Blitzortung.org - A low cost Time of Arrival Lightning Detection and Lightning Location Network

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This document is constantly evolving. Please send improvements, typos, or remarks at `mailto:blitzortung@gmx.org`. It is not allowed to publish excerpts of this document on websites that are not under our control. Most of the receiving stations are currently operating in Germany, but we are emphatically interested to extend our activities to other continents. Just try to contact with us.

Blitzortung.org is the first free an non-commercial lightning detection and lightning location system of the world. The data provided by Blitzortung.org is only used for private and entertainment purposes. Blitzortung.org is not an offocial information service for lightning data. A commercial use of data from Blitzortung.org is strongly prohibited, even by the users that send data to our server.

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Contents

1   Introduction

How lightning initially forms is still a matter of debate [BSL09]. Scientists have studied root causes ranging from atmospheric perturbations (wind, humidity, friction, and atmospheric pressure) to the impact of solar wind and accumulation of charged solar particles. Ice inside a cloud is thought to be a key element in lightning development, and may cause a forcible separation of positive and negative charges within the cloud, thus assisting in the formation of lightning. It was not obvious, that lightning deals with electricity, since the electric current does not flow through the air. This, on June 10th 1752, Benjamin Franklin flies a kite during a thunderstorm and collects a charge in a Leyden jar when the kite is struck by lightning, enabling him to demonstrate the electrical nature of lightning. He also invented the lightning rod, used to protect buildings and ships.
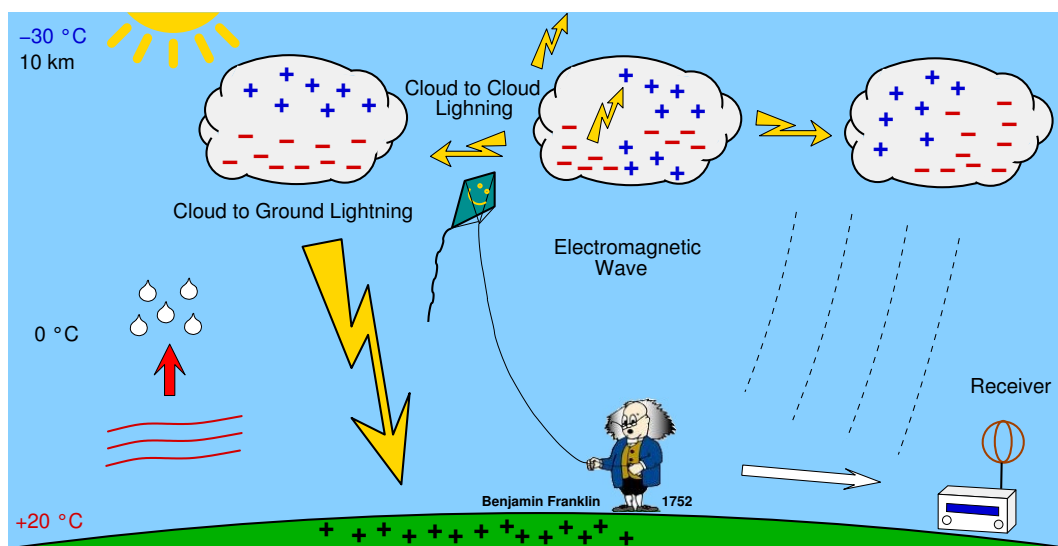

Figure 1:   How lightning forms

A lightning discharge emits radio frequency energy over a wide range of frequencies. When high currents occur in previously ionized channels during cloud-to-ground flashes, the most powerful emissions occur in the VLF range. VLF (very low frequency) refers to radio frequencies in the range of 3 KHz to 30 KHz. An essential advantage of low frequencies in contrast to higher frequencies is the property that these signals are propagated over thousands of kilometers by reflections from the ionosphere and the ground. In general, a lightning discharge generates several short duration pulses running between a storm cloud and the ground, or between or within storm clouds. The current flow generates an electric field parallel to the current flow, and a corresponding magnetic field perpendicular to the electric field.

The lightning location network Blitzortung.org consists of several VLF lightning re-

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Figure 2: Some lightning discharges in the atmosphere, ©Bernd März

ceiver sites and one central processing server for each larger region. The receiver sites transmit their data in short time intervals over the Internet to our server. Every data sentence contains the precise time of arrival of the received lightning strike impulse ("sferic") and the geographic position of the receiver site. With this information from all receiver sites the exact positions of the discharges are computed. The sferic positions are made available in raw format to all users that transmit their data to our server. The users can use the raw data for all non-commercial purposes. The lightning activities of the last two hours are displayed at http://www.Blitzortung.org on several public maps recomputed every minute.

Blitzortung.org is a community of receiver site operators who transmit their data to a central server, programmers who develop and/or implement algorithms for the location or visualization of sferic positions, and people who assist anyway to keep the system running. There is no restriction on membership. There is no fee and no contract. All people who keep the network in operation are volunteers. If a receiver site stops pooling its data, the server stops providing the access to the archive of sferic positions for the corresponding user.

The aim of the project is to accomplish a low budget lightning location network based on a high number of receiver sites spaced close to each other, typically separated by 50 km - 250 km. The hardware you need to participate to the network consists of an antenna, Ferrite or loop, a VLF pre-amplifier, our evaluation board, a GPS receiver providing an 1PPS (one-pulse-per-second) signal, and a personal computer permanently connected to the Internet. You can get the PCBs, the A/D-converter, and the programmed micro-controller from us. To participants not from Germany we sometimes also send complete
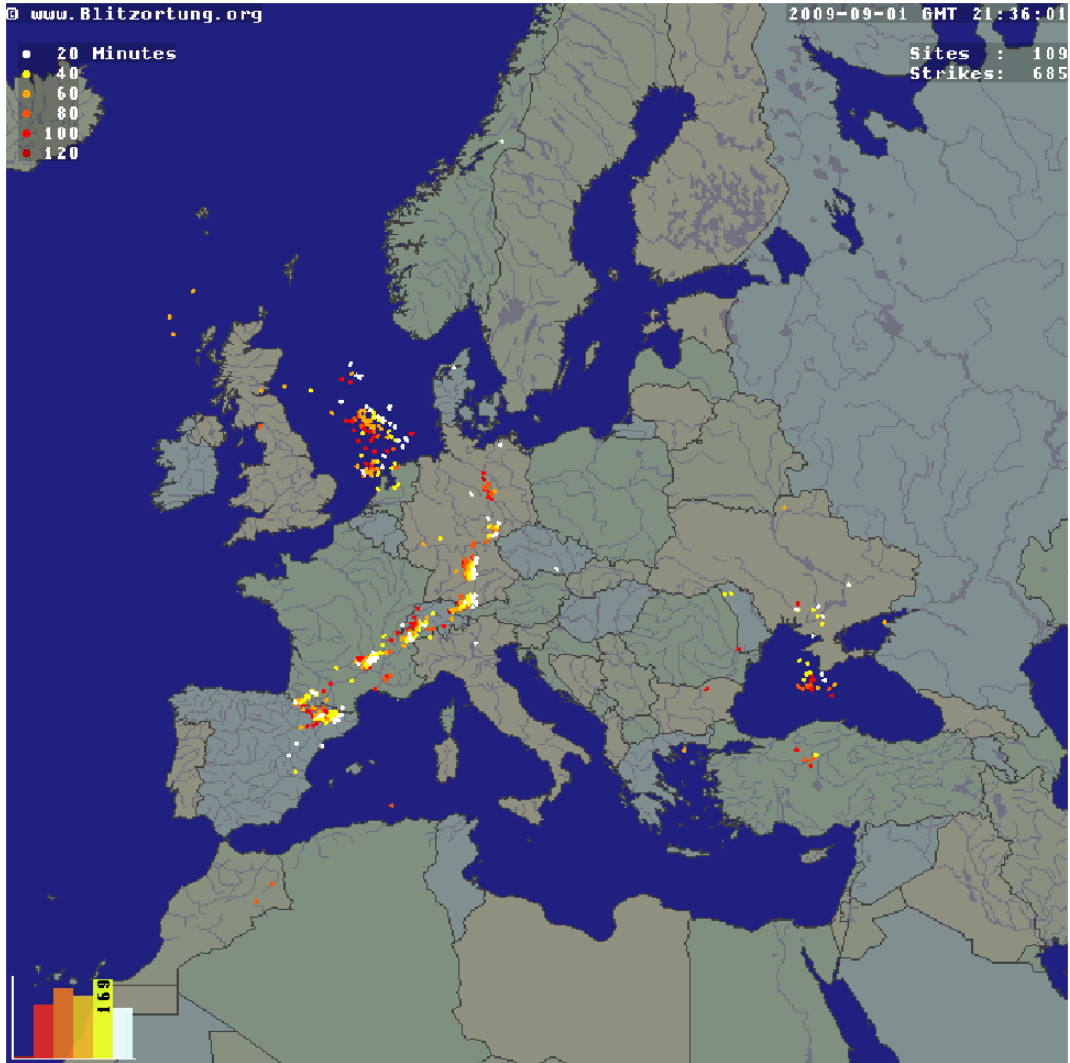
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Figure 3: A lightning map of Europe from Blitzortung.org

kits as shown in Figure 4. We do not send completely assembled kits. We do not have the time to assemble the kits for you. You either can assemble the kits by yourself or should look for somebody who can assemble the kits for you.

Note that it is not possible to compute positions or at least accurate directions with the data from one station. We need the data of several stations (at least four stations) to compute strike positions. There is currently no software that enables you to set up a connection with other sites like the LR software of Frank Kooimann for the direction finding system. The computation of strike positions is currently only done by one of our computing servers.

The next sections will explain how you can setup an own receiver for lightning discharges.
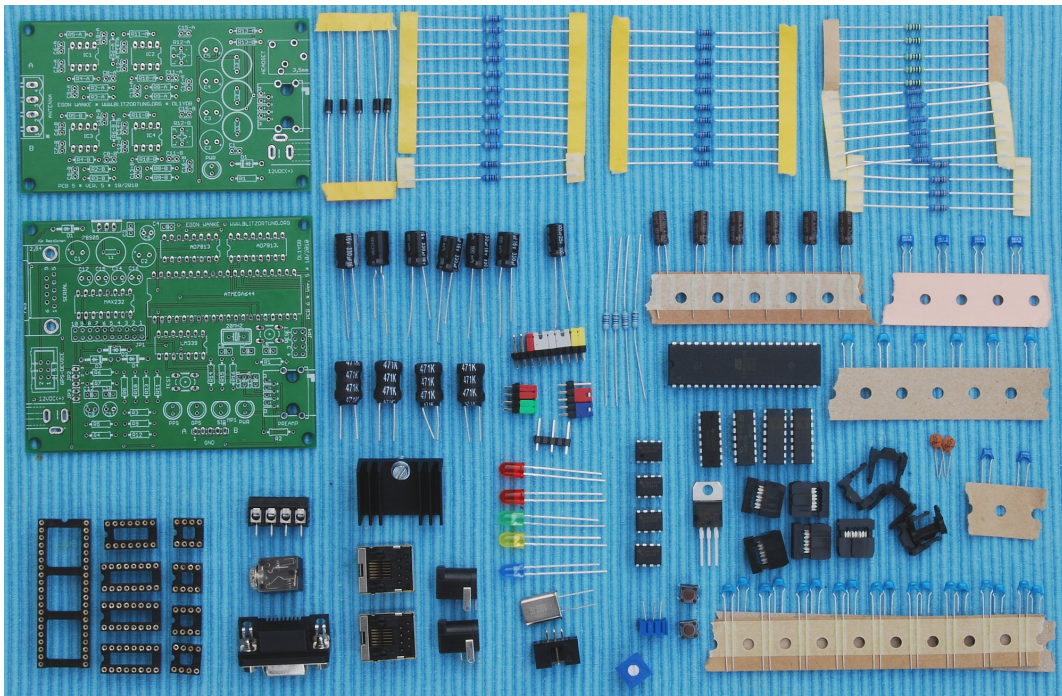
Figure 4: The pre-amplifier kit and the evaluation board kit

2 VLF antennas

2.1 The lightning signals

Waves with a frequency between 3 KHz and 30 KHz have a length between 100 km and 10 km. A suitable antenna for these frequencies is a **small loop antenna** with size of less than 1/10000 of the wavelength in circumference. Small loops are also called magnetic loops, because they are more sensitive to the magnetic component of the electromagnetic wave, and less sensitive to near electric field noises when properly shielded. If the loop is small with respect to the wavelength, the current around the antenna is nearly completely in phase. Therefore, waves approaching in the plane of the loop will cancel, and waves in the axis perpendicular to the plane of the loop will be strongest. This property changes if the loop becomes larger.
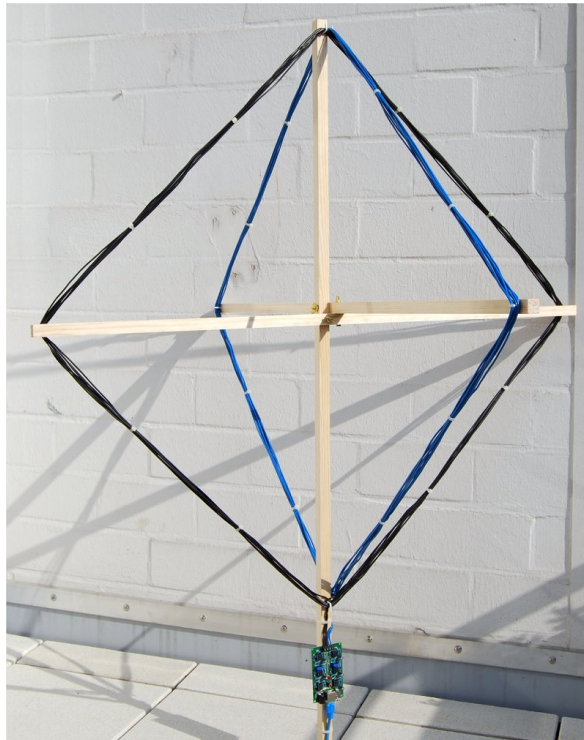
Figure 5: Two orthogonal crossed VLF loop antennas, 8 turns, diagonal size 1 m connected to pre-amplifier PCB 3 Version 2.

The electric field of the radio waves emitted by cloud-to-ground lightning discharges is mainly oriented vertically, and thus the magnetic field is oriented horizontally. To cover all directions (all-around 360 degree) it is advisable to use more than one loop. A suitable solution can be obtained by two orthogonal crossed loops as they are used for a direction finding system.

Figure 6: A spectrogram of the signal received by a 35 cm ferrite rod antenna. The signal was recorded by a Creative Professional E-MU 0202 sound card with a sampling frequency of 192 KHz. The spectrogram is made by Spectrum Lab. Vertical lines shows radio transmissions for special purpose, and do not affect our reception.

