

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

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This document will continually change due to further developments and improvements. Please send your remarks to <mailto:blitzortung@gmx.org>. Most of the receiving stations are currently operating in Europe, but we are emphatically interested to extend our activities to other continents. Please contact us, if you are interested to start the activity in your region.

Blitzortung.org is the first free and non-commercial low-cost lightning detection and lightning location network of the world. The data provided by **Blitzortung.org** is only used for private and entertainment purposes. **Blitzortung.org** is not an official 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.

Publishing this document or excerpts of this document on websites not under our control is unwanted.

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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.

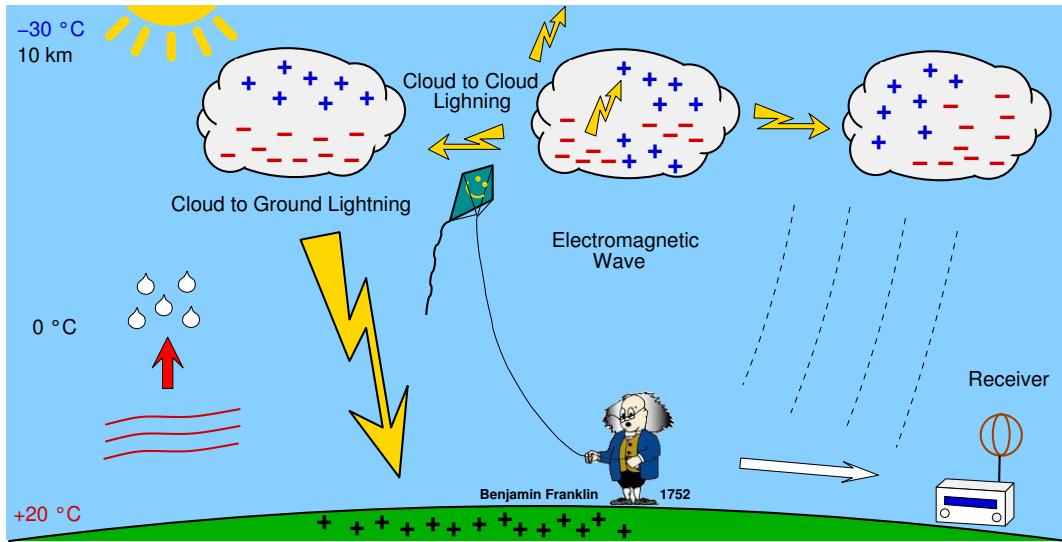


Figure 1: How lightning forms

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-



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 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 amplifier, our controller 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 kits as shown in Figure 4 and 5. We do not send completely assembled kits. We do not have the time to

