Wireless 24+1 channel EEG/ECG system:

User and interface manual

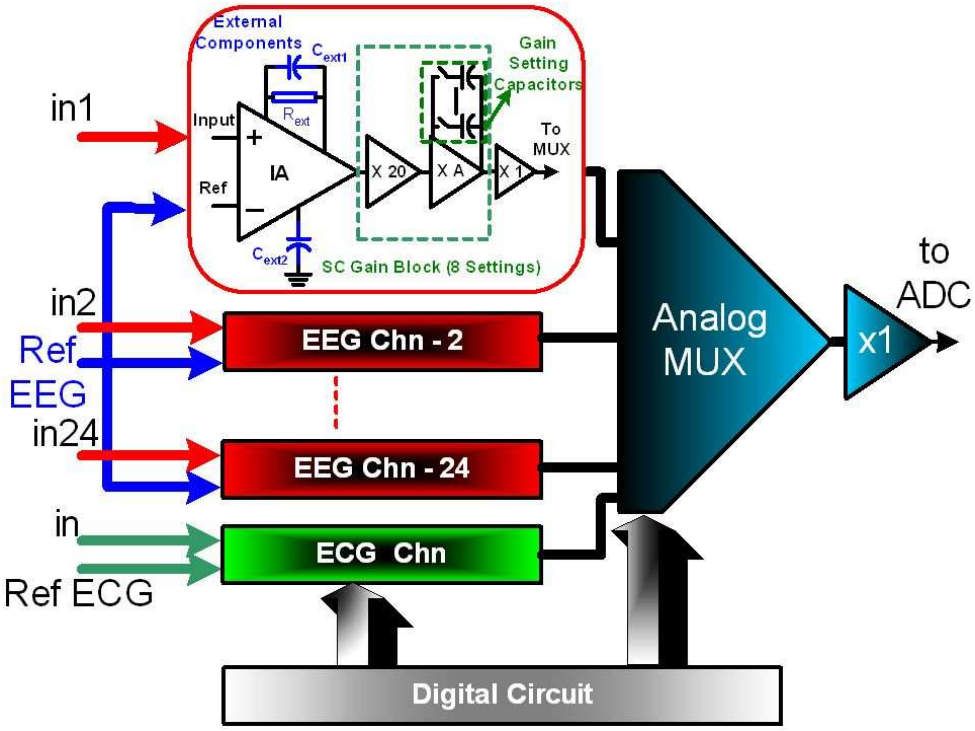
Document history record

issue	date	description of change
0.1	03/07/2006	document created
0.2	14/09/2006	corrected channel numbering drawing

Table of contents

1 Analog front-end specifications:

Each channel of the analog front-end ASIC consists of a high CMRR instrumentation amplifier, followed by a switched-capacitor gain block. The gain of each channel can be adjusted by electronically selecting the gain capacitance of the switched-capacitor gain block. There are 8 different gain modes ranging from 200 to 10000 for the EEG channels and from 20 to 1000 for the ECG channel.



The front-end instrumentation amplifier has bandpass filter characteristics. In the wireless system, the lower cut-off frequency is 0.5Hz, resulting in a -60 dB DC gain. This filters the DC differential input voltage effectively. In addition to that, feedback path of the instrumentation amplifier, forces the input pairs to operate at the same operating point. Therefore, even under high DC differential input voltage, the instrumentation amplifier achieves 100 dB CMRR. As a result, it effectively suppresses the input common mode voltages coupled to the human body, while amplifying the microvolt level biopotential signals. The upper cut-off frequency is 70Hz. The total input referred voltage noise of each channel is 1.3 μV_{rms} in a 0.5 Hz – 80 Hz bandwidth.

The sample rate is 1024 Hz/channel.