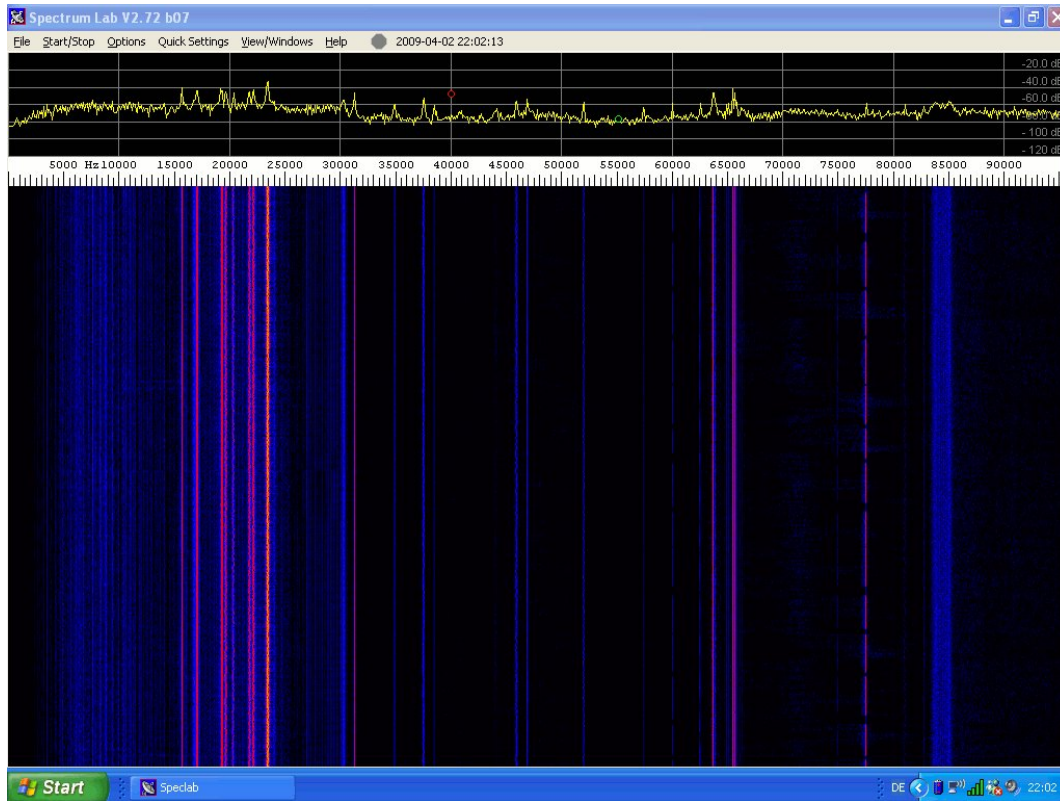The electromagnetic signals of lightning discharges are not waves of a fixed frequency. The signals have more or less the form of an impulse and thus emits waves over a wide range of frequencies. Every of these impulses is unique and looks different. To measure the time of arrival of a lightning discharge, we need a wide-band receiving system, and not a tuned system. The antenna should be large to get a high voltage caused by the change of the electromagnetic field. If the loop consists of more than one winding, the wire placed side by side forms a capacitance.

However, the unavoidable own resonance frequency of a loop should be as high as possible such that we can easily suppress these frequencies by a low-pass filter. **Please avoid any additional tuning capacitor**. Figure 7 shows to the left a signal received by two equal sized un-tuned loops antennas. These loops have no additional tuning capacitor. The resonance frequency of the antenna is approximately at 1000 KHz (= 1 MHz). The used pre-amplifier reduces frequencies of 1000 KHz by -72 dB (=4000 times). To the right of Figure 6, Loop B is connected to a parallel tuning capacitor of 1 μF. Now, the tuned

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frequency is the antenna is approximately 10 KHz. Since lightning impulses often contain a lot of energy at 10 KHz, the tuned loop antenna only outputs unusable uniform waves of 10 KHz. This shows that it is very important to use a pure loop without any parallel capacitor.
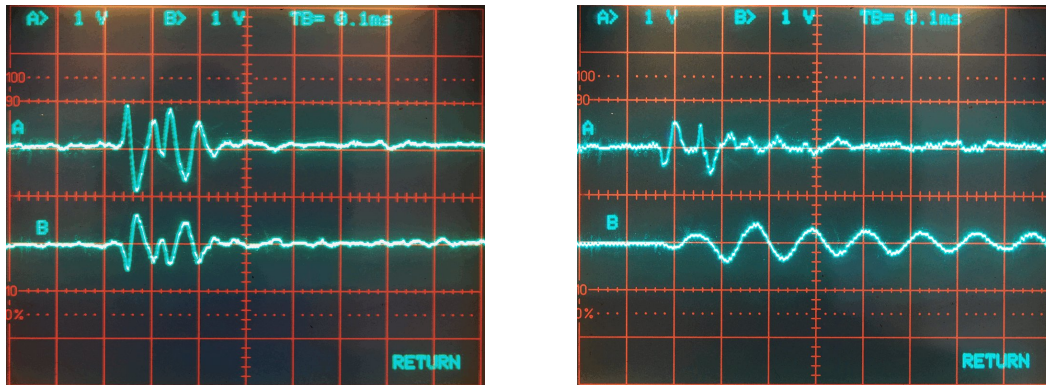

Figure 7: To the left, a signal received by two loop antennas without tuning capacitors, to the right, antenna B is tuned to approximately 10 KHz. This signal can not be used for time measurement.

2.2 Frame antennas

It is easy to set up a frame antenna for VLF frequencies by yourself. Useful construction manual can also be found at the Internet. Two example at

http://members.inode.at/576265/LightningRadarSystem.zip

written by Gerald Ihninger and

http://users.edpnet.be/DanielV37/Detecteur3/Antenna/Antenna.htm.

written by Daniel Verschueren. Both instruction manuals are made for the participants of the lightning radar project http://www.lightningradar.net.

For a square frame antenna with a diagonal of 1 m and 8 turns of wire you need

- approximately 4 m of 20×20 mm wooden coving,

- 2×25 m cable with a single conductor of area 1.5mm^2 (this corresponds to a diameter of 1.38 mm),

- 8 screw hooks,

- 3 screws/washer/wingnuts, and

- some cable ties.

The assembling takes about two hours. The price for the material is approximately 40 Euro in a German home improvement store.
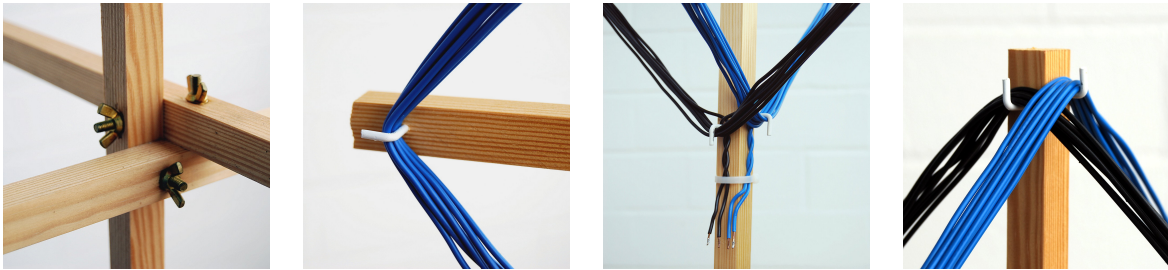
Figure 8: Assembling details for the frame antenna

A shielding of the E-field can significantly improve the signal to noise ratio, especially in metropolitan areas. This can improve the detection rate of lightning discharges. As we only want the magnetic part of the signal (H-field), any Electric field (E-field) is unwanted. The shielding of a loop antenna can be realized for example by wires in a copper tube. It is important that the tube is not closed. It can either be separated at the top or at the bottom. If it is separated at the bottom, then only one end of the copper tube has to be connected with the ground of the pre-amplifier.

Figure 9: ©Daniel Verschueren

2.3 Coaxial cable antennas

A cheep loop antenna can easily be constructed using coaxial cable. You can use an arbitrary impedance, but the 75 Ohm version are very cheap to get. With 20 Meter coaxial cable you can form a loop with 3 turns and a diameter of 180 cm. The shield has to be broken in the middle. Keep 20 cm cable for the connection at both ends. Such a construction will create a loop with an induction of approximately 60 uH and a self-resonance at 2 MHz.

180cm

+ Ground -

Figure 10: A coax antenna, ©Richo Andersen

Cut off the plastic sheath,

remove the wire grid,

put the separated plastic sheath back,

and cover the area by a flexible hose.
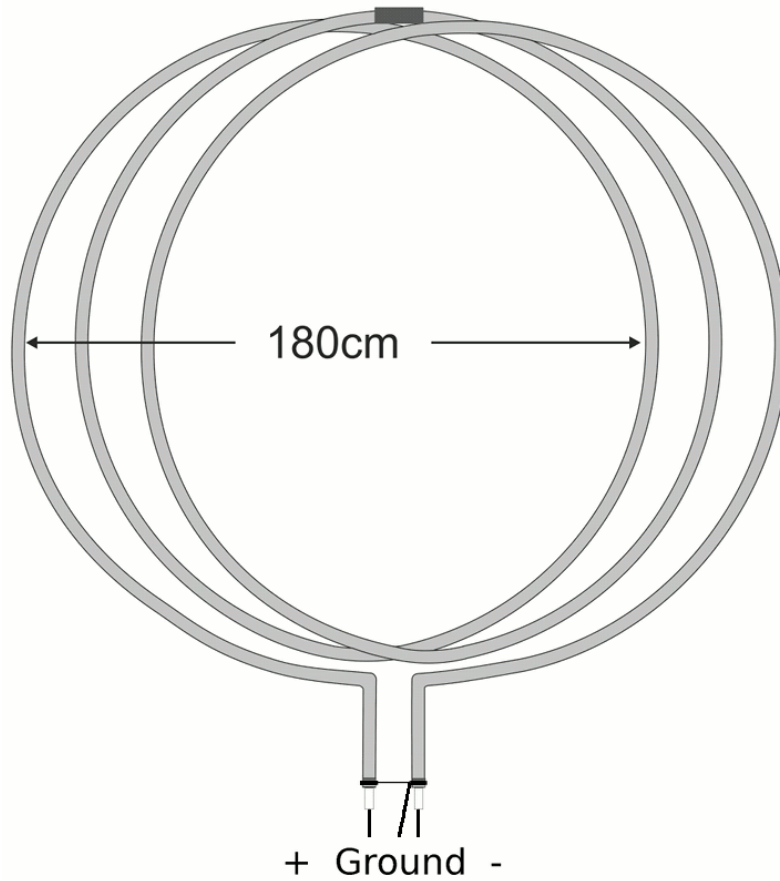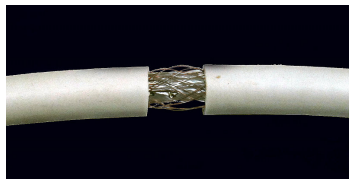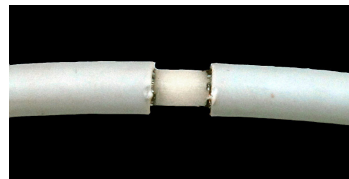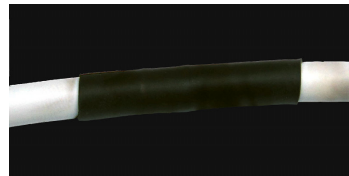
©Richo Andersen

Figure 11: Cutting the wire grid in the middle of the coaxial antenna
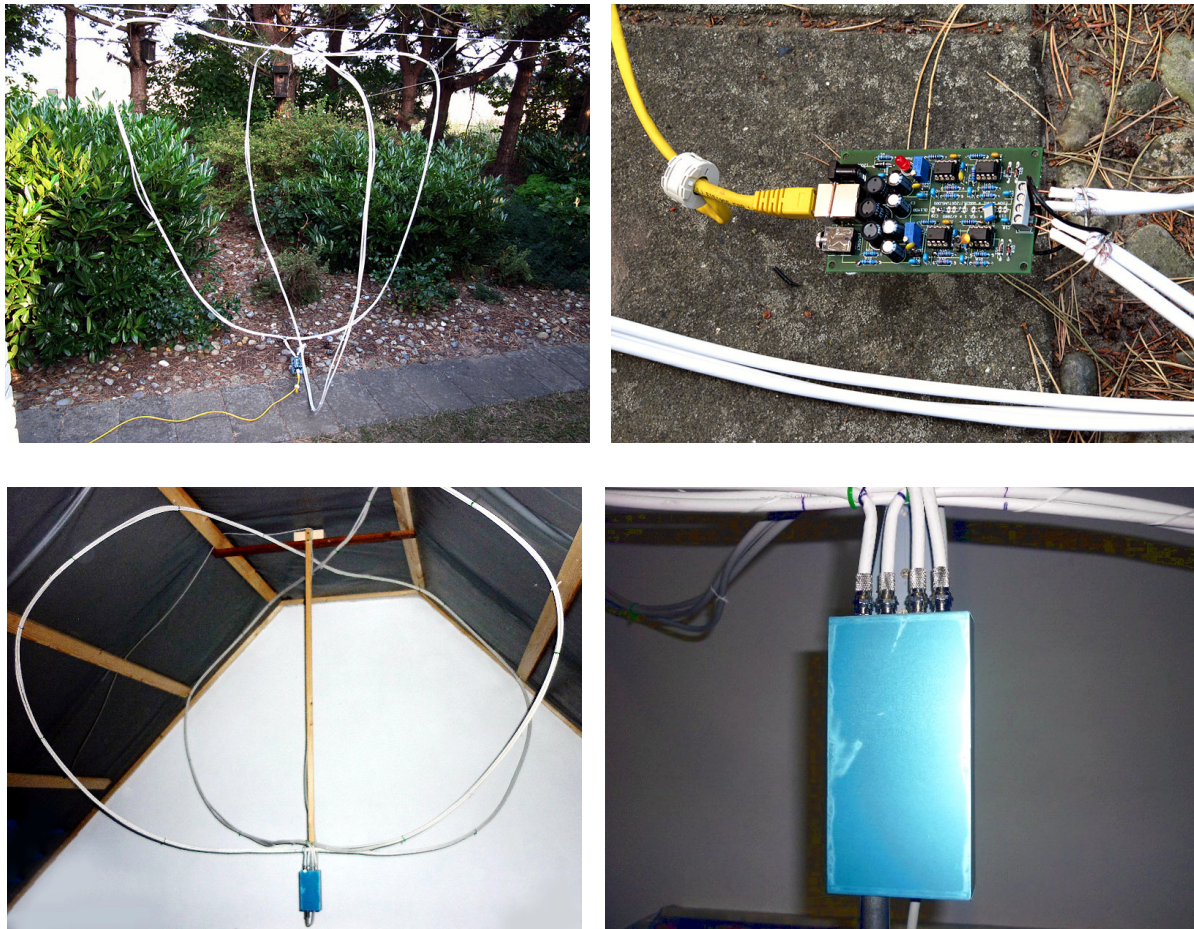
Figure 12:   Connecting a coax antenna, ©Richo Andersen and Bernhard Kilimann

2.4 Ferrite rod antennas

The size of the antenna can extremely be reduced by using ferrite rods, but a ferrite rod antenna needs a higher number of turns to get the same voltage compared with the larger loop antenna. That is, a corresponding ferrite rod antenna has a lower resonance frequency than the larger loop antenna. This is one reason why the loop antennas are more adequate than small ferrite rod antennas. The resonance frequency of the ferrite rod antenna for wide-band VLF reception should not fall below 100 KHz. Suitable ferrite rod antennas can be obtained from http://www.sfericsempfang.de.
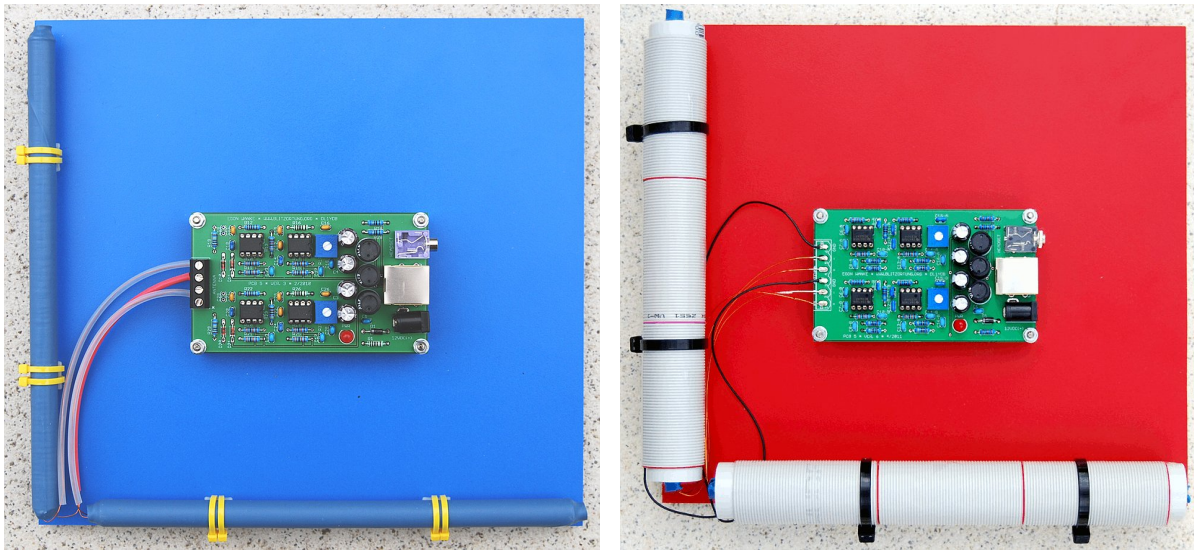
Figure 13: Two 20 cm ferrite rod antennas mounted on a PVC board connected to pre-amplifier PCB 5 Version 1, and two 20 cm ferrite shielded rod antennas mounted on a PVC board connected to pre-amplifier PCB 5 Version 6

Please do not twist the connection cable of the ferrite rod antennas. This creates a capacity and leads to a lower self resonance.

