At the end of the command/query the Line-Feed <LF> is generated by typing a CTRL-J (^J):

```

The IP address can be set via the menu item "IP Settings". At delivery the IP
address is set to 192.168.0.5 and the Subnet-Mask to 255.255.0.0.

The implemented web server allows to monitor and remote- control the device
with a standard web-browser. Since run-time code is automatically loaded from
the NI- website a second network adapter connected to the internet is needed.
The web-server of the LNHR DAC can be accessed via its IP address on the port
80000: IP#:8000/LNHR_DAC .html e.g: 192.168.0.5 :8000/LNHR_DAC.html

NOTE 1: The showed voltages are calculated from set-point values. Since the DA
C
output voltages can have an absolute error of +/-1mV, the showed voltages may
be different to the real DAC voltages.

NOTE 2: The resolution of the DAC corresponds to 1.2uV. Therefore during
editing the voltage in uV resolution the last digit may skip some values.

all on^J
0
all s?^J
ON;ON;ON;ON;ON;ON;ON;ON
all v?^J
7FFF80;7FFF80;7FFF80;7FFF80;7FFF80;7FFF80;7FFF80;7FFF80

```

1) SET COMMANDS:

A SET command (single or multiple) must be terminated by a <LF>.

1.1) SET a single DAC-Channel to a DAC-Value (HEX):

"DAC-CH[1...8] <SPACE> DAC-Value (HEX) [0x000000...0xFFFF00] <LF>"

The DAC-Value (HEX) corresponds to the following voltages:

0x7FFF80 = 0 V
 0xBFFF40 = +5 V
 0xFFFF00 = +10 V
 0x3FFFC0 = -5 V
 0x000000 = -10 V

Examples:

SET DAC-Channel 1 to 0 V: "1 7FFF80<LF>"

SET DAC-Channel 3 to -2.5 V: "3 5FFFA0<LF>"

SET DAC-Channel 8 to +3.4 V: "8 AB8473<LF>"

1.1.1) SET ALL DAC-Channel to a DAC-Value (HEX):

"ALL <SPACE> DAC-Value (HEX) [0x000000...0xFFFF00] <LF>"

Examples:

SET ALL DAC-Channels to 0 V: "ALL 7FFF80<LF>"

SET ALL DAC-Channels to +10 V: "ALL FFFF00<LF>"

1.2) SET a single DAC-Channel Status (ON or OFF):

"DAC-Channel [1...8] <SPACE> Status [ON/OFF] <LF>"

Examples:

SET DAC-Channel 1 ON: "1 ON<LF>"

SET DAC-Channel 5 OFF: "5 OFF<LF>"

1.2.1) SET ALL DAC-Channels to a Status (ON or OFF):

"ALL <SPACE> Status [ON/OFF] <LF>"

Examples:

SET ALL DAC-Channels ON: "ALL ON"

SET ALL DAC-Channels OFF: "ALL OFF"

When a SET command is received and processed successfully, the device responds with zero ("0") followed by a <CR+LF>. This "no error" replay must be awaited before the next SET command can be send. If the SET command cannot be interpreted, an error-code with a <CR+LF> is returned; the meaning of the error-code is as following:

"0" = No error (normal)
 "1" = Invalid DAC-Channel
 "2" = Missing DAC-Value or Status
 "3" = DAC-Value out of range
 "4" = Mistyped
 "5" = Remote writing not allowed (local editing is performed)

Up to sixteen SET commands can be combined in a multiple SET command. Each SET command must be separated by a semicolon (";") and terminated with a <LF>. For each of the SET commands its own error-code is generated (followed by a <CR+LF>).

Example:

SET DAC-Channel 3 to -5V; DAC-Channel 3 ON; DAC-Channel 4 to 0V; DAC-Channel 8 OFF:

"3 3FFFC0;3 ON;4 7FFF80;8 OFF<LF>"

→ "0<CR+LF>", "0<CR+LF>", "0<CR+LF>", "0<CR+LF>"

When using a control-software (automatic sweep etc.), it is strongly recommended to read and interpret the error-code after each SET command. That results in a reliable data transfer with a handshaking between the device and control-software.

2) QUERY DATA COMMANDS:

A QUERY command must be terminated with a question-mark ("?") followed by a <LF>. Only single QUERY commands can be released. If a QUERY command cannot be interpreted, the device response with a question-mark ("?") followed by a <CR+LF>.

2.1) QUERY a DAC-Value (HEX) of a single DAC-Channel:

"DAC-Channel [1...8] <SPACE> V?<LF>" → DAC-Value (HEX) [0x000000...0xFFFF00]

Examples:

QUERY DAC-Value of Channel 1: "1 V?<LF>"

→ "7FFF80<CR+LF>"

QUERY DAC-Value of Channel 8: "8 V?<LF>"

→ "AB8473<CR+LF>"

2.1.1) QUERY ALL DAC-Values (HEX):

"ALL <SPACE> V?<LF>"

→ DAC-Value 1; DAC-Value 2;...; DAC-Value 8(HEX) [0x000000...0xFFFF00]

Example:

QUERY ALL DAC-Values: "ALL V?<LF>"

→ "7FFF80;7FFF80;3FFFC0;7FFF80;FFFF00;000000;7FFF80;AB8473<CR+LF>"