2 Hardware manual

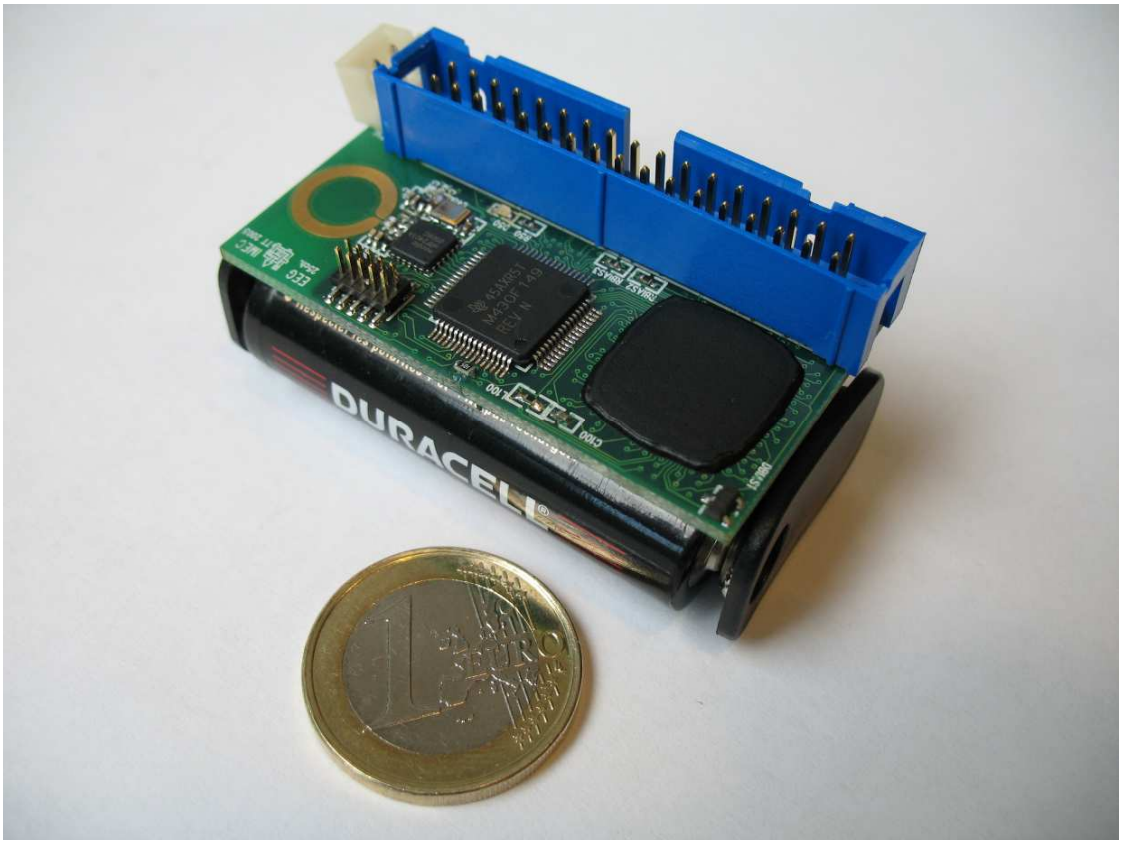


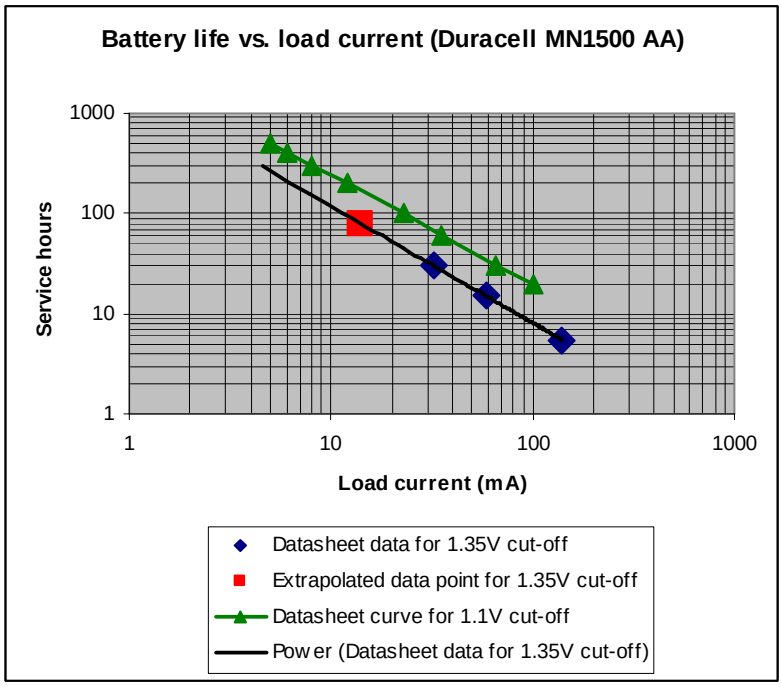
Figure: miniaturized EEG system including batteries

2.1 Power supply

The system needs a 2.7V – 3.3V power supply to operate within specifications. This power is supplied from 2 alkaline AA batteries. The supplied batteries are Duracell MN1500 alkaline batteries.

The power consumption of the complete system, in data mode, is 14 mA @ 3V = 42 mW.

Since the system will go out of spec below 2.7V, we cannot utilize the full battery capacity. Our cut-off voltage must be 1.35V, instead of the usual 0.9V-1.1V.



On the above curve the service life in hours of the battery is plotted versus the load current., for a cut-off voltage of 1.35V as well as 1.1V. The result is therefore that, with these Duracell AA batteries, the service life is around 79.5 hours, or over 3 days of continuous measurement. If cheaper (lower capacity) AA batteries are used, the battery life will of course also be lower.

2.2 Electrode connections

The connections to the electrodes are made through a standard 34-pin 100-mil pitch header. This can be connected to an IDC flatcable or to individual electrodes. It is recommended to keep the cable length short (wear the system on the body, as in the picture below), to reduce motion artefacts.