It is not necessary to align the two antennas to north/south and west/east. The antennas only have to be placed horizontally, because the magnetic field of radio waves emitted by cloud-to-ground lightning discharges is mainly oriented horizontally. If you are using ferrite rod antennas, you have to strip the insulation of the copper enameled wires, before the blank copper wires can be soldered to the pre-amplifier board. The wires definitively have to be soldered to the board. It is not possible to tighten such thin wires sufficiently good with the screws of the terminal block. If you are using the ferrite rod antennas of http://www.sfericsempfang.de, then one of the two copper enameled wire ends has a knot. Connect these wires with the hot inputs of your pre-amplifier. If you are using PCB 5.1, PCB 5.2, or PCB 5.3 the knots should be connected to pin 1 and 4. If you are using PCB
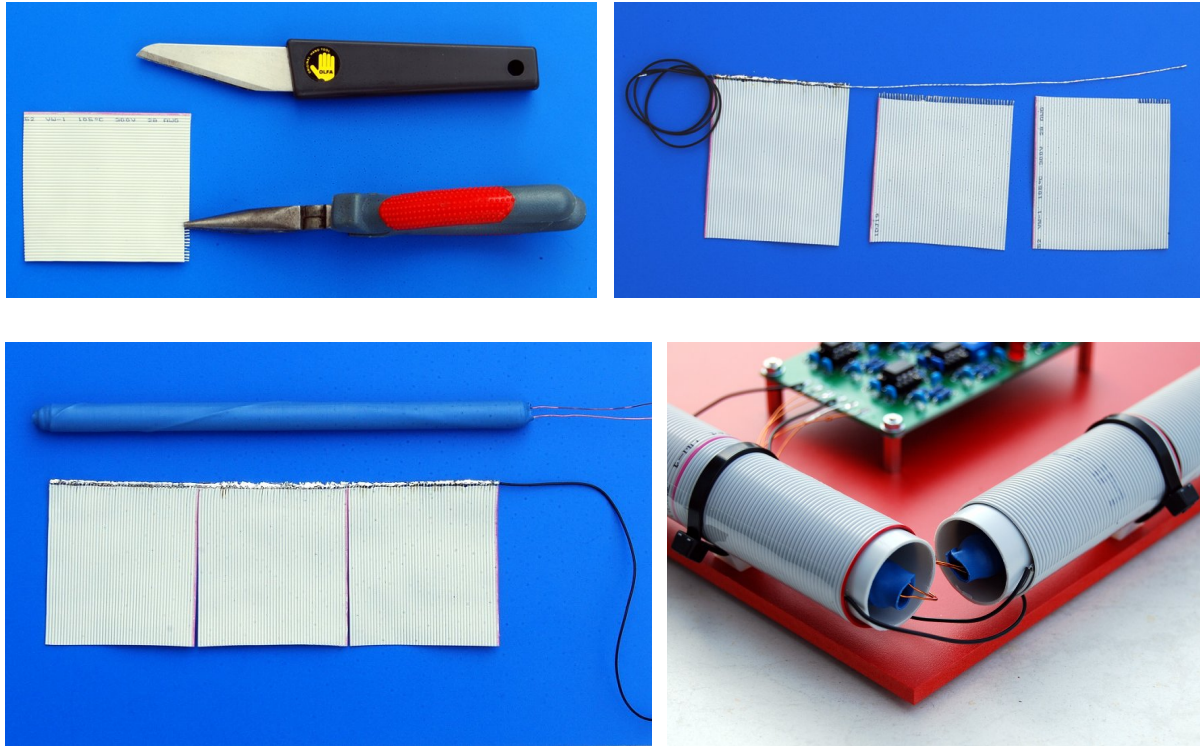
Figure 14: Shielding a ferrite rod antenna with ribbon cable
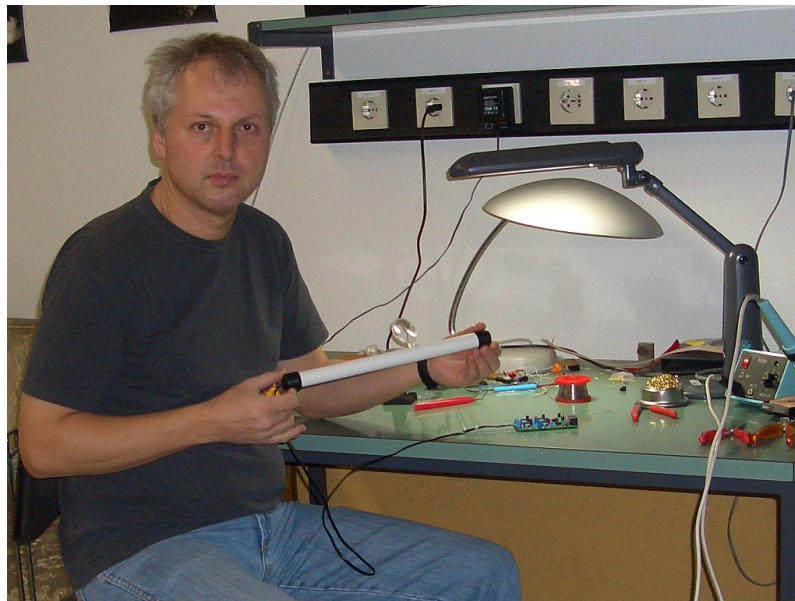
Figure 15: A 35 cm ferrite rod antenna in my hands

5.4 or PCB 5.5 the knots should be connected to pin 1 and 3.

Figure 16: A quite location far away from VLF noises

2.5 Electrical antennas

It is also possible to use an **electrical antenna**, i.e., an antenna sensitive to the electric component of the electromagnetic wave. As already mentioned above, the electric field of the radio waves emitted by cloud-to-ground lightning discharges is mainly oriented vertically. That is, in the simplest case, the electrical antenna is a vertical wire directly connected to one channel of the pre-amplifier. Note that it is important that the wire is directly connected to the input of the pre-amplifier. If you use our pre-amplifier PCB 5 Version 5, connect it to the hot input at capacitors C7-A or C7-B, i.e., to the eye number 1 or 3 of the terminal block, and connect the other two inputs to ground. Do not use coaxial connection cables. This could generate a phase shift which leads to an inaccurate time measurement. Figure 17 shows an example of a simple electrical antenna consisting of 1 meter cable. The amplification of the second channel should be switched off. You can, for example, remove the operational amplifiers.

The advantages of an electrical antenna are the following. 1.) Since it receives signals from all horizontal directions, we need only one antenna instead of two antennas. 2.) The received signals are very clean and free of any resonances frequencies. Figure 18 shows a signal of a lightning discharge received by an electrical antenna (above) and received by a ferrite rod antenna (below). 3.) It is possible to determine the polarity of the lightning discharge, if the lightning discharge was not to far away. 4.) It is easy to construct for a very low price. However, an electrical antenna has also some disadvantages. 1.) It is very sensitive to field electric noises. 2.) It has to be placed outside or at least on an attic, and thus, conditions for lightning protection have to be respected.

When using an electrical antenna, the **ground** of the pre-amplifier and thus also the ground of the evaluation board should be connected to a large expanse of metal such as a safety hand rail around a roof. Note that the ground of the boards should never be

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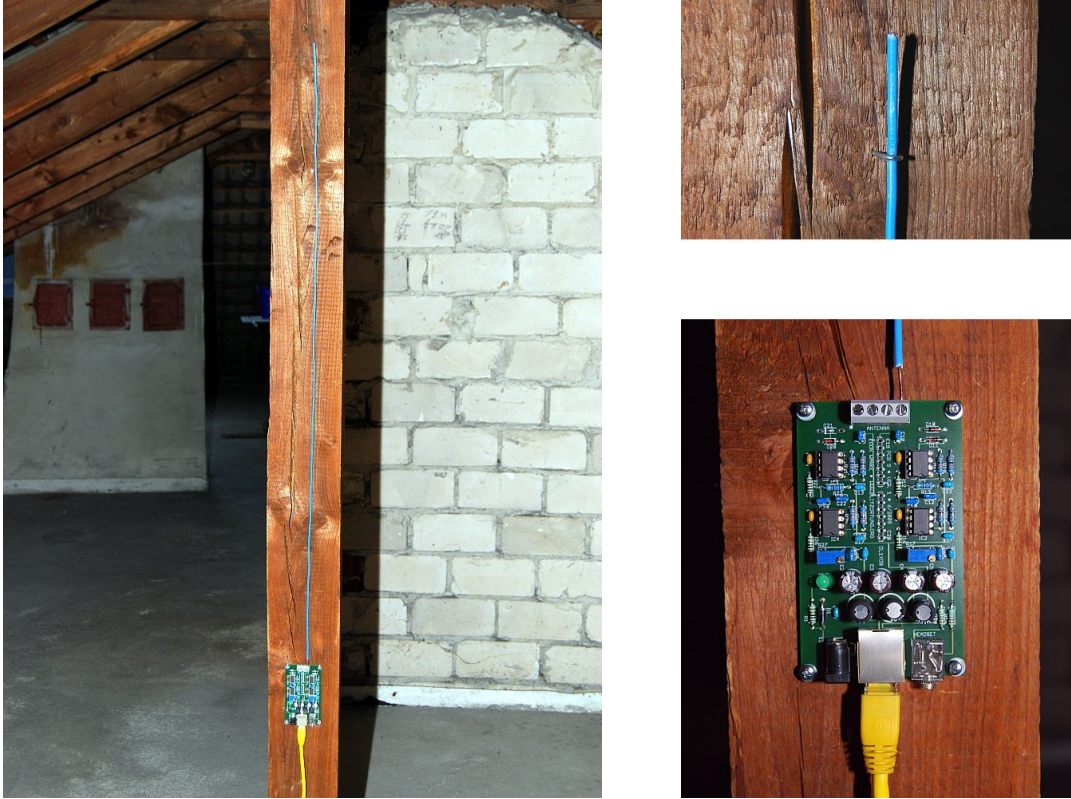
Figure 17: A wire of 1 meter length used as an electrical antenna connected to pre-amplifier PCB 5 Version 1
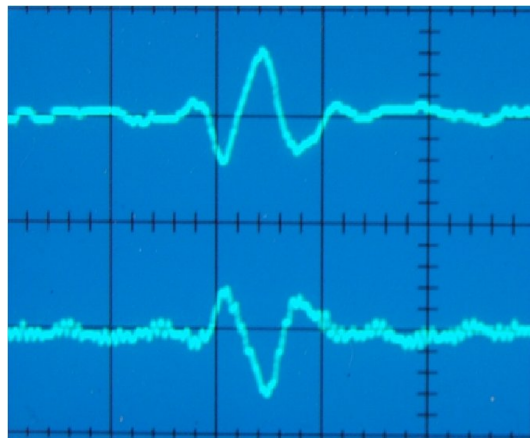
Figure 18: A signal of a lightning discharge received by an electrical antenna (above) and by a loop antenna (below)

connected to the ground wire of the electrical supply system. Usually some grounding is already given if the serial 9-ways Sub-D plug is connected to the PC. A grounding is not

necessary for ferrite rod antennas.

The circuit diagram of Figure 19 shows how to connect an electrical antenna to the pre-amplifier PCB 5 Version 6. The second input has to be connected to ground. The 1 M resistor is inserted to avoid electrostatic charges.
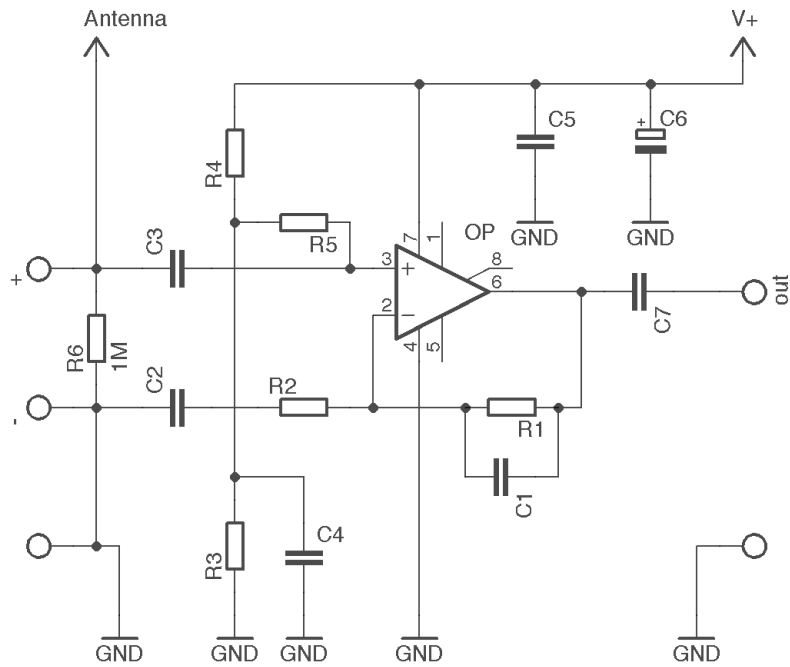
Figure 19: The modification for electrical antennas

3 VLF pre-amplifier

3.1 Description

Our VLF pre-amplifier is realized by standard operational amplifiers (op-amps). The output of an op-amp is controlled either by negative feedback, which largely determines the magnitude of its output voltage gain, or by positive feedback, which facilitates regenerative gain and oscillation. Operational amplifiers have in general a high input impedance and a low output impedance.
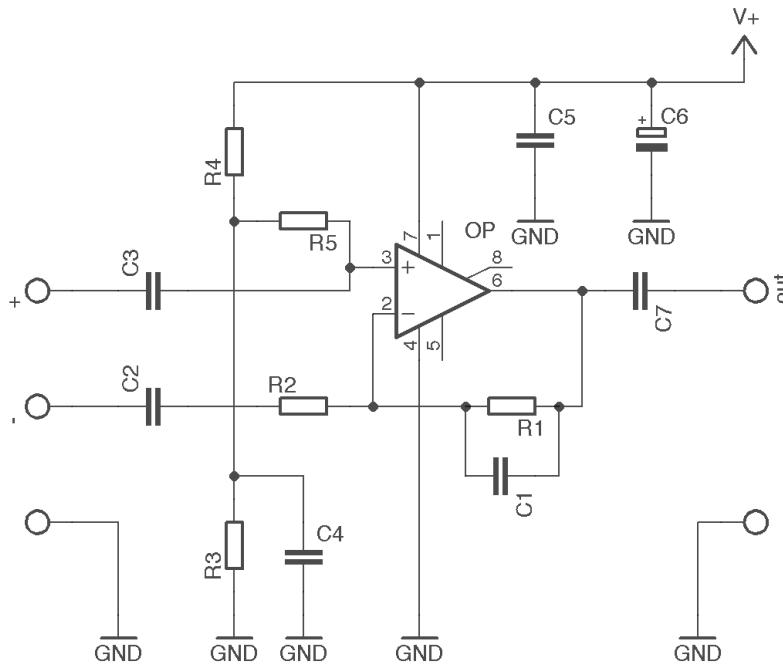
Figure 20: An operational amplifier stage in single-supply operation with non-inverting gain

Our VLF pre-amplifier uses a first-order active low-pass filter with a cutoff frequency between 15 KHz and 70 KHz determined by

$$f \quad = \quad \frac{1}{2 \cdot \pi \cdot R_1 \cdot C_1},$$

see Figure 20 for R_1 and C_1. The low-pass filter reduces the signal amplitude by half (about -6 dB) every time the frequency doubles, in each op-amp. The filter is mainly used to reduce the signals nearby the self-resonance frequency of the loop antenna. A loop antenna with more than one turn has a self-resonance frequency depending on the capacity between the loop wires. If you are using a coax antenna or an electrical antennas, you can choose higher cutoff frequencies than 15 KHz. The gain of the amplifier is determined by

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the voltage divider R_1/R_2 and can be computed by $1 + \frac{R_1}{R_2}$. Table 1 shows some common R_1/C_1 pairs with a cutoff frequency of approximately 15 KHz/33 KHz/72 KHz and the corresponding gains with $R_2 = 1.0$ K, $R_2 = 2.2$ K, and $R_2 = 4.7$ K for one stage.