2.2) QUERY a DAC-Status (ON or OFF) of a single DAC-Channel:

"DAC-Channel [1...8] <SPACE> S?<LF>" → STAT [ON/OFF]

Examples:

QUERY DAC-Status of Channel 1: "1 S?<LF>"

→ "ON<CR+LF>"

QUERY DAC-Status of Channel 8: "8 S?<LF>"

→ "OFF<CR+LF>"

2.2.1) QUERY ALL DAC-Status (ON or OFF):

"ALL <SPACE> S?<LF>" → Status 1;Status 2;...;Status 8 [ON/OFF]

Example:

QUERY ALL DAC-Status: "ALL S?<LF>"

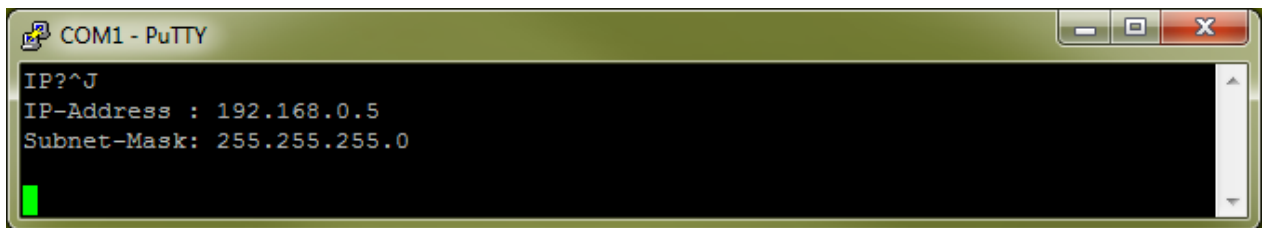
→ "ON;OFF;ON;OFF;ON;ON;ON;OFF<CR+LF>"

3) QUERY INFORMATION COMMANDS:

Several text and status information can be recalled via the serial interface or via TCP/IP Telnet. All these query command must be terminated with a <LF>:

"?"	Shows an overview of the RS-232 ASCII COMMANDS
"HELP?"	Shows the HELP text (as on local LCD)
"SOFT?"	Shows the software release of the device (as on local LCD)
"HARD?"	Shows information on the used hardware (as on local LCD)
"POWER?"	Shows the status of the power supply voltages (as on local LCD)
"STAT?"	Shows the write status: "0" = Remote writing enabled; "5" = Disabled
"SPECS?"	Shows the typical specifications of the device (as on local LCD)
"IP?"	Shows the IP-Address and the Subnet-Mask (as on local LCD)
"CONTACT?"	Shows the contact address and further information (as on local LCD)

The ASCII-text can be displayed on a standard terminal-program (e.g. PuTTY). Here the responses to an IP query command via serial port (RS-232):



The screenshot shows a PuTTY terminal window titled "COM1 - PuTTY". The terminal displays the command "IP?^J" and the response: "IP-Address : 192.168.0.5" and "Subnet-Mask: 255.255.255.0". A green cursor is visible at the end of the last line.

4) REMARK:

For a given output voltage ($V_{out}[-10\text{ V} \dots +10\text{ V}]$) the decimal DAC-Value (DACval [0...16'776'960]) is given by:

$$\text{DACval} = (V_{out} + 10) \cdot 838'848$$

For a given decimal DAC-Value (DACval [0...16'776'960]) the output voltage ($V_{out} [-10\text{ V} \dots +10\text{ V}]$) can be determined by:

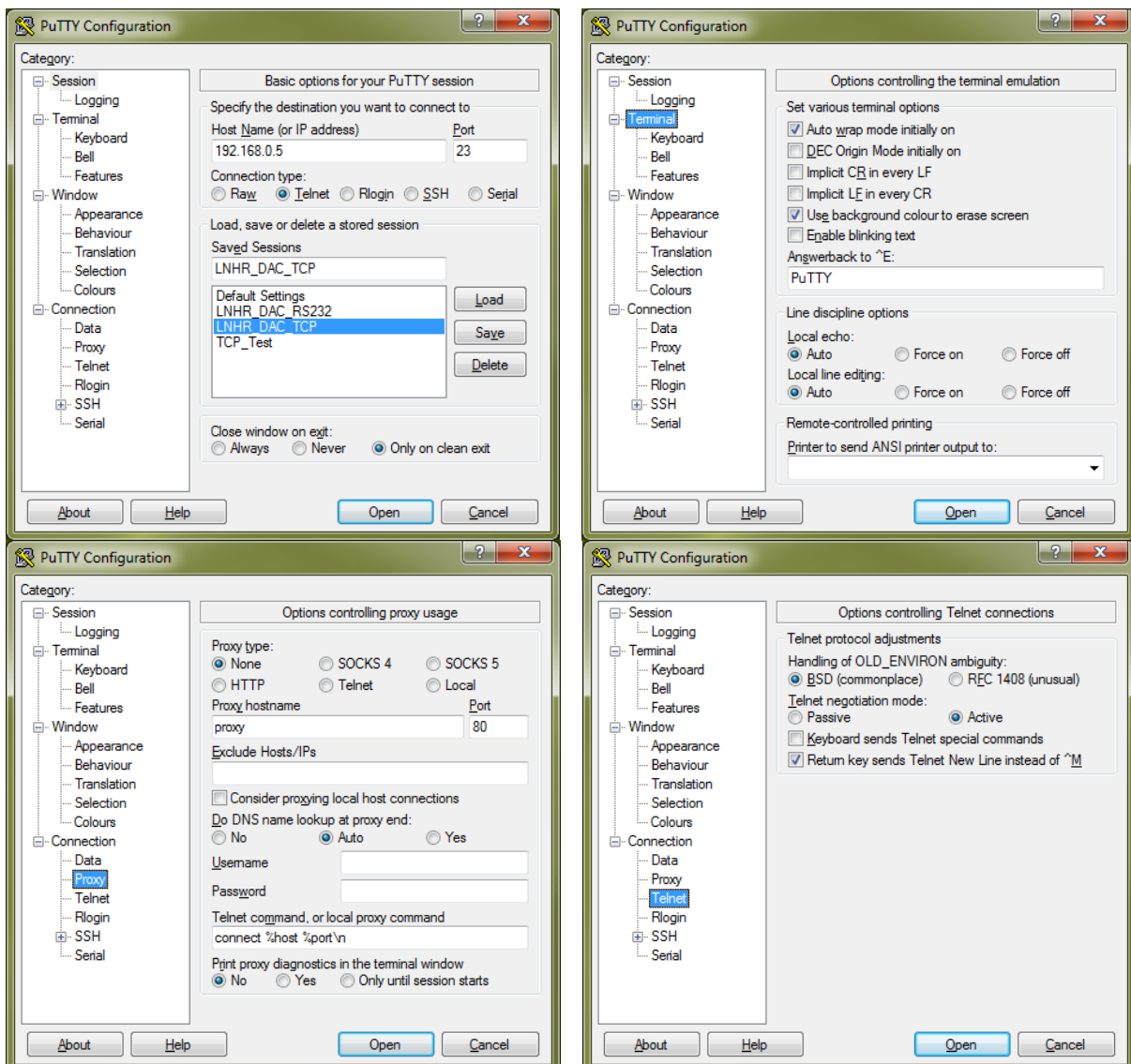
$$V_{out} = (\text{DACval} / 838'848) - 10$$

10. Remote Control via Ethernet (TCP/IP Telnet)

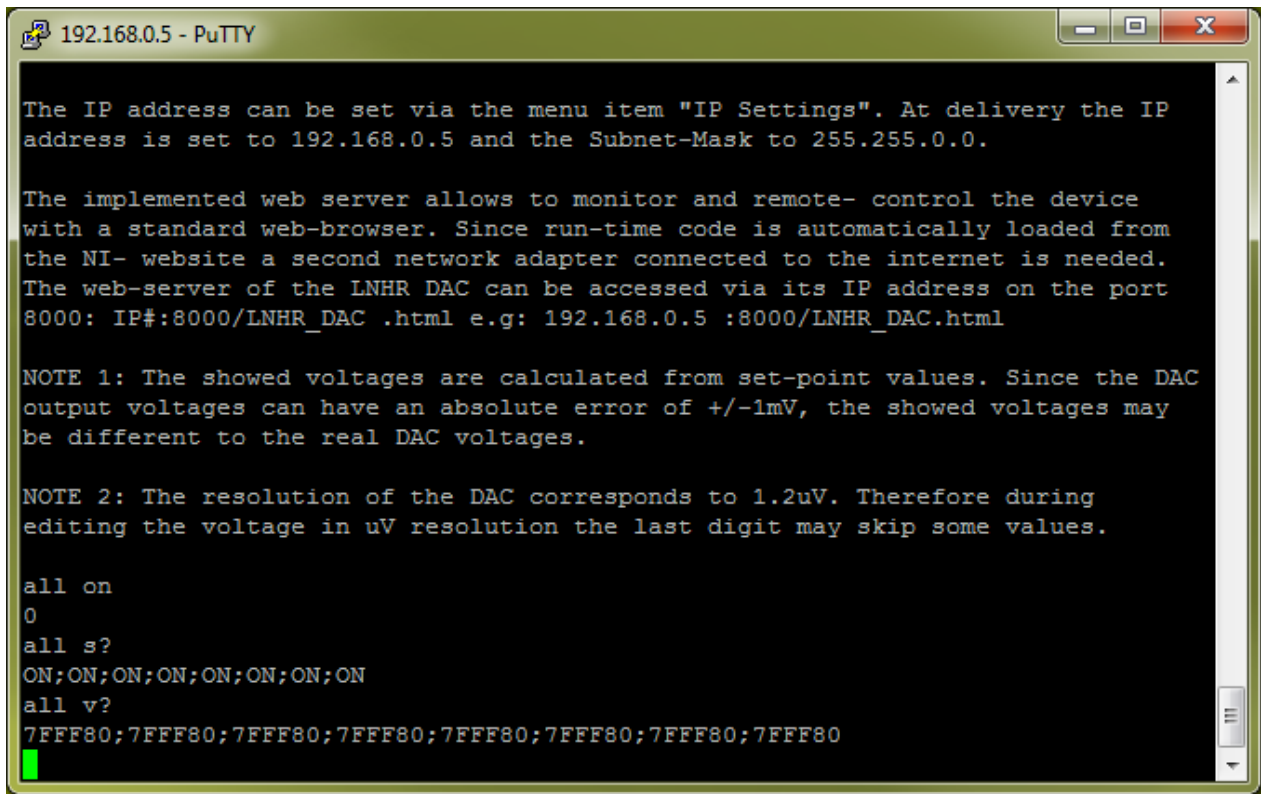
The device can be controlled remotely via the TCP/IP Telnet by using the same simple ASCII commands as described before. The commands can be sent and received either via the serial port (RS-232) or via the Ethernet port using the TCP/IP Telnet (port 23) protocol. The IP-address of the LNHR DAC is set via the menu item **IP Settings**. At delivery the IP-address is set to 192.168.0.5 and the subnet-mask is 255.255.255.0.