Figure: Wireless EEG system worn and connected to 4 electrodes

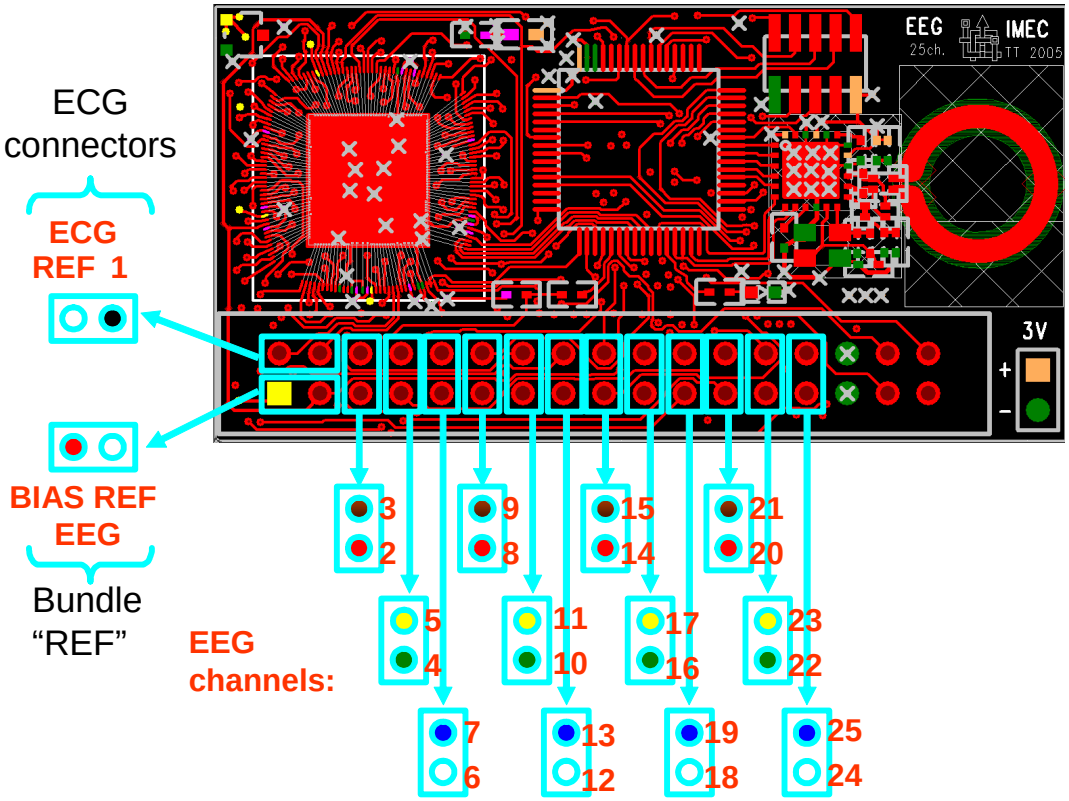


Figure: Electrode connections diagram (top view on system/connector) – the numbering was wrong in issue 0.1 (swapped 2 and 3, 4 and 5, etc.)

The figure above lists the mapping of the ECG and EEG channels, reference connections and ground (bias) connection to the connector pins.

It is recommended to place the EEG reference electrode on the center line. The ground (bias) electrode can be placed where convenient. A good reference connection is essential for good EEG measurements, so pay attention to the quality of this electrode connection. A reasonably good ground connection is also necessary to properly bias the circuit and reduce interference.

The differential ECG electrodes (ECG ref and ECG channel 1) can be placed on the chest, and can be used to correlate EEG data with the ECG waveform. The ground (bias) connection is shared with the EEG measurement.

2.3 Receiver

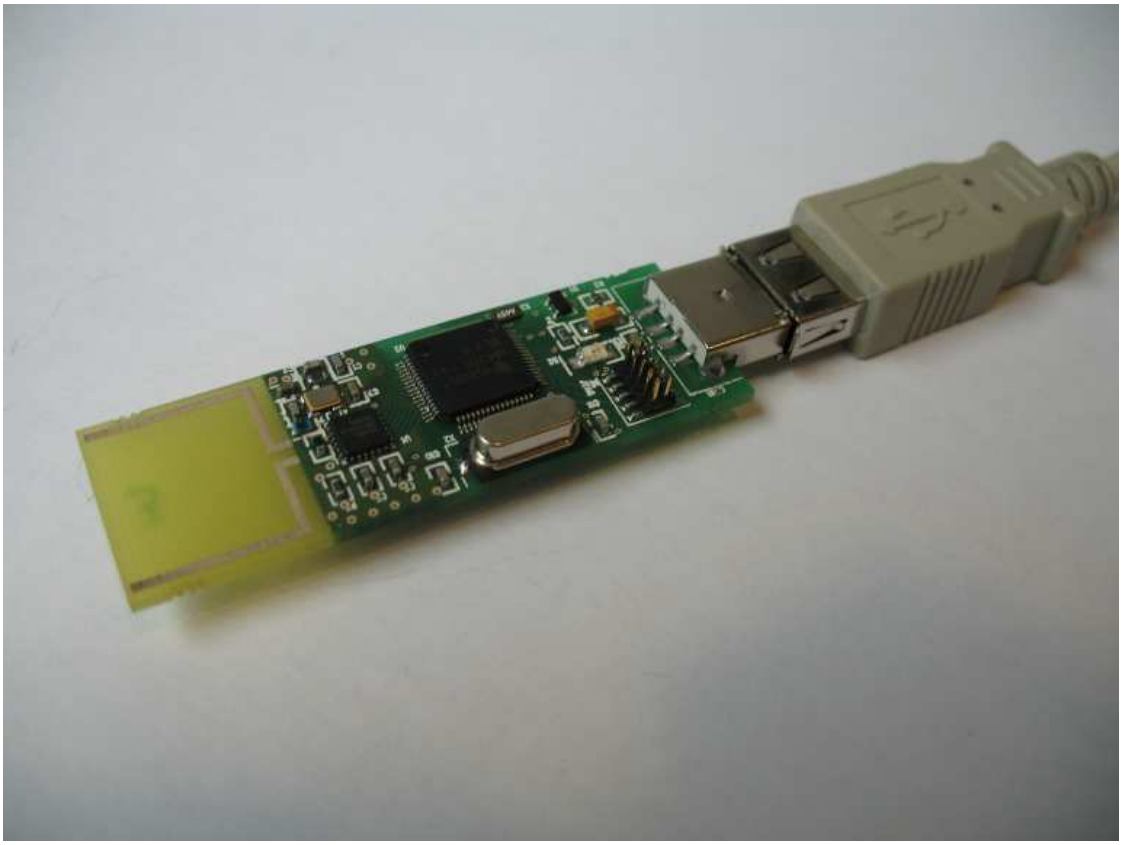


Figure: USB stick receiver, plugged into extension cable

For optimal wireless reception, the USB stick should not be plugged directly into a PC port, but should be connected to the PC with a USB extension cable. Position the USB stick horizontally on the table (as on the picture) and not adjacent to metal objects for optimal reception.

Note that with the current version of the 24-channel EEG system there is an undesired orientation dependency: in certain orientations of system and receiver, the wireless reception will be very bad. A solution for this problem exists (improved antenna) but is not yet implemented in the current system. Therefore, for now it is recommended to avoid these bad orientations when performing experiments.

2.4 Operation

After inserting/connecting the batteries, the system will go into configuration mode. In this mode you can send configuration commands (e.g. EEG/ECG gain, impedance measurement, ..) etc. to the system (see software manual).