R_1	C_1	Cutoff frequency	Gain for		
			$R_2 = 1.0\text{K}$	$R_2 = 2.2\text{K}$	$R_2 = 4.7\text{K}$
47 K	220 pF	15.4 KHz	48	22	11
47 K	100 pF	33.8 KHz	48	22	11
47 K	47 pF	72.1 KHz	48	22	11

Table 1: R_1/C_1 pairs for the low-pass filter with a cutoff frequency of approximately 15 KHz/33 KHz/72 KHz, additionally, R2/C2 forms a High-Pass filter reducing the 50 Hz signals and its harmonics.
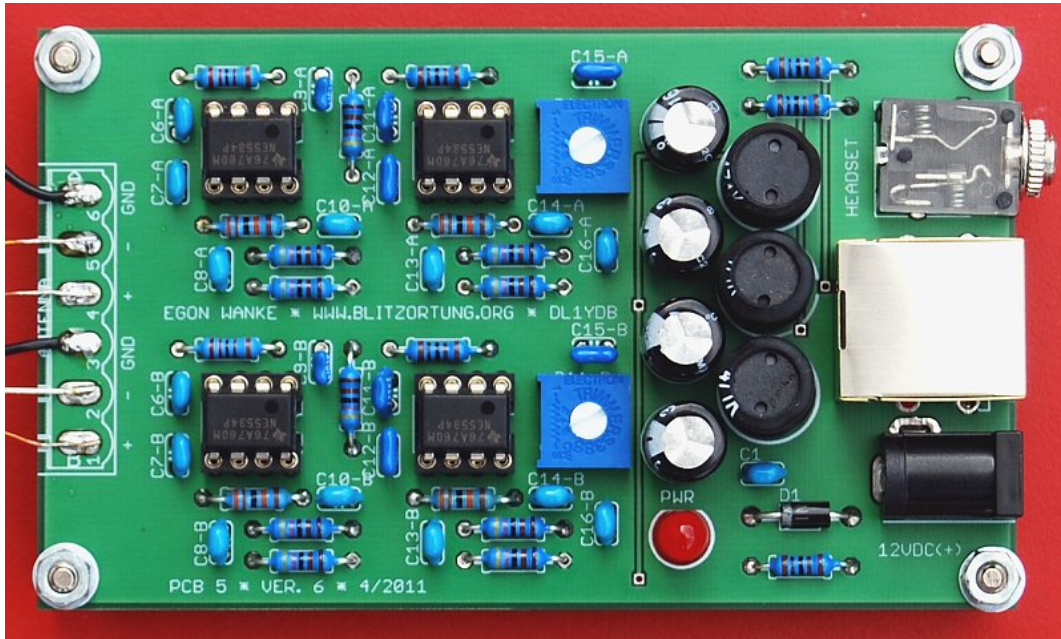
Figure 21: An assembled pre-amplifier PCB 5 Version 6

The printed circuit board PCB 5 realizes a two channel two stage VLF pre-amplifier. For the sake of simplicity, the amplifier operates in single-supply mode with non-inverting attenuation, see Figure 23 for the circuit diagram. The gain of each stage is approximately 23 if we choose R2-A/B = 2.2 k and R7-A/B = 2.2 k. We adjust the pre-amplifier circuit from time to time to improve its quality for our special application and to reduce the price. If you want to use your own pre-amplifier, please send us the circuit diagram. It is very important that you do not include delaying parts like inductions in the signal ways. The

latest version of our pre-amplifier is PCB 5 Version 6. The part list is shown in Table 2, the PCB layout is shown in Figure 22, and the complete circuit diagram is shown in Figure 23.

Operational amplifier	IC1, IC2, IC3, IC4	NE5534
LED, standard	PWR	LED 5mm (red)
rectifier diode	D1	1N4001
Resistor, metal film	R3-A/B, R8-A/B	330 K
	R4-A/B, R5-A/B, R6-A/B, R9-A/B, R10-A/B	47 K
	R2-A/B, R7-A/B indoor / metropolitan areas / unshielded or normal operation or outdoor / rural areas /shielded	4.7 K 2.2 K 1.0 K
	R1, R12-A/B	1 K
Trimmer	R11-A/B	50 K
Capacitor, electrolytic,	C2, C3, C4, C5	470 μF/330 μF
Capacitor, ceramic	C1, C8-A/B, C10-A/B, C13-A/B, C14-A/B, C16-A/B	100 nF (104)
	C11-A/B	22 nF (223)
	C6-A/B, C7-A/B, C12-A/B,	10 nF (103)
	C9-A/B, C15-A/B	220 pF (221)
Inductor, ferrite	L1, L2, L3	470 μH/330 μH

Table 2: The list of electronic parts for the VLF pre-amplifier PCB 5 Version 6

The DC jack can be used for power supply with positive polarization at the center. The power of the pre-amplifier can also be supplied by the evaluation board and vice versa. The voltage should not fall under 6 Volt and should not exceed 15 Volt. The normal operation is 12 Volt. The series resistance R1 to the power control LED should be adjusted to the supplied voltage. For 12 Volt and a standard LED a series resistor between 330 and 4.7 K is adequate. We prefer 1 K for R1. You can also use a switching power supply, if you place
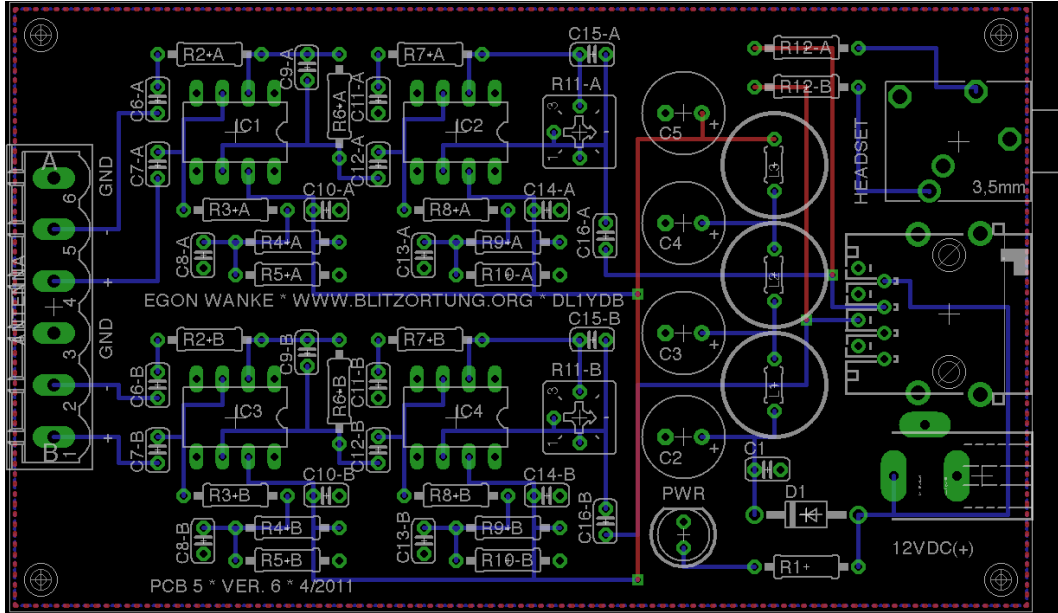
Figure 22: The layout of the VLF pre-amplifier PCB 5 Version 6

it far away from the antennas.

The 3.5 mm jack socket can be used to connect a stereo headphone. This provides an easy and affective way to detect interfering devices and thus to find the best place for an undisturbed operation.Note that the headphone has to be unplugged during normal operation.

3.2 Adjustments

The output voltage of the pre-amplifier should be between -2.5 Volt and $+2.5$ Volt. These are the reference voltages of the analog digital converter at the evaluation board. In most cases, the board is used under the following circumstance: 12 V power supply, two unshielded square loop antennas (diagonal size 1 m) with 8 turns (wire 1.5 mm^2) connected to the input, or two 20 cm unshielded ferrite rod antennas, resistors R2-A/B and R7-A/B = 2.2 K. In this cases, you can turn both trimmers fully up. If you still have to much interferences, you should reduce the amplification by the 50 K trimmers. You will reduce the amplification to the half by adjusting the trimmers to 24 K, and to a fourth by adjusting them to 11 K. The amplifications of these configurations are

$$
\begin{array}{rcl}
\left(1 + \frac{47\text{K}}{2.2\text{K}}\right) \cdot \left(1 + \frac{50\text{K}}{2.2\text{K}}\right) & = & 530 \\
\left(1 + \frac{47\text{K}}{2.2\text{K}}\right) \cdot \left(1 + \frac{24\text{K}}{2.2\text{K}}\right) & = & 266 \\
\left(1 + \frac{47\text{K}}{2.2\text{K}}\right) \cdot \left(1 + \frac{11\text{K}}{2.2\text{K}}\right) & = & 134
\end{array}
$$

A much more effective way to reduce interferences is a shielding of your loop or ferrite

rod antenna. If you use shielded antennas, then you can increase the amplification by R7-A/B = 1.0 K.

If the resonance frequency of your home made loop antenna is accidentally tuned at a long wave radio station you can use a small tuning parallel capacitor of at most 1 nF. Do not use larger tuning capacitors with your loop antenna. Never use a tuning capacitor with a ferrite rod antenna or in connection with an electrical antenna. The possibly existing resonance frequency of your loop antenna should not fall below 1 KHz.
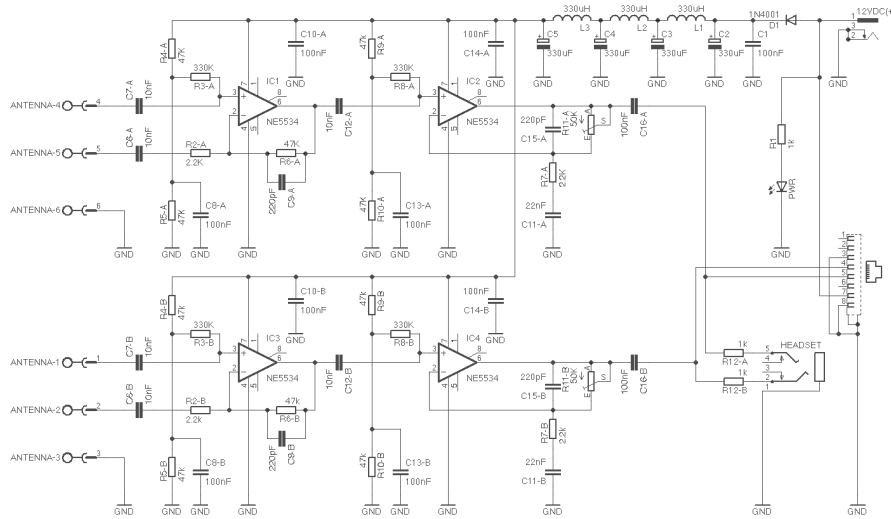
Figure 23: The circuit diagram of the pre-amplifier board PCB 5 Version 6

4   The evaluation board

4.1   The architecture

The heart of the evaluation board is the Atmel 8-bit AVR micro controller ATmega644 running with a clock frequency of 20 MHz. The board also contains two separate 10-bit analog-to-digital converters AD7813 that operate in high speed mode, i.e., not powered down between conversions. In this mode of operation the converters are capable to provide a throughput of up to 400 ksps = 400.000 measurements per second. Unfortunately, the ATmega644 is not able to process the data as fast as provided. Therefore, we use only 8-bit conversions with a throughput of approximately 350 ksps.
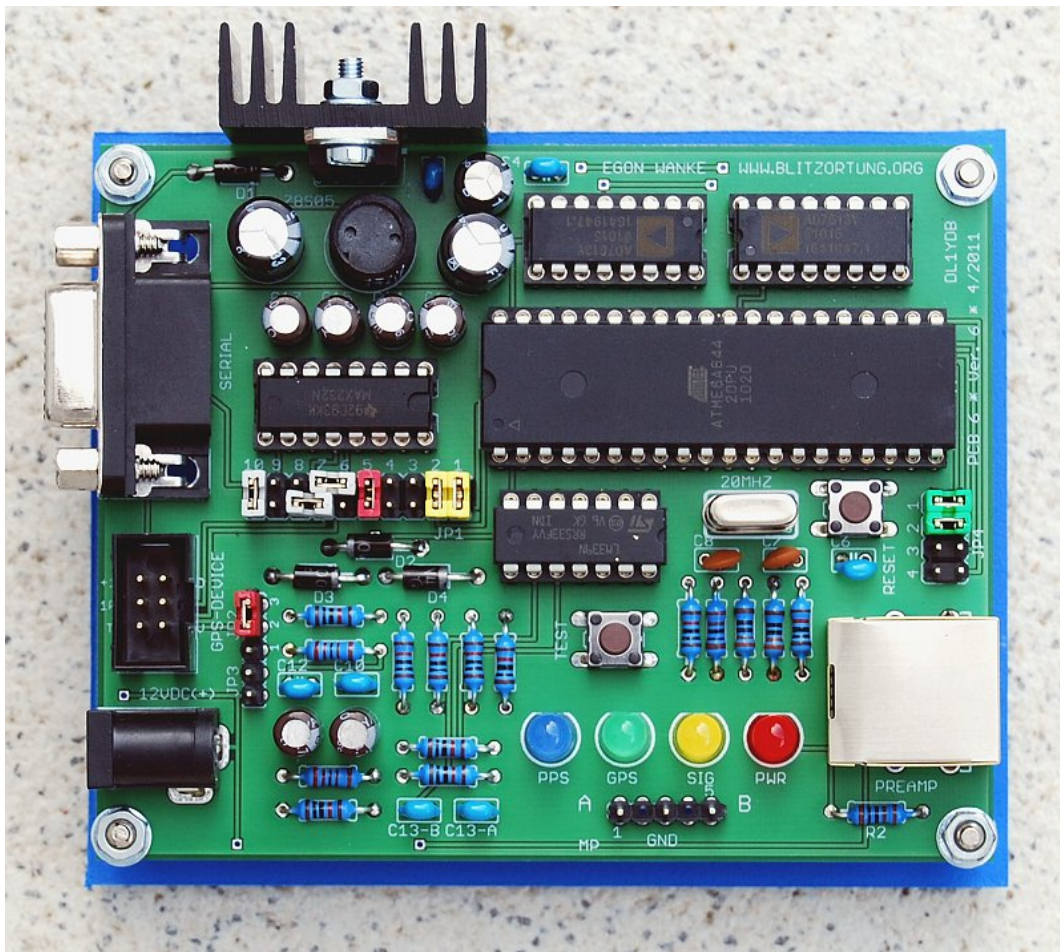
Figure 24:   An assembled evaluation board PCB 6 Version 6

The other integrated circuits of the board are a quad comparator LM339 to activate the analog-to-digital conversion, if the input signal exceed a threshold of ±0.45 Volt, and a

dual driver/receiver MAX232 that converts the TTL input level into RS-232 output level and vice versa, if necessary.