For a reliable data transfer via TCP/IP Telnet, handshaking between the LNHR DAC and the control software running on the host computer is mandatory. Proper handshaking is implemented in the TCP/IP Telnet LabVIEW drivers, which are included on the USB-stick.

The ASCII commands can be tested by using a standard TCP/IP Telnet-program (e.g. PuTTY on Windows systems). The commands are not sensitive to UPPER and lower case typing. The terminal-program must be configured so that a send line is terminated with a Carriage-Return <CR> and Line-Feed <LF>. To see the typed-in commands on the computer monitor, the local echo of the terminal-program must be turned on. Here is the PuTTY Configuration when testing the commands via a Telnet communication:



Below is a typical Telnet PuTTY window with some SET- and some QUERY-commands is shown. A command line is terminated by pressing the ENTER key which releases a <CR> and <LF>:



```

192.168.0.5 - PuTTY
The IP address can be set via the menu item "IP Settings". At delivery the IP
address is set to 192.168.0.5 and the Subnet-Mask to 255.255.0.0.

The implemented web server allows to monitor and remote- control the device
with a standard web-browser. Since run-time code is automatically loaded from
the NI- website a second network adapter connected to the internet is needed.
The web-server of the LNHR DAC can be accessed via its IP address on the port
8000: IP#:8000/LNHR_DAC .html e.g: 192.168.0.5 :8000/LNHR_DAC.html

NOTE 1: The showed voltages are calculated from set-point values. Since the DAC
output voltages can have an absolute error of +/-1mV, the showed voltages may
be different to the real DAC voltages.

NOTE 2: The resolution of the DAC corresponds to 1.2uV. Therefore during
editing the voltage in uV resolution the last digit may skip some values.

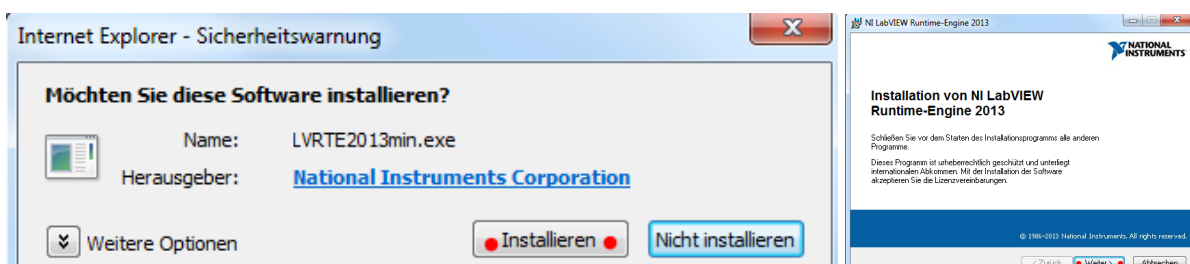
all on
0
all s?
ON; ON; ON; ON; ON; ON; ON; ON; ON
all v?
7FFF80; 7FFF80; 7FFF80; 7FFF80; 7FFF80; 7FFF80; 7FFF80; 7FFF80

```

11. Remote Control via Ethernet (Web-Browser)

The LNHR DAC can further be easily controlled remotely via the Ethernet port by using the Internet Explorer (IE) from Microsoft. The IE is strongly recommended since it supports ActiveX components. If the LNHR DAC is directly connected to computer a crossed (X) network cable is recommended. The IP-address can be set via the menu item **IP Settings**. At delivery the IP-address is set to 192.168.0.5 and the subnet-mask to 255.255.255.0.

When the web-page of LNHR DAC is called the first time (and no LabVIEW or LabVIEW- Runtime is installed on the host computer) the following message pops up since the LabVIEW Runtime-Engine 2013 must be installed before the web page can be displayed:



If you agree, the *LVRTE2013min.exe* gets automatically downloaded and installed from the National Instruments web resources. This installation takes several minutes.

The web-page of the LNHR DAC uses port 8000 and it can be accessed via the following web-address:

http://IP-address:8000/LNHR_DAC.html (http://192.168.0.5:8000/LNHR_DAC.html).