If no command is received within 20 seconds, the system automatically switches to measurement mode. If any command is received, this timeout is aborted and only an explicit "start measurement" command will cause the system to enter measurement mode.

Once in measurement mode the only way to return to configuration mode is a power-on reset (disconnect/reconnect the batteries). This is a consequence of the fact that the radio is constantly transmitting EEG data and does not have time to listen for incoming commands. A positive side-effect of this is that during long-term measurements there is no risk of the system erroneously receiving a command over the wireless interface which could disturb the measurement.

3 Software installation

3.1 System requirements

- PC with Windows 2000, XP *(Windows 98, ME may work but this is untested)*
- Administrator rights (for installing the USB drivers)

3.2 USB stick drivers

For the "USB stick" receiver, Virtual Com Port drivers need to be installed on the PC. The drivers can be downloaded from the website of FTDI, for the FT232BM device: http://www.ftdichip.com/Drivers/VCP.htm

After having downloaded the drivers to your hard disk, log in as administrator and plug in the USB stick in one of the USB ports. A "Found New Hardware…" dialog box will appear. Browse to and install the USB bus driver (ftdibus.inf) in the package that you downloaded earlier. After successful completion of the driver installation, a second "Found New

Hardware…" dialog box will appear. Browse to and install the USB port driver (ftdiport.inf) in the package that you downloaded earlier.

After completion of this procedure, you will have an additional COM port in the system (e.g. COM5). This can be verified from System -> Hardware -> Device Manager -> Ports. You can log in as a normal (non-administrator) user now.

If you plug the USB stick in a different USB port on the PC, it *may* be needed to repeat the driver installation process (administrator rights needed). Also, if you plug the USB stick in a different USB port, a different virtual COM port is normally assigned (e.g. COM6 instead of COM5).

3.3 Visualization software

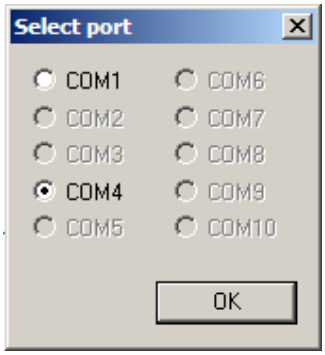
The DataView visualization & control software consists of a standalone .EXE file (dataview.exe) which can be installed to and executed from any desired place on the PC's hard drive. A suggested installation approach is:

- create a new folder, e.g. 'EEG24-DataView', in C:\Program Files
- copy the dataview.exe into this folder
- place a shortcut to this dataview.exe file on the desktop / start menu

4 Software manual

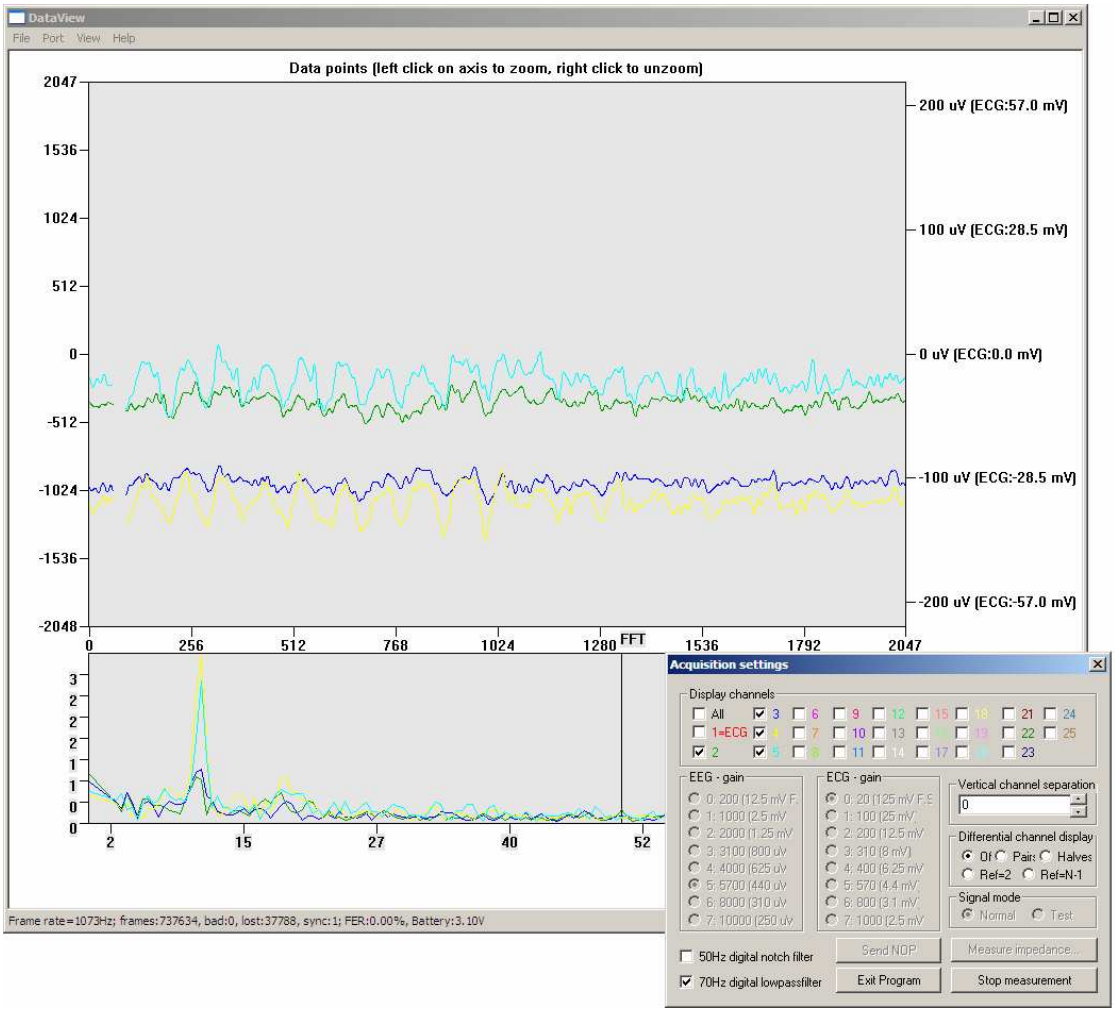
4.1 Port configuration

When dataview.exe is started, you will be asked for the COM port of the USB stick receiver (see screenshot below). Usually the default selection should be correct and you can just press OK.