An internal timer of the controller is initialized to run with clock frequency divided by 8 and will be triggered by the rising edge of the 1PPS signal from the GPS receiver. The counter difference between two 1PPS signals is approximately 2500000, thus one counter unit corresponds to 400 ns. If the signal from the receiver reaches the thresholds of ± 0.45 Volt, the controller captures the counter and starts the analog-to-digital conversion. After that the controller takes 128 samples of every AD converter. This corresponds to a sampling duration of approximately $360\mu s$. Additionally, the controller permanently reads the GPRMC and GPGGA data sentences of the GPS receiver and stores the time, the geographic position, the altitude, and the number of used satellites.

4.2   Power supply

The pre-amplifier and the evaluation board can be connected by a 1-to-1 cat cable via the RJ45 jacks. We prefer a shielded Cat 6 cable. This connection also allows you to use the same power supply for both boards.

The DC jack can be used for separate power supply with positive polarization at the center. The voltage should not fall under 6 Volt and should not exceed 15 Volt. The normal operation is 12 Volt.

4.3   The LEDs

Figure 25:   The LEDs of the evaluation board

If power supply is connected to the board, then the following should happen:

- The (red) PWR LED will glow and the other three LEDs will blink four times. This just indicates that the controller is running.

- The (yellow) SIG LED will flash every time the controller outputs a data sentence containing strike signal information.

- The (blue) 1PPS LED will blink every time the GPS provides a 1PPS signal. This should be every second.

Resistor, metal film	R1, R3, R4, R6, R8, R9, R10, R11, R12, R13	10 K
	R5, R7	2.2 K
	R2, R14	1 K
	R15, R16	330 Ohm
Capacitor, electrolytic radial, pitch 2.5 mm	C1, C2	470 μF/330 μF
	C5	100 μF
	C9, C11, C14, C15, C16, C17	4.7 μF
Capacitor, ceramic pitch 2.5 mm	C3, C4, C6, C10 C12, C13-A, C13-B	100 nF (104)
	C7, C8	15 pF
Inductor, ferrite	L1	470 μH/330 μH
rectifier diode	D1, D2, D3, D4	1N4001
LED, standard	PWR LED	LED 5 mm (red)
	SIG LED	LED 5 mm (yellow)
	GPS LED	LED 5 mm (green)
	PPS LED	LED 5 mm (blue)
Quartz crystal	Q1	20 MHz
Voltage regulator	IC1	78S05
Comparator	IC2	LM339
Driver/receiver	IC3	MAX232
Analog-to-digital converter	IC4, IC5	AD7813
Micro controller	IC6	ATmega644 20PU

Table 3: The part list for the evaluation board PCB 6 Version 6

- The (green) GPS LED starts blinking if the controller recognizes a GPRMC data sentence from the GPS. If the (green) GPS LED is off, then in most cases the baud rate of the GPS differs from the baud rate of the controller. To find the right baud rate, change the setting of jumper JP4 and push the reset switch. If the GPS device is on track, that is, if the GPRMC data sentence contains status "A"' and not status "V", the green GPS LED will glow permanently. This is usually already the case when the GPS device receives at least one satellite. If the green GPS LED remains blinking, you should move the GPS to a more adequate place on a window or on a place in view of the sky.

The LED series resistors R2, R14, R15, and R16 need to be adjusted to the supplied voltages. For standard LEDs, the series resistor R2 (12 Volt) should be chosen between 1 K and 4.7 K, the series resistors R14, R15, and R15 (5 Volt) should be chosen between 330 Ohm and 1 K. We prefer 1 K for R2 and R14, and 330 Ohm for R15 and R16.

4.4   The measuring point
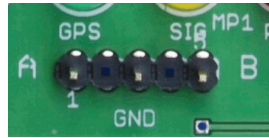
Figure 26:   The Measuring Point MP 1 of the evaluation board

The measuring point MP1 at PCB 6 Version 6 provides at Pin 1 and Pin 5 the two signals from the pre-amplifier. Pin 3 of MP1 is connected to the ground of the board. These pins can be used to control the pre-amplifier output with an oscilloscope or other measuring instruments. You should not use instruments with low impedance, because this could reduce the signal strength.

4.5   The jumper settings

The jumper settings at PCB 6 Version 6 have the following meanings.

1. Jumper JP1 performs several different tasks.
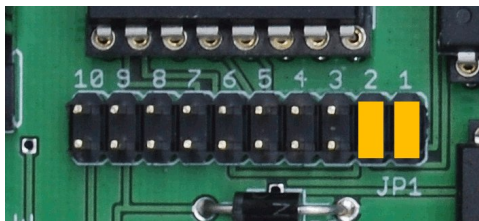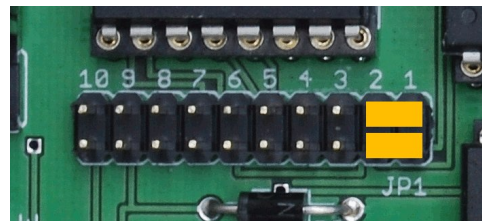
normal operation   output of GPS to output of board

Figure 27:   Setting of Jumper JP1

The first two columns of JP1 from the right numbered 1 and 2 are used to bypass the serial connection to/from the controller. The setting shown in Figure 27 to the left connects the output of the GPS device with the input of the controller and the output of the controller with the output of the board. This is the normal operation. The setting to the right separates the controller from the serial stream. It connects

Sub-D output RS232	Sub-D output TTL
Sub-D input = GPS in	Sub-D input RS232 → GPS input TTL
GPS output TTL	GPS output RS232
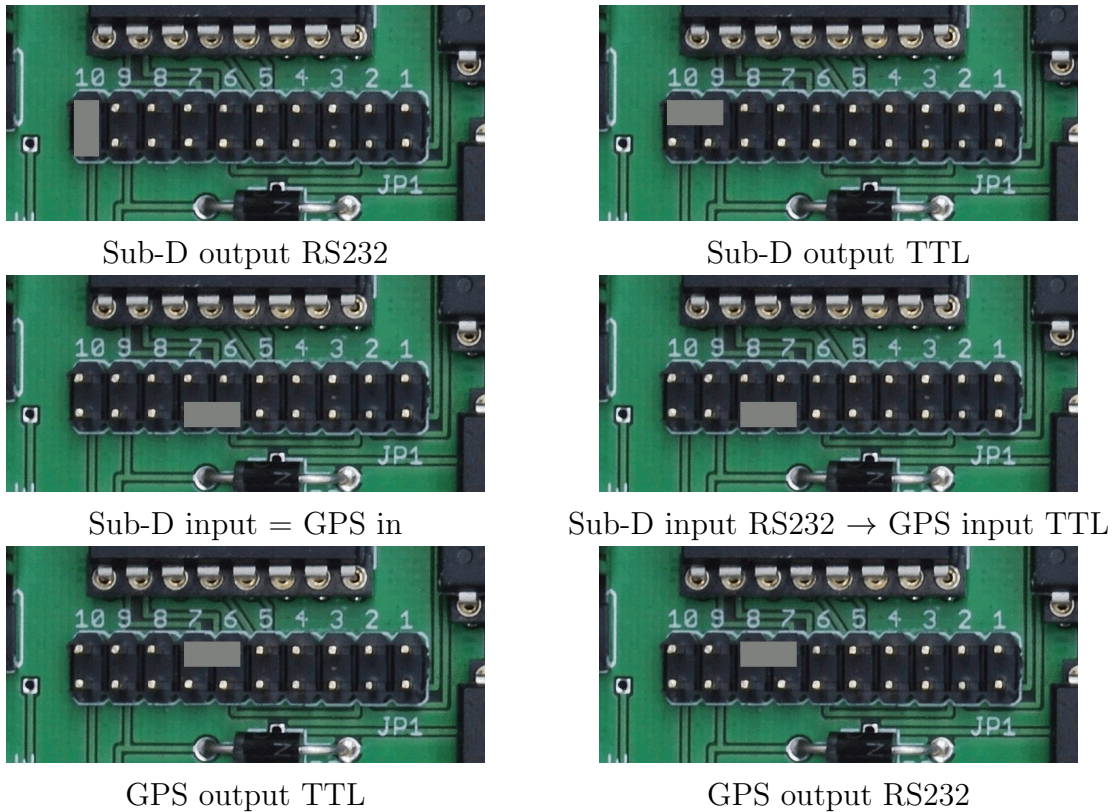
Figure 28: Setting of Jumper JP1

the output of the GPS device with the output of the board. This setting allows you to monitor the output of the GPS device at the serial interface of the board.

Columns 6 to 10 of JP1 are used to switch between TTL and RS232 level on the serial interface of the board and the GPS device.

The remaining three columns of JP1 numbered 3 to 5 are used to select the positive voltage at pin 1 of the GPS connector, if Jumper JP3 is set to pass this voltage to Pin 1. The voltage can be set to +5 Volt or approximately +4,3 Volt, +3,6 Volt or +2.9 Volt caused by a voltage drop of approximately 0.7 Volt by every of the three diodes.

2. Jumper JP2 allows you to connect Pin 1 of the GPS connector with GND or +5/+4.3/+3.6/+2.9 Volt depending on the setting of Jumper JP1, see Figure 30 to the left. JP3 allows you to connect +12 Volt to Pin 9 of the serial 9-ways Sub-D connector, see Figure 30 to the right. This allows you to power the PCBs via pin 9 of the serial connector.

3. Jumper JP4 serves two functions. First, it allows you to change the baud rate of the board between 4800, 9600, 19200, and 38400 Baud, 8 bit, 1 stop bit, no parity, see

<div align="center">

+2.9 Volt	+5.0 Volt

+4.3 Volt	+3.6 Volt

</div>
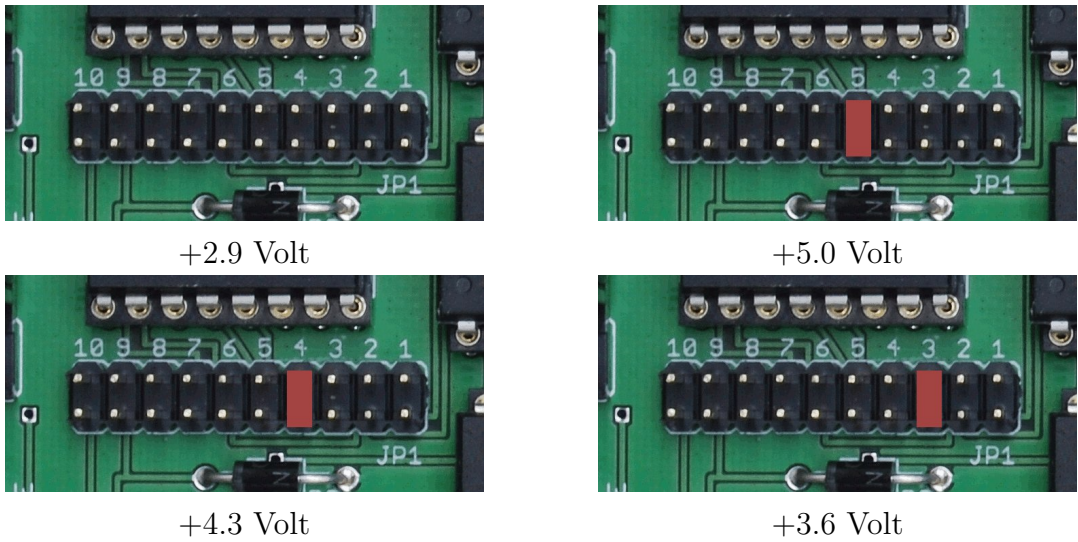
Figure 29: Setting of Jumper JP1

Set Pin 1 of the GPS connector to

open   +   GND

Set Pin 9 of the serial connector to

open   +12Volt
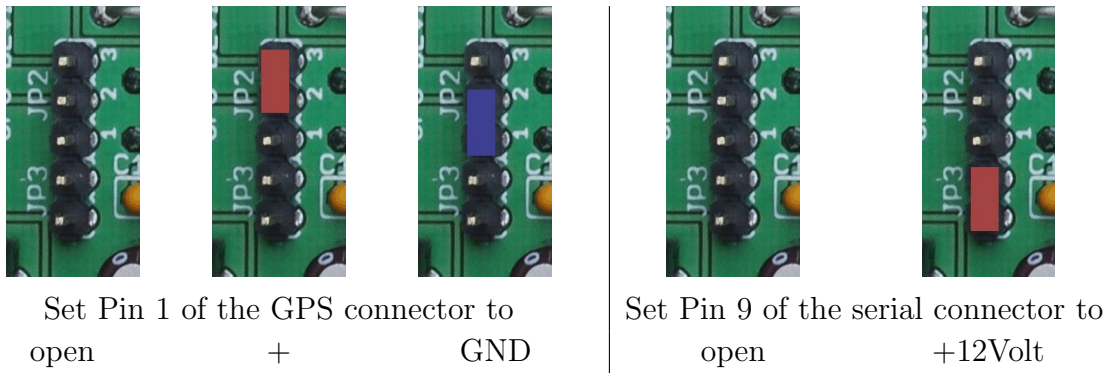
Figure 30: The settings for Jumper JP2 and JP3

Figure 31, and second, it can be used to switch between different output formats, see see Figure 32.

4800 Baud   9600 Baud   19200 Baud   38400 Baud
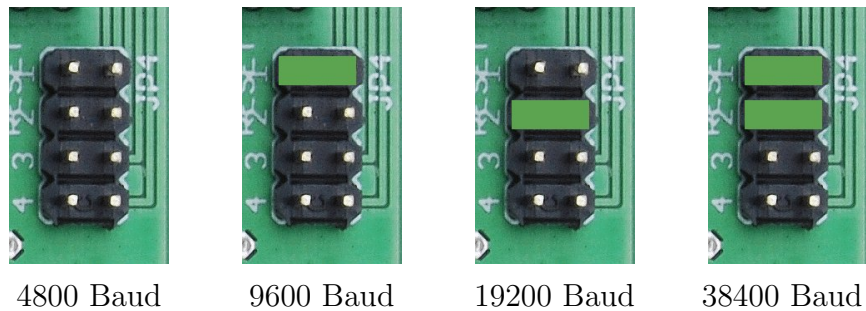
Figure 31: Setting of Jumper JP4

If Jumper JP4 is set to "both channels", then the controller will output 64 values of

both channels. In the setting "channel A" and "channel B", the controller will output 128 values of channel A or channel B, respectively. In the setting "best channel", the controller will output 128 values of the channel that receives the strongest signal. The decision will be made separately for each signal.

both channels   channel A   channel B   best channel
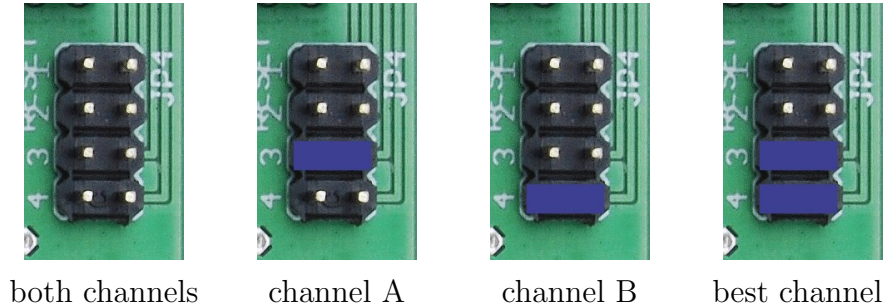
Figure 32: Setting of Jumper JP4

4.6 The GPS connector

The 6 way straight header wire-to-board connector is used for the GPS connection, see also Section 5 how to connect common GPS receivers to the board. The pin assignment is shown in Table 4. The power supply for the GPS receiver can be connected to Pin 6 if it works with the same voltage as the evaluation board. It can be connected to Pin 1 if it needs only 3 Volt or 5 Volt. Note that the voltage regulator 78S05 could extremely heat up, if the current of the GPS receiver exceeds 100 mA.