The embedded web-server allows monitoring and controlling the LNHR DAC by using the Internet Explorer as web-browser:

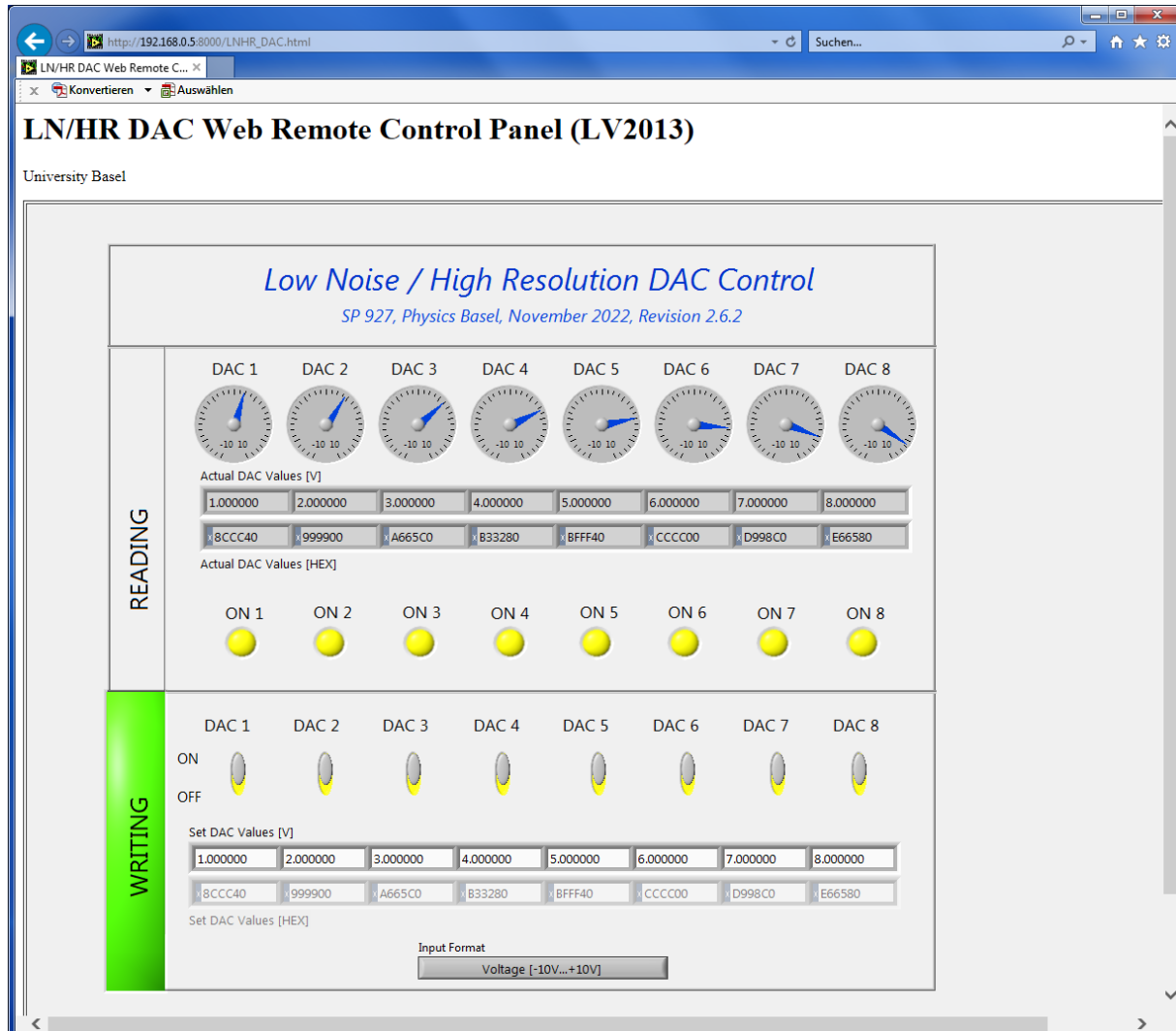


Figure 1: Shows the web remote control panel of the LNHR DAC. Via the web-page the device can be monitored and DAC values/status can be modified.

The upper part of the web-page (READING) shows the actual DAC output voltages and the status (ON/OFF) of all the DAC outputs. The read DAC values are displayed in voltage [-10.000000 V...+10.000000 V] as well as in hexadecimal values [0x000000...0xFFFF00].

While a DAC value is being locally modified by a user, writing via the web-page (and also via RS-232 and Telnet) gets disabled. Then the underlying color in the field WRITING changes to red and all the controls get disabled and greyed-out.

When remote writing is enabled, the color of the WRITING field changes to green. A button allows toggling between the two different input formats for the DAC values: In the lower row in hexadecimal values [0x000000...0xFFFF00] and in the upper row in voltages [-10.000000 V...+10.00000 V].

The LNHR DAC can be accessed in parallel via RS-232 and Telnet commands and via the web-browser. The last written DAC value stays valid until it is changed either via a RS-232 or Telnet SET command or via an input from the web-browser. The web-page can be used to monitor the device during it is remotely controlled via the serial port or via a TCP/IP Telnet connection.

The update rate of the web-page is relative slow (5 times/sec) and is therefore not suitable for fast reading and writing from/to the LNHR DAC.