4.2 Main GUI window

Then you will enter the main GUI screen:

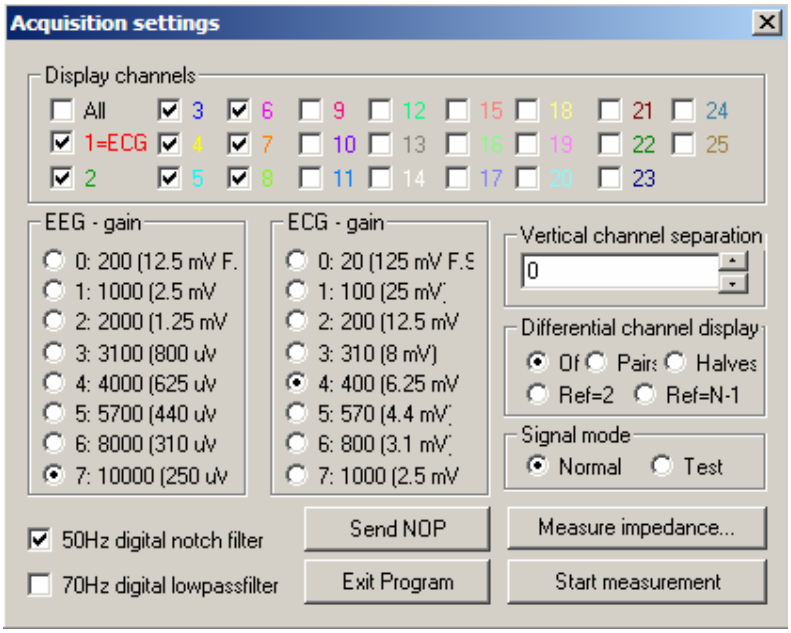


On the main window there is a plot of EEG voltage vs. time (samples), with a different color curve for the different channels. On the horizontal scale, 1024 samples corresponds to 1 second of time. You can zoom in on the plot by clicking on the axes (left-click to zoom, right-click to unzoom).

Below the time plot there is an FFT window (this appears only during measurement, and only if enabled from the View -> FFT menu). 50Hz is indicated by a vertical black line, which allows to easily identify mains noise (in Europe).

4.3 Acquisition settings window

A subwindow contains the acquisition settings (if this window is closed, you can make it re-appear from View -> Acquisition settings).



From this window, the channels that are displayed on the plots can be selected. Also optional high-order digital 70Hz lowpassfilter and/or 50Hz notch filter can be enabled here. For best signal integrity, it is recommended to enable the 70Hz lowpassfilter but not the 50Hz notch filter.

One can also force a vertical separation of the channel plots (useful if two curves overlap each other to distinguish the two), and to display differentially (EEG channels only, not ECG channel 1) in certain configurations:

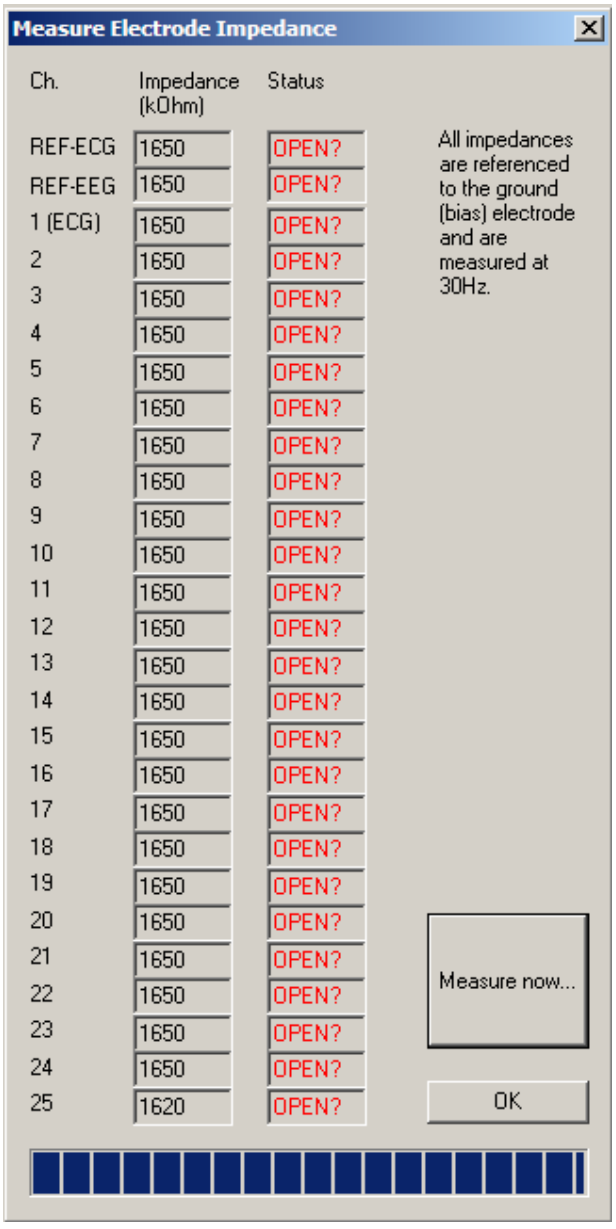
- no differential display
- pairwise 2-3,3-2,4-5,5-4,…
- halves: 2-14,3-15,…
- all channels referenced to channel 2 (first EEG channel)
- all channels referenced to channel 25 (last EEG channel)

The following commands are only available in configuration mode:

- configuring of the EEG and ECG gain (this automatically adjusts the scale of the plots also)

- change signal mode from normal to test mode (in test mode all channels produce a fake ECG waveform with a different phase, this can be useful for testing the wireless communication or software without having actual EEG electrodes connected)
- send no-operation command: you can verify the wireless communication this way, as the LED on the system should blink briefly; also it disables the 20-second timeout; otherwise this command has no effect
- impedance measurement: this leads to a subwindow, see below

4.4 Impedance measurement



From this window you can measure the impedance of all electrodes (including the reference electrodes) to the ground (bias) electrode, measured at 30Hz.