Header pin	Description
1	+5/+4.3/+3.6/+2.9 Volt, Ground, or open
2	serial output
3	serial input
4	1PPS input
5	GND
6	V+ before voltage regulator (+12 Volt)

Table 4: Pin assignment of the connector for the GPS receiver.

The 9-way Sub-D plug is the connector for the serial RS232 interface, 1 stop bit, no parity. The input to the board is passed to the GPS receiver. The output of the board provides data formatted NMEA 0183, Version 2.0. There are two types of sentences starting with BLSEC and BLSEQ, see Table 5 and 6. A BLSEC sentence is output every second, a BLSEQ sentence is output every time one of the inputs exceeds the threshold voltages of the comparators.

Figure 33: The layout of the evaluation board PCB 6 Version 6.

```
$BLSEC,36693D,065422,130308,A,5111.9534,N,00647.0902,E,51.20000,M,05*51<CR><LF>
         ^      ^      ^     ^ ^         ^ ^          ^ ^       ^ ^  ^ ^
         |      |      |     | |         | |          | |       | |  | |
         |      |      |     | |         | |          | |       | |  Checksum
         |      |      |     | |         | |          | |       | |
         |      |      |     | |         | |          | |       | Number of satellites in use
         |      |      |     | |         | |          | |       |
         |      |      |     | |         | |          | |       Measuring unit, M=meter
         |      |      |     | |         | |          | |
         |      |      |     | |         | |          | Altitude above/below mean sea level
         |      |      |     | |         | |          |
         |      |      |     | |         | |          Longitude hemisphere, E=east or W=west
         |      |      |     | |         | |
         |      |      |     | |         | Longitude, 7 deg 39.3538'
         |      |      |     | |         |
         |      |      |     | |         Latitude hemisphere, N=north or S=south
         |      |      |     | |
         |      |      |     | Latitude, 51 deg 11.953
         |      |      |     |
         |      |      |     |Status, A=active or V=invalid
         |      |      |
         |      |      Date, 13.03.2008
         |      |
         |      Time, 21:29:17 UTC
         |
         Counter, 24 bit hexadecimal
```

Table 5: Format of the BLSEC sentence. The information of the Time/Date field refers to the point in time of the preceding 1PPS signal, i.e., the time is 1 second slow.

```
$BLSEQ,36693D,CC1FDE08 ... 817F*03<CR><LF>
         ^      ^                 ^
         |      |                 |
         |      |                 Checksum
         |      |
         |      265 hexadecimal characters, 2 x 64 byte,
         |      CC first byte channel 1, 1F first byte channel 2,
         |      DE second byte channel 1, 08 second byte channel 2,
         |      ...
         |      81 last byte channel 1, 7F last byte channel 2,
         |
         Counter, 24 bit hexadecimal
```

Table 6: Format of the BLSEQ sentence. This sentence transmits 64 bytes of each analog digital converter. This corresponds to a time span of 200 μs. The time between conversions is 3.125 μs.

Figure 34: The circuit diagram of the evaluation board PCB 6 Version 6

5 GPS receiver

The GPS device has to provide a one-pulse-per-second (1PPS) output with an accuracy of at least $\pm 1\mu s$, and a serial interface using either RS232 or TTL level. The communication between the GPS device and the evaluation board is done with 4800, 9200, 19200, or 38400 Baud, 1 stop bit, and no parity. The evaluation board reads the GPRMC and GPGGA sentences from the GPS output. These sentences refer to the immediately preceding 1PPS output and look like follows.

```
$GPRMC,191410,A,4735.5634,N,00739.3538,E,0.0,0.0,181102,0.4,E,A*19
        ^     ^ ^        ^ ^          ^ ^   ^   ^      ^   ^ ^ ^
        |     | |        | |          | |   |   |      |   | | |
        |     | |        | |          | |   |   |      |   | | Checksum
        |     | |        | |          | |   |   |      |   | |
        |     | |        | |          | |   |   |      |   | Mode
        |     | |        | |          | |   |   |      |   |
        |     | |        | |          | |   |   |      | Hemisphere
        |     | |        | |          | |   |   |      |
        |     | |        | |          | |   |   | Magnetic Variation
        |     | |        | |          | |   |   |
        |     | |        | |          | |   | Date, 18.11.2002
        |     | |        | |          | |   |
        |     | |        | |          | | Track angle in degrees True
        |     | |        | |          | |
        |     | |        | |          | Speed over the ground in knots
        |     | |        | |          |
        |     | |        | |          Longitude hemisphere, E or W
        |     | |        | |
        |     | |        | Longitude, 7 deg 39.3538'
        |     | |        |
        |     | |        Latitude hemisphere, N or S
        |     | |
        |     | Latitude, 47 deg 35.5634'
        |     |
        |     Status, A=active or V=invalid
        |
        Time, 19:14:10 UTC
```

Table 7: The GPRMC data sentence

During the last decade, there were several low cost stand-alone GPS devices available providing a 1PPS output, but unfortunately most of them are no longer offered by the manufacturers. The GPS devices today are mainly integrated as auxiliary modules in navigation systems, cellular phones, and other devices. However, some of the good old GPS mouses can sometimes be bought low priced at online auctions.

The GPS devices we have used so far are the Garmin 35-HVS, the Garmin 16-HVS, the Garmin 35-LVS, the AQTIME VP-200T, the Fortuna U2/PS2, and the EM-406A module. We next explain how to connect these GPS receivers to the evaluation board.

The **Garmin 35-HVS** and **Garmin 16-HVS** are designed to withstand rugged oper-

```
$GPGGA,191410,4735.5634,N,00739.3538,E,1,08,0.9,545.4,M,46.9,M,0,0*47
       |      |         | |           | |  | |   |     |   |    | |  |  | | | |
       |      |         | |           | |  | |   |     |   |    | |  |  | | | Checksum
       |      |         | |           | |  | |   |     |   |    | |  |  | | |
       |      |         | |           | |  | |   |     |   |    | |  |  | | DGPS station ID number
       |      |         | |           | |  | |   |     |   |    | |  |  |
       |      |         | |           | |  | |   |     |   |    | |  |  | time in seconds since
       |      |         | |           | |  | |   |     |   |    | |  |  | last DGPS update
       |      |         | |           | |  | |   |     |   |    | |  |
       |      |         | |           | |  | |   |     |   |    | |  Meters
       |      |         | |           | |  | |   |     |   |    | |
       |      |         | |           | |  | |   |     |   |    | Height of geoid (mean sea
       |      |         | |           | |  | |   |     |   |    | level) above WGS84 ellipsoid
       |      |         | |           | |  | |   |     |   |    |
       |      |         | |           | |  | |   |     |   Meters
       |      |         | |           | |  | |   |     |
       |      |         | |           | |  | |   Altitude, above mean sea level
       |      |         | |           | |  | |
       |      |         | |           | |  | Horizontal dilution
       |      |         | |           | |  |
       |      |         | |           | | Number of satellites
       |      |         | |           | |
       |      |         | |           | Quality
       |      |         | |           |
       |      |         | |           Longitude hemisphere, E or W
       |      |         | |
       |      |         | Longitude, 7 deg 39.3538'
       |      |         |
       |      |         Latitude hemisphere, N or S
       |      |
       |      Latitude, 47 deg 35.5634'
       |
       Time, 19:14:10 UTC
```

Table 8: The GPGGA data sentence

ating conditions and are completely water resistant. They operate from a 6 Volt to 40 Volt unregulated supply. These GPS devices can easily be supplied by the 12 Volt power of the evaluation board. They include a receiver and antenna in the same housing with one cable for the power supply and communications. The GPS antenna must have a clear view of the sky. Generally these GPS antennas will not work indoors. They come with 5 meters of cable ending either stripped and pre-tinned assembled for a flexible connection or with an RJ45 connector attached to the cable end. The wires we need for the connection to the evaluation board have the following colors and have to be connected to the following pins of the straight header at the evaluation board.

Jumper 1 has to connect the RS232 serial input of the evaluation board to the RS232 input of the GPS device, the RS232 output of the GPS device to the TTL input of the Controller, and the TTL output of the controller to the RS232 output of the evaluation board. Jumper JP2 has to set the power on/off switch of the Garmin GPS device to
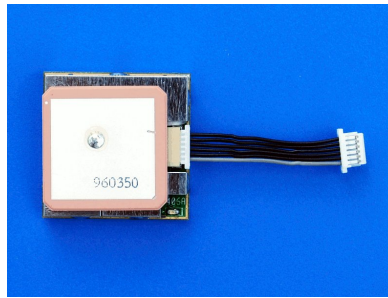
Garmin 16 HVS   AQTIME VP-200T   Fortuna U2 PS2

Garmin 25 HVS/LVS   EM-406A

Figure 35:   Some GPS devices/modules providing a 1PPS output

Color	Description	Header
yellow	power on/off switch	1
white	serial input RS232	2
blue	serial output RS232	3
grey	1PPS output	4
black	power ground	5
red	+12 Volt	6
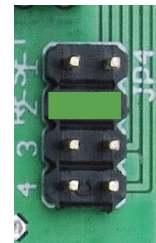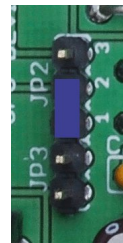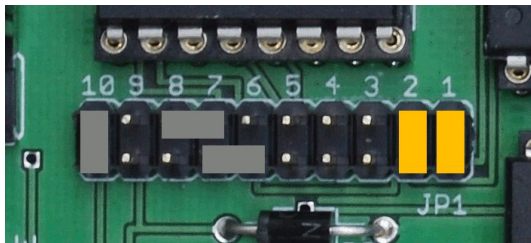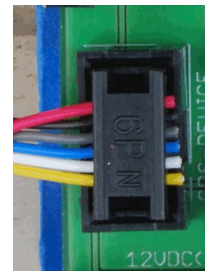
Figure 36:   A Garmin 16/35 HVS connected to the evaluation board

ground. The baud rate can be setto 19200 Baud by Jumper 4. This is the maximum speed for these GPS devices. The 1PPS is not output by default. This feature has first to be set up by an initialization. Our tracker program initializes the GPS device by sending the following strings.

```
$PGRMO,GPGGA,1*20
$PGRMO,GPGSA,0*35
$PGRMO,GPGSV,0*22
$PGRMO,GPRMC,1*3D
$PGRMO,GPVTG,0*25
$PGRMO,PGRMM,0*32
$PGRMO,PGRMT,0*2B
$PGRMO,PGRME,0*3A
$PGRMO,PGRMB,0*3D
$PGRMCE*0E
$PGRMC,,,,,,,,,,5,,2,4,*00
```

Table 9: Initialization strings for Garmin GPS devices

This initialization turns off the data sentences GPGSA, GPGSV, GPVTG, GPRMM, GPRMT,GPRME, and PGRMB, turns on the GPRMC and GPGGA sentences for an output by every second, set the baud rate to 19200 Baud, and activates the 1PPS output with a duration of 100 ms. The baud rate and 1PPS mode changes take effect on the next power on cycle. By default, the baud rate is set to 4800 Baud.

The **Garmin 35-LVS** differs from the Garmin 35-HVS only in the voltage of the power supply. The LVS version is designed to operated from a voltage of 3.6 Volt to 6 Volt. Its current consumption is approximately 150 mA. Here we recommend to use a separate voltage regulator, or a separate power supply. Both can easily be connected to the board if the red wire of the GPS is connected to Pin 1 of the straight header. Then at Pin 1 (ground) and Pin 2 (+V) of Jumper J2 a power supply for the GPS device can be connected. If you are using a sufficient large cooling device, you can also connect Pin 2 to the 5 Volt power of the evaluation board provided after the voltage regulator, see Figure 37.

Note that these old Garmin 35 GPS devices sometimes produce some low acoustic noises which seems to be not worryingly.

The **AQTIME VP-200T** is a timing GPS receiver and antenna in a compact weather-proof enclosure for time-measuring application. It outputs a 1PPS pulse with $\pm 100 ns$ tolerance. It has also a flexible power supply of 8 Volt to 40 Volt. The power consumption

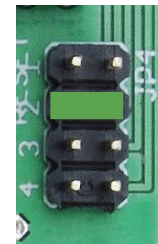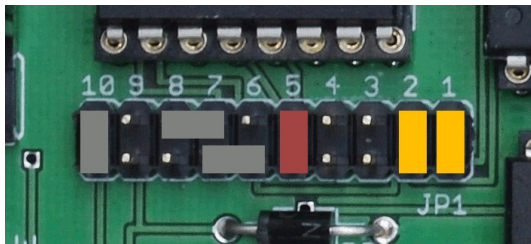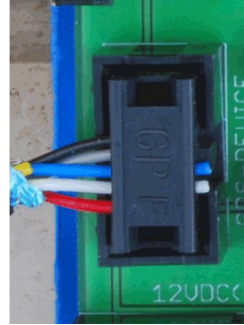| Color	Description	Header
red	+5 Volt	1
white	serial input RS232	2
blue	serial output RS232	3
grey	1PPS output	4
black	power ground	5
		6

Figure 37: A Garmin 35-LVS connected to the evaluation board

is typically 1.1 W. The device can also easily be supplied by the 12 Volt power supply of the evaluation board. It comes with 5 meters of cable ending with a 9-ways Sub-D plug for the serial interface, a DC plug for power supply, and a phono plug for the 1PPS signal. The wires we need for the connection to the evaluation board have the following colors (if the plugs are cut off) and can be connected to the following pins of the straight header.

The AQTIME VP-200T provides the 1PPS signal with a duration of 100 ms by default. The initialization by the tracker program switches off the data sentences GPGLL, GPGSA, GPGSV, GPDTM, and PGZDA. The data sentences GPRMC and GPGGA are switched on for an output of every second. Unfortunateyl, the AQTIME VP-200T only supports a data transfer rate of 4800 Baud.

```
$PFEC,GPint,GGA01,GLL00,GSA00,GSV00,RMC01,DTM00,VTG00,ZDA00*52
```

Table 10: Initialization strings for San Jose Navigation GPS devices

The **Fortuna U2-PS/2** is a small GPS mouse using a SiRF-II chip-set. The body is not completely water resistant, and thus not adequate for outdoor mounting. It comes with 2 meters of cable ending in a female 6-ways Mini-DIN plug. Although the GPS module provides the 1PPS output with a duration of 100 ms, the signal is not connected to the cable. This can be changed by a simple modification. Note that there are several versions

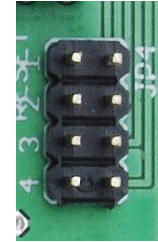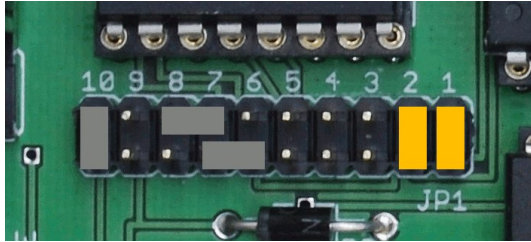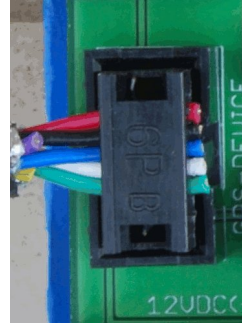| Color	Description	Header
green	serial input RS232	2
white	serial output RS232	3
blue	1PPS output	4
black	power ground	5
red	+12 Volt	6

Figure 38:   An AQTIME VP-200T connected to the evaluation board

of the Fortuna U2. Some of them provide an USB interface (Fortuna U2-USB). These receivers can not be used in connection with the evaluation board. Newer versions use a SiRF-III chip-set. We do not know whether the SiRF-III module also provide the 1PPS output. If somebody has find out this, please give us some feed back such that we can include this information here.