12. Output Noise

The typical DAC output noise voltage of the device is only $0.5 \mu\text{V}_{\text{RMS}}$ which corresponds to peak to peak noise voltage of about $3.3 \mu\text{V}_{\text{PP}}$. This RMS-noise is measured in a frequency band of 0.1 Hz to 100 Hz. The noise has a typical $1/f$ -frequency characteristic, that's why around 80% of the noise is generated in the low frequency band between 0.1 Hz and 10 Hz. The specific measured noise of your device is appended in the end. Measuring such low noise levels is quite challenging; short and good cables, low vibration environment and an elaborated test setup are mandatory. The noise may vary slightly over time and therefore repeated noise measurements must be averaged (at least ten = 100 sec) to get a reasonable value. A good portion of the noise is generated from the $\pm 10 \text{ V}$ reference voltages; that's why the noise at DAC output voltages near zero is about 30% smaller than at full range ($+10 \text{ V}$ or -10 V).

Since the noise level is different from device to device, each unit and each channel is qualified for noise performance after production. The noise is measured at five different DAC output voltages of 0 V , $+5 \text{ V}$, $+10 \text{ V}$, -5 V and -10 V . Therefore a maximum noise voltage of $1 \mu\text{V}_{\text{RMS}}$ ($6.6 \mu\text{V}_{\text{PP}}$) averaged over ten sweeps (100 sec) can be guaranteed.

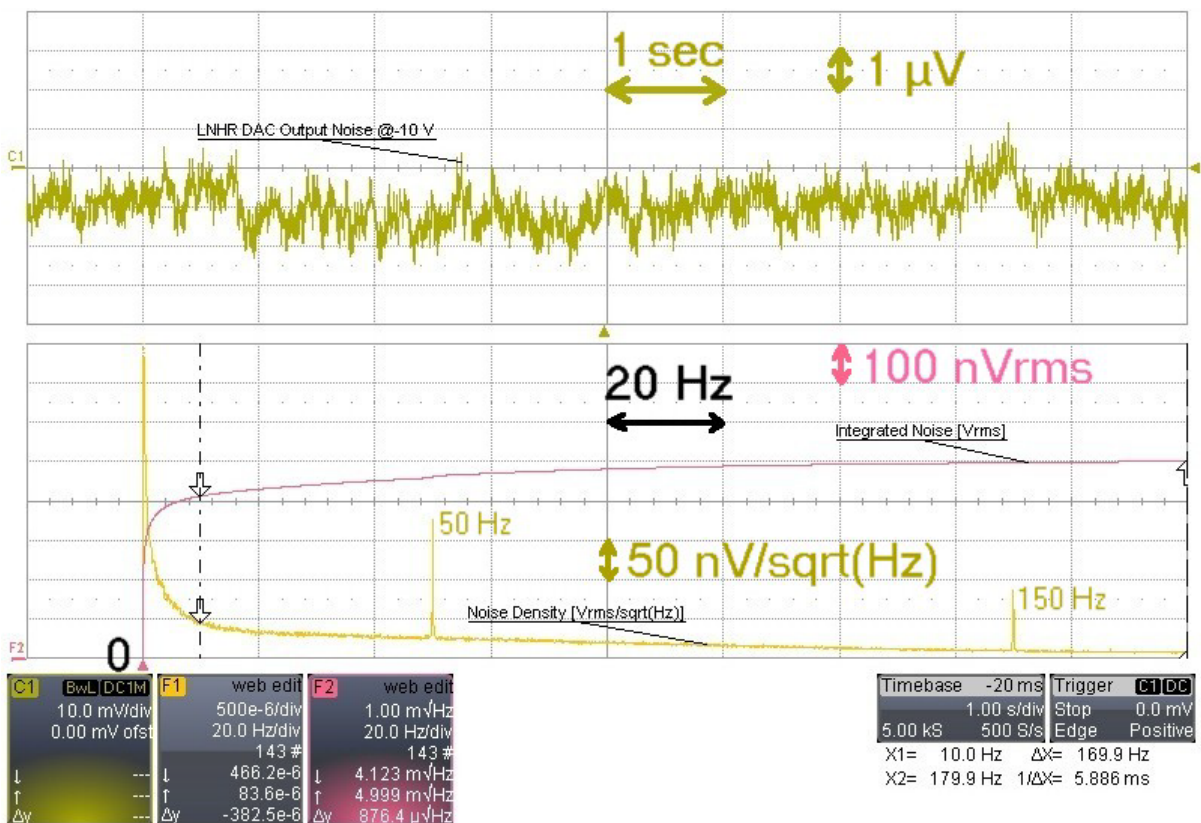


Figure 2: A noise measurement by using a low noise, AC-coupled ($f_{\text{HP}}=0.03 \text{ Hz}$), battery powered preamplifier (SR560) with a gain of 10^4 and a bandwidth of 100 Hz. This typical noise of $0.5 \mu\text{V}_{\text{RMS}}$ is measured at a DAC output voltage of -10 V . The upper plot (olive green) shows the time domain noise signal over 10 second; a peak to peak voltage of around $3.3 \mu\text{V}_{\text{PP}}$ can be registered.

In the lower plot the averaged FFT noise spectra (ocher) and the integrated noise spectra (pink) is shown in the frequency domain. The integrated RMS-noise from 0.1 Hz up to 180 Hz is exactly $0.5 \mu\text{V}_{\text{RMS}}$. The noise spectra is generated by using 143 averages (10 sec sweep), which corresponds to a total measuring time of almost 25 minutes. The unavoidable mains frequency (50 Hz) and its third harmonic (150 Hz) can clearly be identified in the noise spectra.