The measurement is relatively slow, so a progress bar at the bottom indicates the progress.

For EEG, a typical target is below 10 kOhm. Make sure you have a good ground connection when performing this measurement, as the ground electrode impedance will be in series with the electrode impedance.

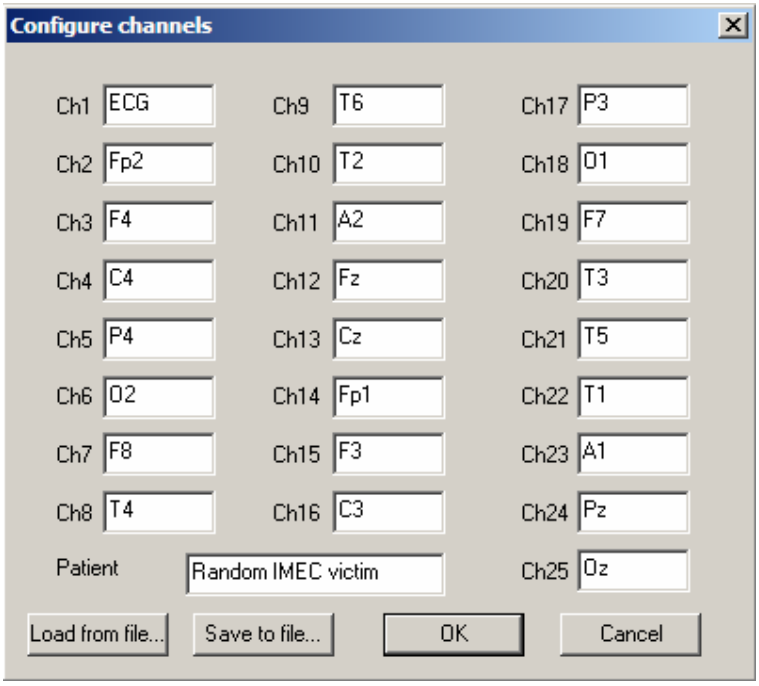
4.5 Start/stop measurement

After the necessary configuration has been done, you can start the measurement and start acquiring data. When done you can press the 'stop measurement' button to stop acquiring data, but until a power-cycle is performed on the EEG system, it will keep sending data and the configuration commands will not be functional.

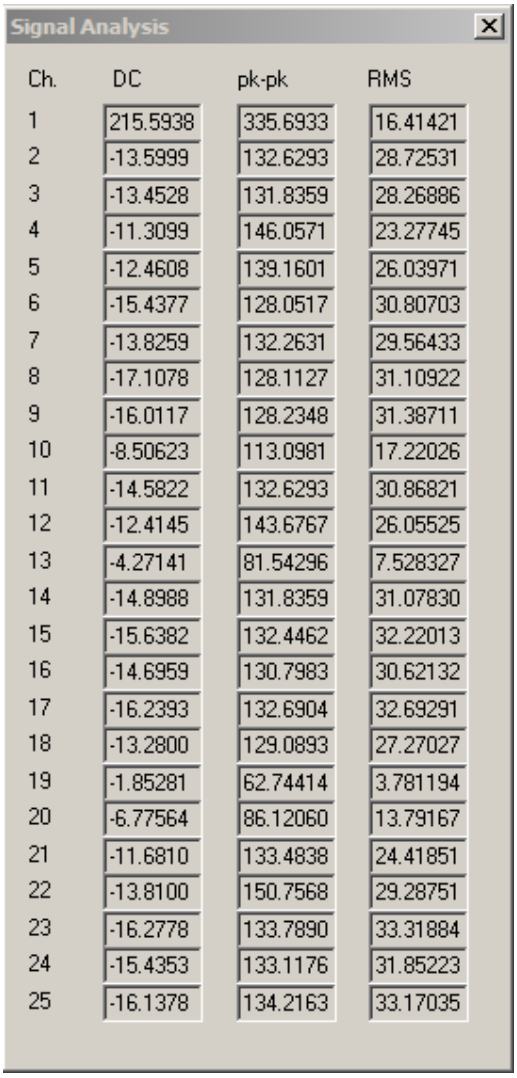
4.6 Other useful features:

File -> Record EDF: you can enable recording to an EDF file here. Recording will start on the next 'start measurement' after this option has been enabled.