To modify the Fortuna U2 we have to open die housing by taking out the two screws on the backside. Then we can remove the cap and will find a soldered copper box, see Figure 39 to the left. The cap contains two slices that makes the base of the device magnetic, see Figure 39 to the right. These two slices usually fall down when opening the housing. If we open the copper box we will find the GPS module. We have to move the yellow wire from Pin 2 to Pin 9, see Figure 39 in the middle. After that we can solder up the copper box. An easy way to mount the cap with the two magnetic slices is the following. Attach the cap on a metal board by the magnetic slices from inside. Then insert the module and push the housing to the cap. After the modification the 6-way female Mini-DIN plug has the following pin assignment. Note that the information about the pin assignment at the folder enclosed to the original package of the Fortuna U2 is definitely wrong!

The initialization by the tracker program switches off the data sentences GPGLL, GPGSA, GPGSV, GPMSS, GPDTM, and PGZDA. The data sentence GPRMC and GPGGA will be switched on for an output by every second. The communication speed of the serial interface is 4800 Baud by default, but the initialization switches the communication speed to 19200 Baud.
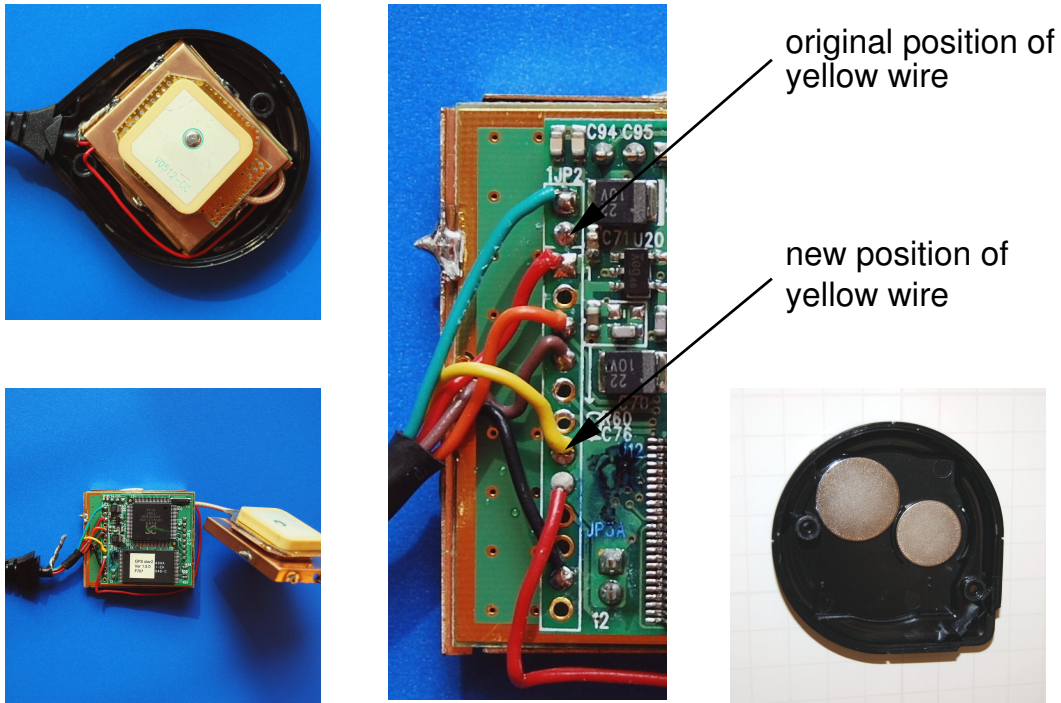
Figure 39: The modification of the Fortuna U2/PS2

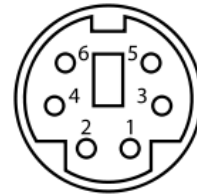| Color	Description	Mini-DIN	Header
orange	serial input RS232	4	2
brown	serial output RS232	2	3
yellow	1PPS output	1	4
black	ground	3	5
red	+5 Volt	6	1

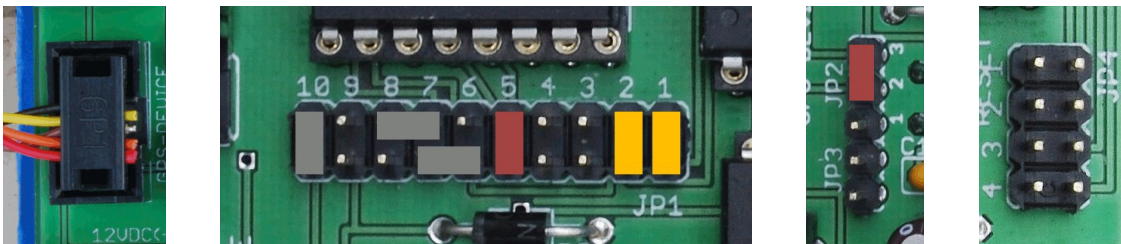Figure 40: The 6-ways female Mini-DIN connector from the front

Figure 41: The Fortuna U2/PS2 connected to the evaluation board

```
$PSRF103,00,00,01,01*25
$PSRF103,01,00,00,01*25
$PSRF103,02,00,00,01*26
$PSRF103,03,00,00,01*27
$PSRF103,04,00,01,01*21
$PSRF103,05,00,00,01*21
$PSRF103,06,00,00,01*22
$PSRF103,08,00,00,01*2C
$PSRF100,1,19200,8,1,0*38
```

Table 11: Initialization strings for SiRF GPS devices

The power supply is 5 Volt, the current consumption is approximately 90 mA. If the temperature of the voltage regulator exceeds 40 degree, it should be mounted on a larger cooling device. The GPS device can alternatively be supplied by a separate voltage regulator or power supply, respectively, similar to the Garmin 35 LVS.

For connecting the GPS device with the evaluation board, you can either cut of the Mini-DIN connector from the cable and connect the wires directly to the jack, or, if you do not like this destructive solution, you can use an extension cable. Unfortunately, many of these GPS mouses are some years old such that the internal backup battery is empty. In these cases, the initialization, the selection of the data sentences and the baud rate of 19200, falls down to the default baud rate of of 4800 Baud, whenever the power supply will be interrupted.

The **EM-406A** is a GPS module using a SiRF-III chip-set. The sensitivity of this device is very high (-159dBm). It can also be used at window side. Since the module has no housing, it should be protected. Figure 42 shows two examples for an integration of the module into the housings of other GPS devices.

Following the manufacturers' specifications, it operates with a voltage of 4.5 Volt to 6.5 Volt and consumes approximately 44 mA, but the module also works fine with 3.6 Volt. The module provides a very short 1PPS output with a duration of 1 μs. The initialization is the same as for the Fortuna U2 using the SiRF-II chip-set. A backup battery keeps all the settings during a power down. The module also contains a LED indicator for GPS fix or not fix. The default baud rate is 4800 Baud. There is one main difference between the EM-406A and all other GPS devices discussed in this section. The serial connection uses TTL signal level (0V/2.85V) and not RS-232 signal level (+3V/-3V). In this case, we have to change the jumper setting for the TTL/RS232 jumper as shown in Figure 43.

The EM-406A module comes with a 6-pin interface cable that can be used to connect a longer connection cable. For our embedding of the EM-406A to the housing of a Navilock

Figure 42: An EM-406A module embedded into the housing of a Fortuna U2/PS2, to the left, and embedded into a housing of a Navilock NL-303P, to the right

NL-303P, the black wire connected to Pin 1 at the module connector was changed to Pin 6. The ground signal is then still available via pin 5 of the module connector.
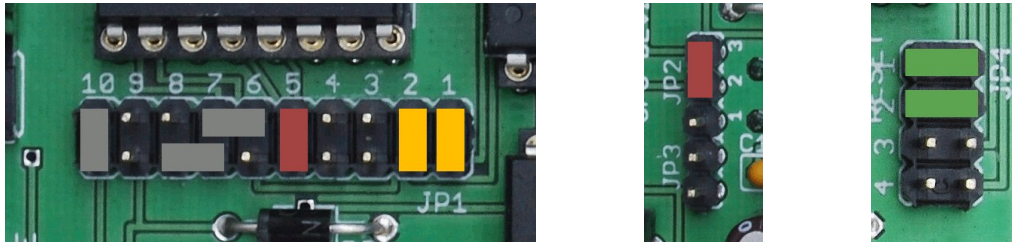

Figure 43: EM-406A connected to the evaluation board using 5 Volt power supply.

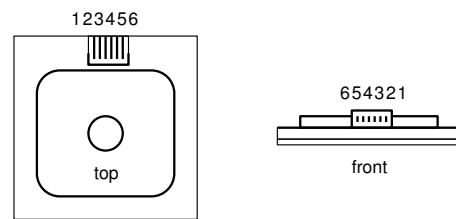| GPS	Description	Header of PCB 6.x
1	ground	5
2	+5 Volt	1
3	serial input TTL	3
4	serial output TTL	2
5	ground	
6	1PPS	4

Figure 44: Pin assignment of the EM-406A module.

There are several further GPS devices that can be connected to the board. For example, the Garmin 17-HVS can be handled in the same way as the Garmin 16-HVS. The RoyalTek RGM-2000 can be modified similar like the Fortuna U2.
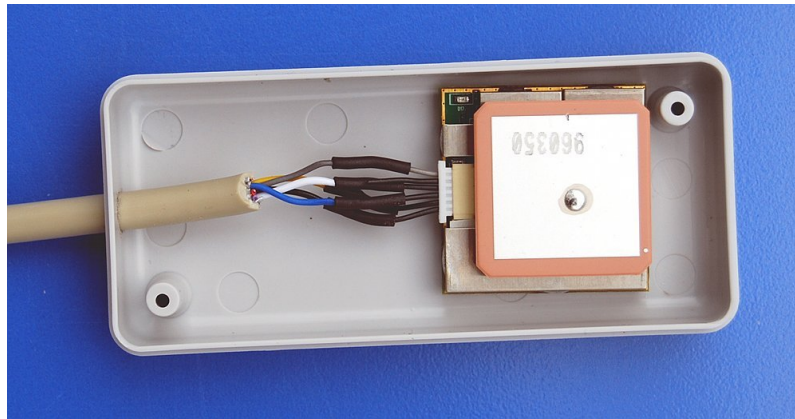
Figure 45: An EM-406A module embedded into a plastic housing

6 Data upload

The data from the evaluation board will be uploaded to our computing server by a *tracker program*. There are two versions of tracker programs, one for computers running Linux operating system and one for computers running Windows operating system. The official tracker program for Linux is written by Egon Wanke. The official tracker program for Windows is written by Edmund Korffmann. You can download these tracker programs from your login page.

To upload data with the Windows tracker program you have to insert your username and password in the "Password" menu. The "Interval" menu allows you to set the time span the tracker will try to establish a connection to our server. It should be set to 20 seconds. Activating the "Auto" flag will cause the tracker to start up automatically after the PC will restart. If the "Minimize" flag is set the tracker window will disappear from the desktop. The "Log" flag activates log file output, and the "Adj. System Time" option allows to synchronize the local clock by the GPS time.
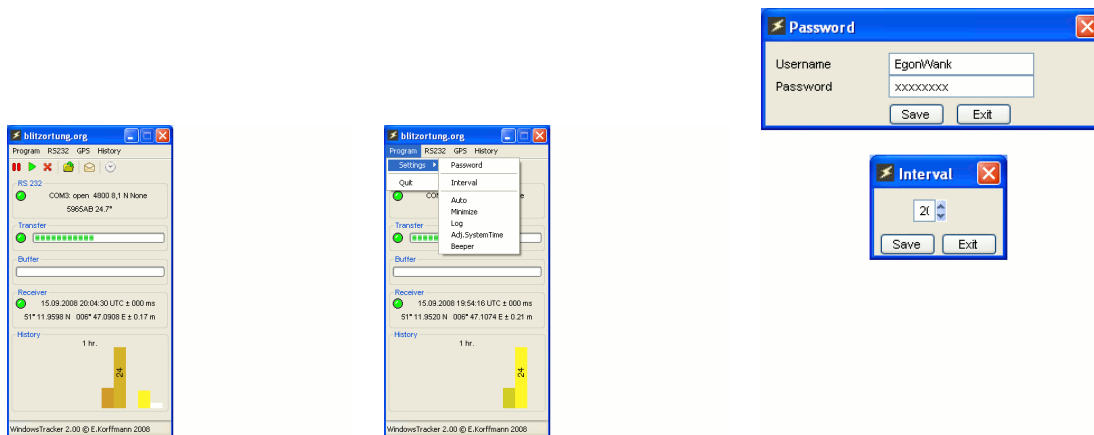

Figure 46: Some screen dumps of the tracker program for Windows.

The serial interface of the evaluation board works by default with 4800 Baud, 1 stop bit, no parity. The GPS menu can be used to initialize the GPS device. If you need an additional initialization strings for your special GPS device, please contact us. The "History" menu allows to change the scaling for the strike number visualization. Here the complete time span and the number of bars can be specified. The hight of a bar corresponds to the number of strikes in the corresponding time interval.

The Linux tracker can also be compiled on OpenWrt, see http://openwrt.org. OpenWrt a Linux distribution for embedded devices. A list of supported devices can be found here http://wiki.openwrt.org/toh/start. You just have to take into account that the device has a serial interface. We have tested the low cost wireless router Linksys WRT54GL. The router can act as a client or bridge in a local network connected to the Internet.
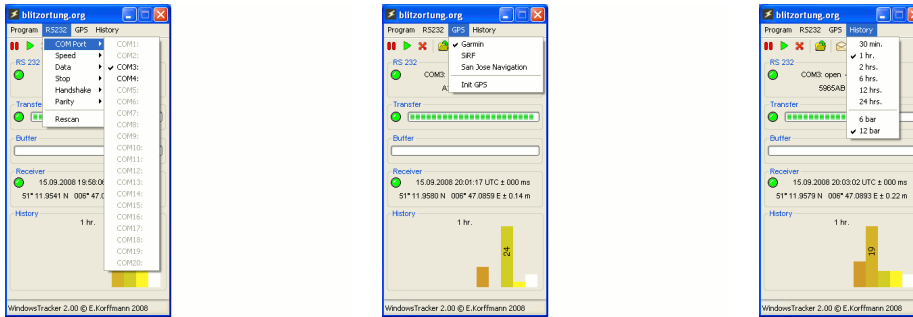
Figure 47: Some screen dumps of the tracker program for Windows.

After you have installed the Firmware OpenWRT Kamikaze 8.09.2 you should first setup your router to get a connection to the Internet.

(The description will be continued soon.)

Figure 48: A modified Linksys WRT54GL router.