13. Grounding

To prevent ground loops and interferences, the DAC output voltages are referred to a common ground which is galvanic-isolated from the housing (earth) and from the computer interface. The common DAC output ground can be shifted by up to ± 20 V with respect to the housing (earth). The ground reference of the DAC outputs is connected to the experiment (e.g. cryostat) via the shields of the BNC cables. Due to the galvanic-isolation, no troublesome ground-loop-currents can flow over the shielding of the cables.

If external AC magnetic fields are present, loop currents can be induced in shields of the eight BNC cables running from the DAC to the experiment. To minimize this effect, bring the BNC cables as close as possible or, even better, twist them.

In addition the computer interface is also galvanic-isolated from the housing (earth) and it can also be shifted by up to ± 20 V with respect to the housing (earth). A switch on the rear side of the device allows the user to select the computer interface between floating or grounded. For electrostatic reason, also in the floating mode, the ground of the computer interface is connected via a 100 kOhm resistor to the housing (earth). With this grounding concept, no optically isolated computer interfaces are needed also in very sensitive experimental environment.

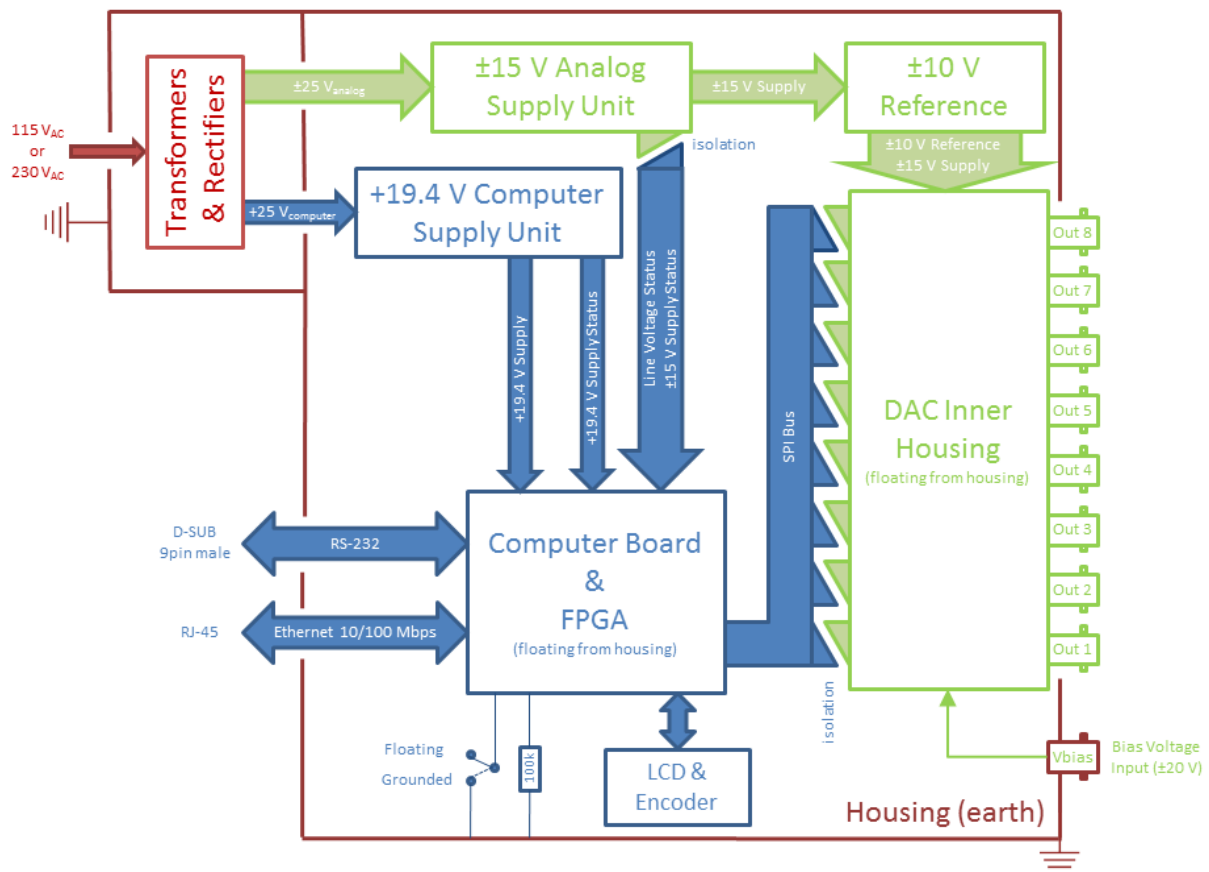


Figure 3: The block diagram of the LNHR DAC and its grounding principle. If the external bias voltage input is left open, the common ground of the DAC outputs is floating with respect to the housing (earth) and the computer interfaces. By driving the external bias voltage, the ground of the DAC outputs can be shifted by up to ± 20 V with respect to the housing (earth).