File-> Configure Channels: allows to set the channel names and patient name as recorded in the EDF file. This can also be saved to / loaded from a text file:



View->Signal Analysis: this window displays for each channel for the currently displayed data the DC, peak-peak and RMS values. This can be useful for e.g. noise measurements with shorted inputs:



Ch.	DC	pk-pk	RMS
1	215.5938	335.6933	16.41421
2	-13.5999	132.6293	28.72531
3	-13.4528	131.8359	28.26886
4	-11.3099	146.0571	23.27745
5	-12.4608	139.1601	26.03971
6	-15.4377	128.0517	30.80703
7	-13.8259	132.2631	29.56433
8	-17.1078	128.1127	31.10922
9	-16.0117	128.2348	31.38711
10	-8.50623	113.0981	17.22026
11	-14.5822	132.6293	30.86821
12	-12.4145	143.6767	26.05525
13	-4.27141	81.54296	7.528327
14	-14.8988	131.8359	31.07830
15	-15.6382	132.4462	32.22013
16	-14.6959	130.7983	30.62132
17	-16.2393	132.6904	32.69291
18	-13.2800	129.0893	27.27027
19	-1.85281	62.74414	3.781194
20	-6.77564	86.12060	13.79167
21	-11.6810	133.4838	24.41851
22	-13.8100	150.7568	29.28751
23	-16.2778	133.7890	33.31884
24	-15.4353	133.1176	31.85223
25	-16.1378	134.2163	33.17035

5 Interface specifications

5.1 Serial interface

This information is provided in order to allow interfacing the wireless EEG system to proprietary software.

The wireless EEG system interfaces to the PC using a USB stick receiver. The USB stick uses a FTDI FT232BM serial ↔ USB converter. FTDI's Virtual Com Port drivers provide a virtual serial port to the application software. From the point of view of the software it is exactly like communicating with a normal serial port, with the condition that your communication libraries need to be able to handle higher, non-standard baud rates.

The correct (virtual) serial port settings for the wireless EEG system are:

- 1000000 bps baud rate (1 Mbps)
- 8 data bits, no parity bit, 1 stop bit
- no flow control

5.2 Data mode

In data mode, you will continuously (at a rate of 1024 Hz = ca. 1 ms interval) receive data frames of the following format:

- `sync byte: 'S' (0x53)`
- `byte 0: frame counter modulo 256`
- `byte 1: battery voltage, 0 = 0V ... 255 = 5.69V (resolution 22 mV) (256=5V/7*8)`
- `bytes 2..26: data channels 1..25 (1=ECG,2..25=EEG), using mu-law 12->8 bit compression around zero level=128`
- **`TOTAL (excluding sync byte):`** `27 bytes`

The sync byte is prepended by the USB stick before every frame. The receiving software can (and should) use this to achieve frame synchronization. At startup, the communication buffers will have filled up and at the end of the buffers partial frames will be present. The sync byte allows to regain frame synchronization after such a (transient) discontinuity. After

the startup phase such synchronization errors should not occur anymore (if they do, perhaps the PC is too heavily loaded; avoid running very CPU-intensive processes in parallel to the data acquisition).

The net data rate can therefore be calculated as 27 * 8 * 1024 = 222 kbit/s. Over air, additional preamble, address and CRC checksum are added, but this is transparent to the user. Only frames with valid address and CRC are passed on to the application, the others will be lost.

The frame counter can (and should) be used to interpolate lost frames. Depending on the signal quality the amount of lost frames can vary from <1% to more than 20%, but it will never be perfectly zero. The effective sample rate must remain constant, else filters, FFT analysis etc. will not produce correct results. Therefore the receiving software must interpolate the lost frames (as the Dataview software does).

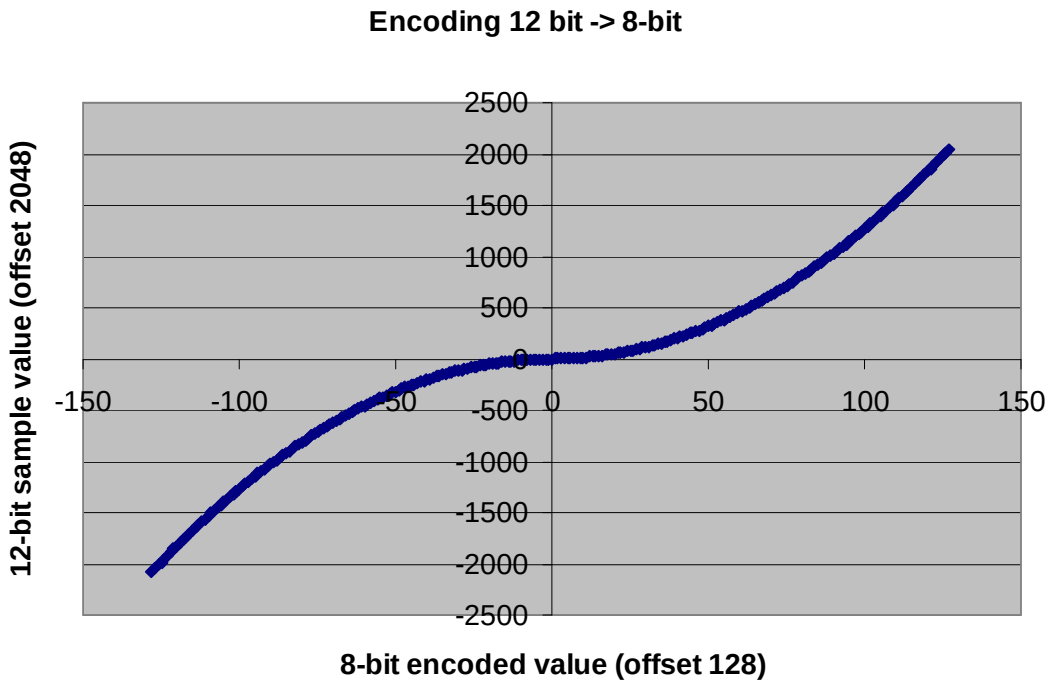
The battery voltage is also transmitted. If this voltage is below 2.7V, the system is operating out of specification. It is recommended to warn the user to replace the batteries if the voltage drops below 2.8V, and enforce battery replacement below 2.7V.