7 Location accuracy

The TOA (time of arrival) lightning location technique is based on hyperbolic curve calculations. The emitted radio signal of a lightning discharge is traveling with the speed of the light. This is approximately 300000 kilometers per second. Each received signal gets a time stamped by the receiver. The difference of two time stamps and the two positions of the two receivers define a hyperbolic curve for the location of the lightning discharge. The point of intersection of three or more such hyperbolic curves defines the unique location of the source of the radio signal, see Figure 49. The computed position is then be assumed to be the location of the lightning. At least 4 sites are needed to define always a unique intersection of the hyperbolic curves. With more than four receiving sites reporting the same signal there is some redundant information available to improve the accuracy and to verify the performance.
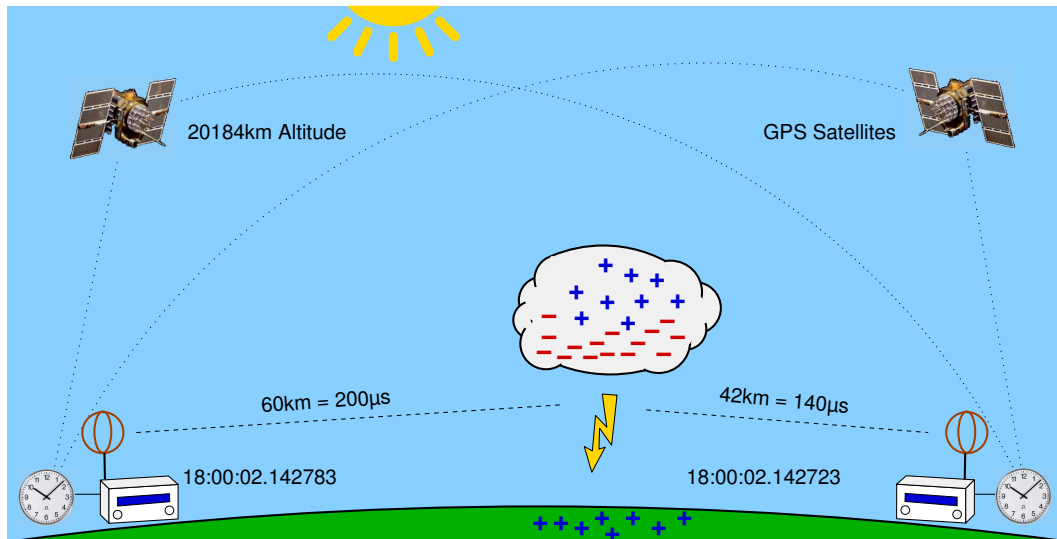

Figure 49: The receiver to the left receives the signal $60\mu s$ later than the receiver to the right, because the lightning discharge is 18 kilometers more far away from the receiver to the left than from the receiver to the right.

A time difference of, for example, ±100 microseconds corresponds to a distance difference of ±30 kilometers. That is, if site A receives the same signal 100 microseconds earlier than site B, the corresponding hyperbolic curve is defined by the set of all points that are 30 kilometers near to site A than to site B. Assume the time stamps have an accuracy of $\pm1\mu s$ and there are four sites arranged such that their positions define a square. If the signal source is exactly in the middle of the square, then the deviation of the computed position to the real source of the signal is greater than $\pm300m \cdot \sqrt{2} = 424m$. It can be much greater if the source of the signal is outside the square.
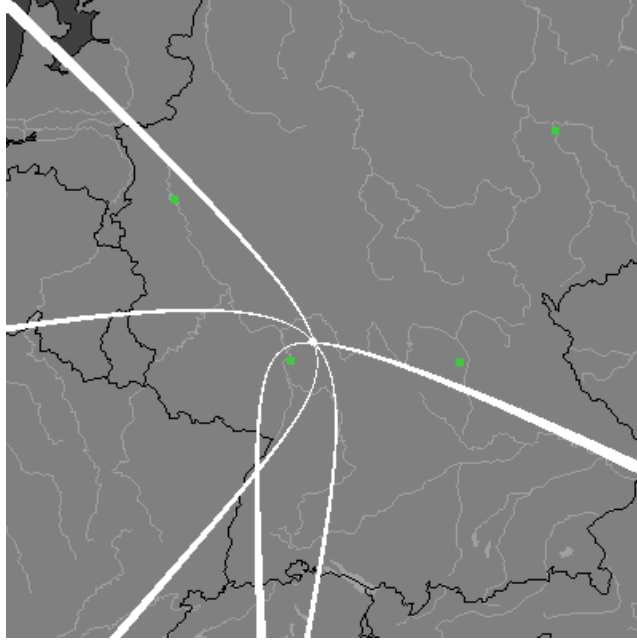
Figure 50: Three hyperbolic curves defined by the three time differences of four sites. The intersection uniquely defines the location of the source of the radio signal.
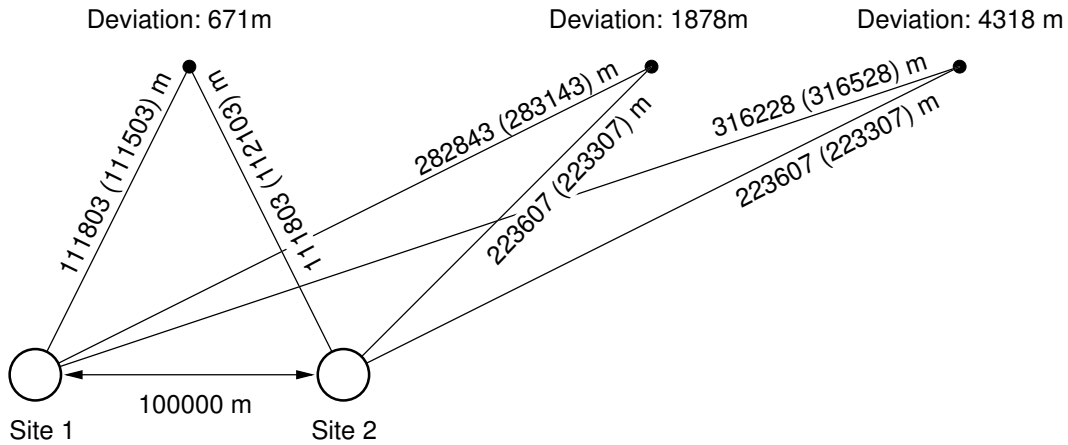
Figure 51: The deviations for an accuracy of $\pm 1\mu S$

The main problem of the TOA lightning location is to assign a received signal a unique characteristic time stamp. This is not easy, because the outline of the signal changes when it travels over long distances. However, if the time stamps are not consistently assigned, the hyperbolic curves does not intersect in a common intersection point. The computations at our server are carried out in two steps. In the first step a starting point is computed using the method from [KS01] applied to the first 6 time stamps. After that a numerical method is used to minimize the sum of the squared distances to the hyperbolic curves.

The computations use spherical coordinates.

Figure 50 shows a comparison of lightning positions computed by blitzortung.org (yellow symbols) and Euclid.org (red Symbols).
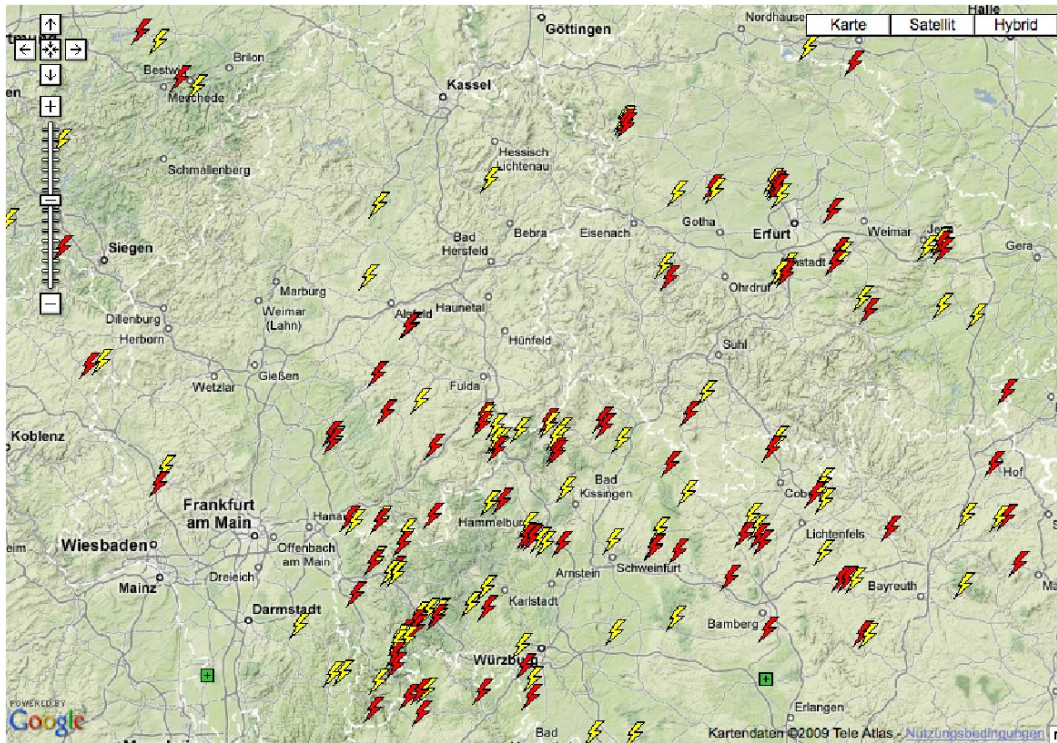
Figure 52: A comparison of lightning positions computed by blitzortung.org (yellow symbols) and Euclid.org (red Symbols)

References

[KS01] W.J. Koshak and R.J. Solakiewicz. TOA Lightning Location Retrieval on Spherical and Oblate Spheroidal Earth Geometries. *Journal of Atmospheric and Oceanic Technology*, 18(2):187-199, 2001.

[BSL09] H.D. Betz, U. Schumann, and P. Laroche (Eds.) Lightning: Principles, Instruments and Applications. *Springer Verlag*, 2009.

8   Prices and how to get the material

We only offer the two PCBs and the programed ATMega644P-20PU micro controller. We do not offer completely assembled kits. You have get to gather all the necessary parts by yourself, but we will try to help you to find a vendor where you can buy all these parts. In exceptional cases, we deliver complete kits (not assembled) if the parts are difficult to get in certain countries. In this case, we sell everything at cost prices without profit-making intentions, and we only sell parts to persons who promise to take part to the network. You will receive our bank account information on request.

To get an overview of the costs for assembling such a system, we state here some examples of prices. These are approximate prices of traders in Germany. Clearly, the prices will differ from country to country, but a rough orientation seems to be always interesting for an estimation of the total costs. Tables 12 and Table 13 show the prices for the parts of both complete kits in Germany at the time this document was written.

The prices for shipping the kits from Germany are

6,90	Euro	with DHL (max 5kg)	within Germany,
17,00	Euro	with DHL (max 5kg)	to European countries,
30,00	Euro	with DHL (max 2kg)	to European countries (not EU),
35,00	Euro	with DHL (max 2kg)	to USA/Canada, and
40,00	Euro	with DHL (max 5kg)	to all over the world.

You additionally need a GPS device providing a 1PPS output, and a VLF antenna. Suitable ferrite rod antennas can be obtained from www.sfericsempfang.de, order number SKS 200 BL (approx. 22 Euro each).

Part	approximate Price
Semiconductors	
4× NE5534	$4 \times 0,40$ €
1× 1N4001, rectifier diode	$1 \times 0,05$ €
1× LED, 5mm, red	$1 \times 0,10$ €
$\sum$	$1,75$ €
Capacities	
$4 \times 470\mu F/330\mu F$, 16V, electrolytic 8x11mm, pitch 3.5mm	$4 \times 0,10$ €
$11 \times 100nF$, ceramic, multi-layer, pitch 2.5mm	$11 \times 0,10$ €
$2 \times 22nF$, ceramic, multi-layer, pitch 2.5mm	$2 \times 0,10$ €
$6 \times 10nF$, ceramic, multi-layer, pitch 2.5mm	$6 \times 0,10$ €
$4 \times 220pF$, ceramic, multi-layer, pitch 2.5mm	$4 \times 0,10$ €
$\sum$	$2,70$ €
Inductors	
$3 \times 470\mu F/470\mu F$, ferrite, pitch 5mm	$3 \times 0,50$ €
$\sum$	$1,50$ €
Resistors	
$4 \times 330k$, metal film	$4 \times 0,10$ €
$2 \times 50k$, trimmer, type Y	$2 \times 0,45$ €
$10 \times 47k$, metal film	$10 \times 0,10$ €
$4 \times 4.7k$, metal film	$4 \times 0,10$ €
$4 \times 2.2k$, metal film	$4 \times 0,10$ €
$7 \times 1k$, metal film	$7 \times 0,10$ €
$\sum$	$3,80$ €
Further material	
1× PCB 5, Version 5	$1 \times 10,00$ €
1× RJ45 jack, 8 ways, shielded	$1 \times 0,60$ €
1× DC jack, PCB, 2.1mm	$1 \times 0,20$ €
1× Jack socket, PCB, 3,5mm	$1 \times 0,25$ €
1× Terminal block, PCB, 6 way, pitch 5mm	$1 \times 0,60$ €
4× IC socket, 8 ways	$4 \times 0,20$ €
1× Power Supply, 12V, stabilized	$1 \times 6,00$ €
$\sum$	$18,45$ €
$\sum$	$\underline{\underline{28,20 \text{ €}}}$

Table 12: Approximated prices of the parts for the pre-amplifier including a power supply

Part	approximate Price
Semiconductors	
1× ATMega644P-20PU	$1 \times 6,50$ €
2× AD7813	$2 \times 8,85$ €
1× LM339	$1 \times 0,20$ €
1× MAX232	$1 \times 0,45$ €
1× 78S05	$1 \times 0,45$ €
4× 1N4001, rectifier diode	$4 \times 0,05$ €
1× LED, 5mm, red	$1 \times 0,10$ €
1× LED, 5mm, yellow	$1 \times 0,10$ €
1× LED, 5mm, green	$1 \times 0,10$ €
1× LED, 5mm, blue	$1 \times 0,30$ €
$\sum$	$26,10$ €
Capacities	
$2 \times 470\mu F/330\mu F$, 16V, electrolytic 8x11mm, pitch 3.5mm	$2 \times 0,10$ €
$1 \times 100\mu F$, 16V, electrolytic 5x11mm, pitch 2.5mm	$1 \times 0,10$ €
$6 \times 4.7\mu F$, 100V, electrolytic 5x11mm, pitch 2.5mm	$6 \times 0,10$ €
$7 \times 100nF$, ceramic, multi-layer, pitch 2.5mm	$7 \times 0,10$ €
$2 \times 15pF$, ceramic, multi-layer, pitch 2.5mm	$2 \times 0,10$ €
$\sum$	$1,80$ €
Inductors	
$1 \times 470\mu F/330\mu F$, ferrite, pitch 5mm	$1 \times 0,50$ €
$\sum$	$0,50$ €
Resistors	
$10 \times 10k$, metal film	$10 \times 0,10$ €
$2 \times 2.2k$, metal film	$2 \times 0,10$ €
$2 \times 1k$, metal film	$2 \times 0,10$ €
2×330, metal film	$2 \times 0,10$ €
$\sum$	$1,60$ €
Further material	
1× PCB 6, Version 5	$1 \times 10,00$ €
1× Crystal, 20MHz	$1 \times 0,25$ €
1× RJ45 jack, 8 ways, shielded	$1 \times 0,60$ €
1× DC jack, PCB, 2.1mm	$1 \times 0,20$ €
1× Straight Header Connector jack, 6 ways	$1 \times 0,25$ €
3× Header Connector plug, 6 ways	$5 \times 0,25$ €
1× Pin header, 40 pins	$1 \times 0,25$ €
10× Jumper	$10 \times 0,10$ €
2× Mini switch	$2 \times 0,15$ €
1× Sub-D plug, PCB, 9 ways	$1 \times 0,35$ €
1× Cooling device, TO220	$1 \times 0,50$ €
1× IC socket, 40 ways	$1 \times 0,65$ €
3× IC socket, 16 ways	$3 \times 0,35$ €
1× IC socket, 14 ways	$1 \times 0,30$ €
1× Connection cable, Sub-D, 9-ways	$1 \times 2,00$ €
1× Network cable, RJ45/RJ45, 5m, CAT5	$1 \times 3,00$ €
1× 1m ribbion cable for shielding ferrite rod antennas	$1 \times 2,00$ €
$\sum$	$23,95$ €
$\sum$	$53,95$ €

Table 13: Approximated prices of the parts for the evaluation board