14. Typical Specifications (Temperature 25 °C, 4 h warm-up)

- Independent DAC output channels: 8
- Output voltage range: ± 10 V
- Output current: max. : ± 1 mA
- Resolution: 24-bit (LSB equal to 1.19 μ V)
- Absolute voltage error: typ. ± 200 μ V; max. ± 1 mV
- Offset voltage error (@ $V_{\text{out}} = 0$ V): typ. ± 100 μ V ; max. ± 500 μ V
- Integral nonlinearity (INL): ± 80 LSB
- Drift over 8 h (T = constant 25 °C): ± 10 μ V
- Temperature drift of output voltage ($V_{\text{out}} > 1$ V): ± 10 ppm/°C
- DAC output voltage during power on or off (BW=20 MHz): < 100 mV_{peak-peak} / < 10 μ s
- ON output source impedance: 500 Ohm // 1.2 μ F
- OFF output impedance to GND: 100 kOhm // 1.2 μ F
- Output bandwidth: 75 Hz
- Overshoot (0 V to +10 V Step): typ. 0.6%, max. 1%
- Rise-time (10% to 90%): 4.7 ms
- Settling time for an error $< 0.1\%$: 18 ms after “no error” echo is received
- Noise (0.1 Hz...100 Hz): typ. 0.5 μ V_{RMS} (3.3 μ V_{pp}); max. 1 μ V_{RMS} (6.6 μ V_{pp})
- DAC output ground is common for all channels and it is galvanic-isolated from housing (earth) and from the computer interface (RS-232 and Ethernet).
- Channel to channel crosstalk isolation: > 140 dB
- Bias voltage (DAC output ground to housing/earth): max. ± 20 V
- Capacitance of DAC output ground to housing (earth): 1.5 nF
- Computer interface ground to housing (earth) voltage: max. ± 20 V
- Capacitance of computer interface ground to housing (earth): 1 nF
- Warm-up time: 4 hours
- Mains voltage supply: 115 V_{AC} / 230 V_{AC} (both +10%, -5%) 50...60 Hz
- Mains power consumption: typ. 25 W, max. 30 W
- DAC update rate (via RS-232 @115 kBaud): 125 DAC values per second
- Housing: 19” width for tabletop use or rack-mount
- Housing dimensions: Width 480 mm, Height 100 mm (2U), Depth 430 mm
- Weight: 8 kg (17.7 lb)

15. Operation Conditions

- Environment: Indoors dry laboratories only
- Ambient temperature between 10 °C (50 °F) and 40 °C (104 °F)
- Altitude up to 2'000 m (6'561 ft).
- Maximum relative humidity 80% for temperatures up to 31 °C (88 °F), decreases linearly to 50% at a temperature of 40 °C (104 °F).
- Pollution degree 1 (no pollution or only dry and non-conductive pollution).

16. Background

The enormous resolution of 24-bit is reached by applying a pulse-width modulation (PWM) on the least significant bit (LSB) of a commercially available 16-bit DAC-chip (Texas Instruments DAC8871). To eliminate the parasitic PWM fundamental frequency of 919 Hz, the voltage output of the DAC-chip is filtered by a low-pass Bessel filter ($f_{-3dB} = 75$ Hz), designed for low noise performance.

To reach the low noise performance of the LNHR DAC, the reference voltages ($\pm 10 V_{ref}$) supplied to the DAC-chip is crucial. To minimize this noise source, pretested and selected low noise voltage reference-chips are used in this device. For further reducing the noise, by around a factor of two, four of these selected low noise voltage reference-chips are combined.

To increase the linearity, a sophisticated calibration procedure is accomplished on each DAC channel after production. This is done by using a precision, stable and high resolution digital voltmeter (Keithley 2010) as reference. 2'000 interpolation voltages between -10 V and +10 V are measured and then the linearity error versus DAC value is fit by a high order polynomial correction function. The determined polynomial linearization coefficients are then transferred and saved onto the LNHR DAC.

The 16-bit DAC-chip has a typical integral nonlinearity (INL) of ± 1 LSB, which corresponds to ± 256 LSB in the 24-bit system of the LNHR DAC. Through the calibration process the INL is reduced by a factor of around three to typical ± 80 LSB.

All internal supply voltages are supervised. If one fails, all DAC outputs are immediately switched OFF. This makes sure that no erroneous DAC output voltage can occur, which could damage sensitive samples attached to the LNHR DAC.

A sbRIO board (9602) from National Instruments is used to control the LNHR DAC and it enables the remote control of the output voltages via Ethernet (TCP/IP-Telnet) and the serial port (RS-232). Also the error corrections for the DAC-chips are calculated in real-time (RT), based on the stored polynomial linearization coefficients. The web-server, running on the RT-processor of the sbRIO board, allows monitoring and controlling of the eight output voltages by using a normal web browser (IE). Further a LC-display (4 x 20 characters) and a rotary/push knob allow the local control and setup of the device by the user.

The FPGA on the sbRIO board performs the time critical SPI-bus communication with the eight independent DAC boards and it manages the pulse-width modulation of the LSB to increase the resolution of the DAC-chips to 24-bit. Further some low-level routines for driving the LCD and reading the rotary/push knob are also implemented in the FPGA.

The programming of the LNHR DAC is carried out by using the following LabVIEW 2013 products: FPGA Module, RT Module and the RT State-Chart Module. The FPGA-program is structured in about 20 Sub-VIs and the RT-code covers around 100 Sub-VIs.