The data consists of 12-bit samples that have been encoded to 8-bit. The encoding makes sure small signals (around zero) have full 12-bit resolution, whereas large-swinging signals (e.g. movement artefacts) are encoded with less resolution. The following look-up table can be used for decoding (mid-scale = 2048 = zero signal level).

```
static const unsigned short decode_table[256] = {
    0,    1,   34,   65,   97,  128,  160,  190,
  221,  251,  281,  311,  341,  370,  399,  428,
  456,  485,  513,  541,  568,  595,  622,  649,
  676,  702,  728,  754,  779,  805,  830,  854,
  879,  903,  927,  951,  974,  998, 1020, 1043,
 1066, 1088, 1110, 1132, 1153, 1174, 1195, 1216,
 1236, 1256, 1276, 1296, 1315, 1335, 1354, 1372,
 1391, 1409, 1427, 1444, 1462, 1479, 1496, 1512,
 1529, 1545, 1561, 1576, 1592, 1607, 1622, 1636,
 1650, 1665, 1678, 1692, 1705, 1718, 1731, 1744,
 1756, 1768, 1780, 1791, 1803, 1814, 1825, 1835,
 1845, 1855, 1865, 1875, 1884, 1893, 1902, 1910,
 1919, 1927, 1934, 1942, 1949, 1956, 1963, 1969,
 1975, 1981, 1987, 1993, 1998, 2003, 2007, 2012,
 2016, 2020, 2024, 2027, 2030, 2033, 2036, 2038,
 2040, 2041, 2042, 2043, 2044, 2045, 2046, 2047,
 2048, 2049, 2050, 2051, 2052, 2053, 2054, 2055,
 2056, 2058, 2060, 2063, 2066, 2069, 2072, 2076,
 2080, 2084, 2089, 2093, 2098, 2103, 2109, 2115,
 2121, 2127, 2133, 2140, 2147, 2154, 2162, 2169,
 2177, 2186, 2194, 2203, 2212, 2221, 2231, 2241,
 2251, 2261, 2271, 2282, 2293, 2305, 2316, 2328,
```

```
 2340, 2352, 2365, 2378, 2391, 2404, 2418, 2431,
 2446, 2460, 2474, 2489, 2504, 2520, 2535, 2551,
 2567, 2584, 2600, 2617, 2634, 2652, 2669, 2687,
 2705, 2724, 2742, 2761, 2781, 2800, 2820, 2840,
 2860, 2880, 2901, 2922, 2943, 2964, 2986, 3008,
 3030, 3053, 3076, 3098, 3122, 3145, 3169, 3193,
 3217, 3242, 3266, 3291, 3317, 3342, 3368, 3394,
 3420, 3447, 3474, 3501, 3528, 3555, 3583, 3611,
 3640, 3668, 3697, 3726, 3755, 3785, 3815, 3845,
 3875, 3906, 3936, 3968, 3999, 4031, 4062, 4095
};
```

A graphical plot of the encoding:



5.3 Command mode

During command mode (after power-up, and before the data mode is started, either by command or by timeout), the system is in receive mode. It can then accept the following single-byte commands:

0x00 = NOP

No-operation command. Can be used to disable the timeout without really doing anything, or for verifying that the radio communication works (LED on system will blink briefly on reception of this command).

0x10-0x17 = set EEG gain
0x18-0x1F = set ECG gain

These commands set the EEG resp. ECG channel gain. The gain is encoded in the bottom 3 bits of the command byte:

EEG			ECG		
Setting	Gain	Full-scale (uV)	Setting	Gain	Full-scale (mV)
0	200	12500	0	20	125
1	1000	2500	1	100	25
2	2000	1250	2	200	12.5
3	3076	813	3	308	8.12
4	4000	625	4	400	6.25
5	5714	438	5	571	4.38
6	8000	313	6	800	3.13
7	10000	250	7	1000	2.5

The default gain at startup is 7 (250 uV full scale) for EEG and 3 (8.12 mV full scale) for ECG.

The LED on the system will blink briefly on reception of the gain command.

0x20 = start measuring data

This command exits command mode and starts data mode. The system's radio will be only transmitting, not receiving. Therefore no more commands are possible until after the system is reset (power cycled).

0x30 = measure impedance

This command initiates a measurement of the impedance of all 25 electrodes as well as the two reference electrodes (EEG and ECG) with respect to the ground electrode. The measurement is performed with a 30Hz stimulus. The maximum AC current through the patient during the measurement is 3 microamperes. The net DC current is zero.

The impedance measurement for all channels takes 18-20 seconds. During this time the LED on the system will blink slowly.

After the measurement is completed, the data is sent in the following frame to the PC: (same length as a normal data frame)

- `sync byte: 'S' (0x53)`
- `byte 0: impedance data for ECG reference electrode`
- `byte 1: impedance data for EEG reference electrode`
- `bytes 2..26: impedance data for channel electrodes 1..25 (1=ECG,2..25=EEG)`
- **`TOTAL (excluding sync byte):`** `27 bytes`

The 8-bit impedance data values are encoded as follows:

- < 100: impedance value in kiloohms
- >= 100: 100 + (impedance value in kiloohms - 100K) / 10K

Therefore 0 = 0K, 10 = 10K, 99 = 99K,

100 = 100K + 10K * (100 - 100) = 100K,

110 = 100K + 10K * (110 - 100) = 200K

255 = 100K + 10K * (255 - 100) = 1.65Mohm (or higher, as this is the limit).

An open (unconnected) electrode will normally give value 255 (corresponding to 1.65Mohm or above).

0x40 - set normal mode

Set the normal signal acquisition mode. This is also the default. The LED on the system will blink briefly on reception of this command.

0x41 - set test signal mode

Set the test signal mode. A fake, synthetic ECG waveform is transmitted on all channels, with a different phase for each channel. This can be used for testing the wireless interface, software, etc. when the system is not connected to an actual patient.

Timeout

If no commands are received within 20 seconds after power-up, the system will automatically proceed to data mode. Reception of any valid command will cancel this timeout.