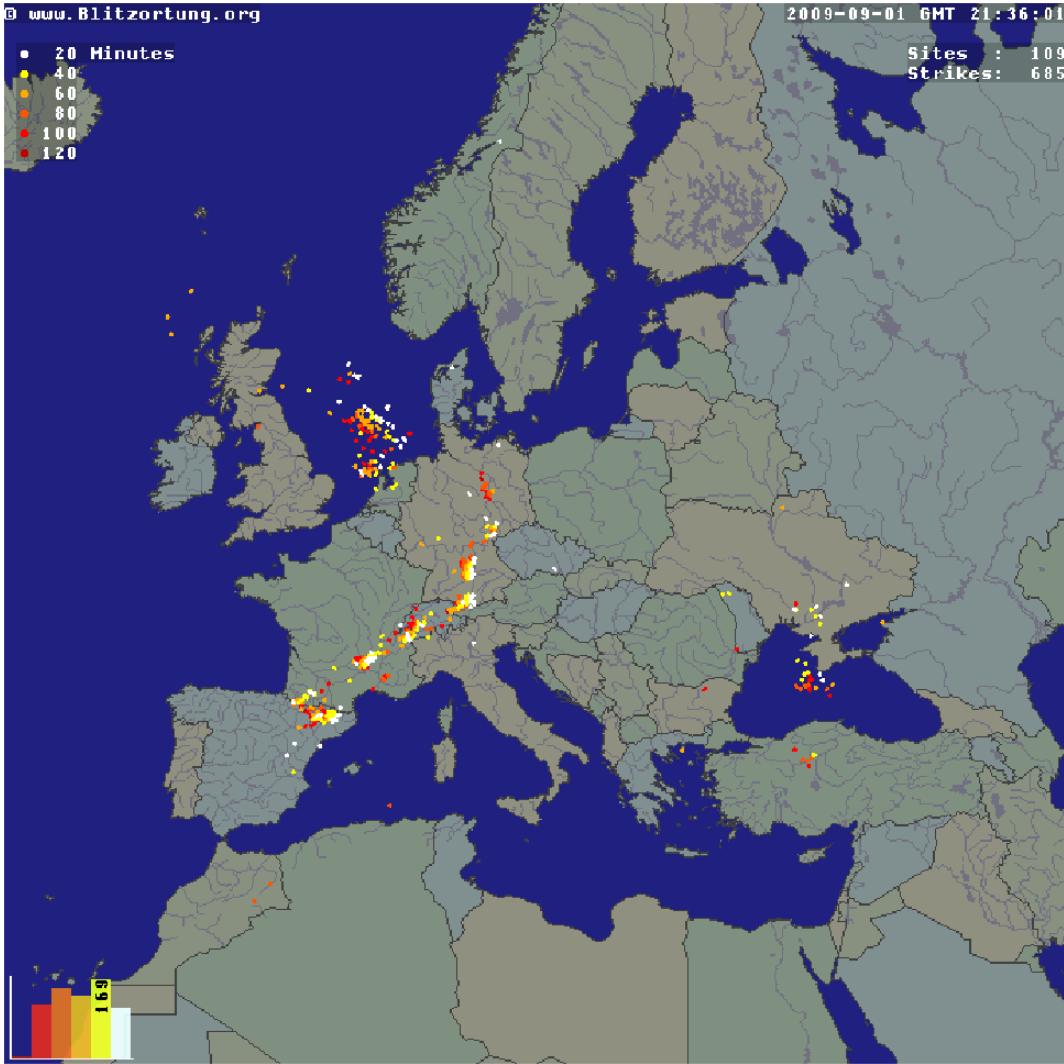


Figure 3: A lightning map of Europe from Blitzortung.org

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.

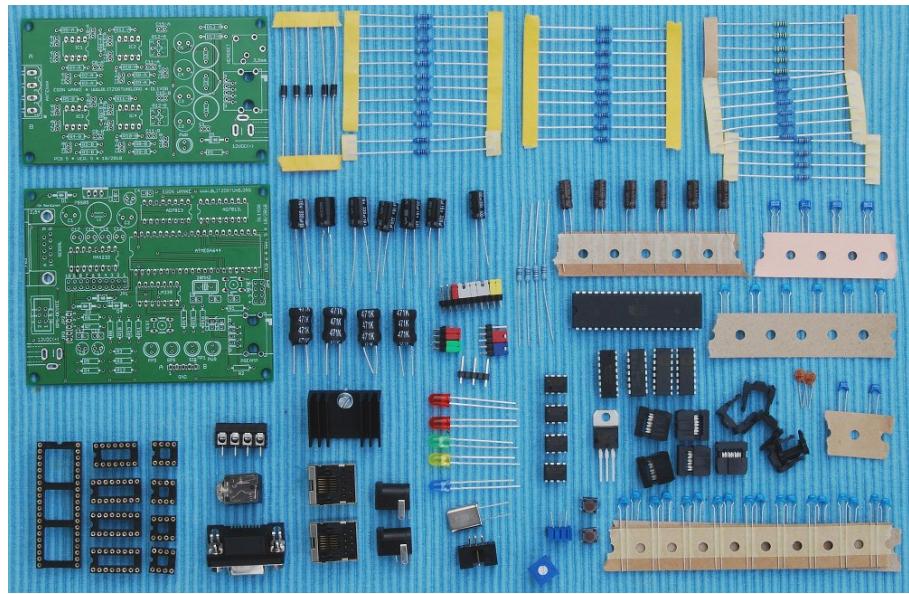


Figure 4: The amplifier kits PCB 5 Version 6 and the controller board kit PCB 6 Version 6

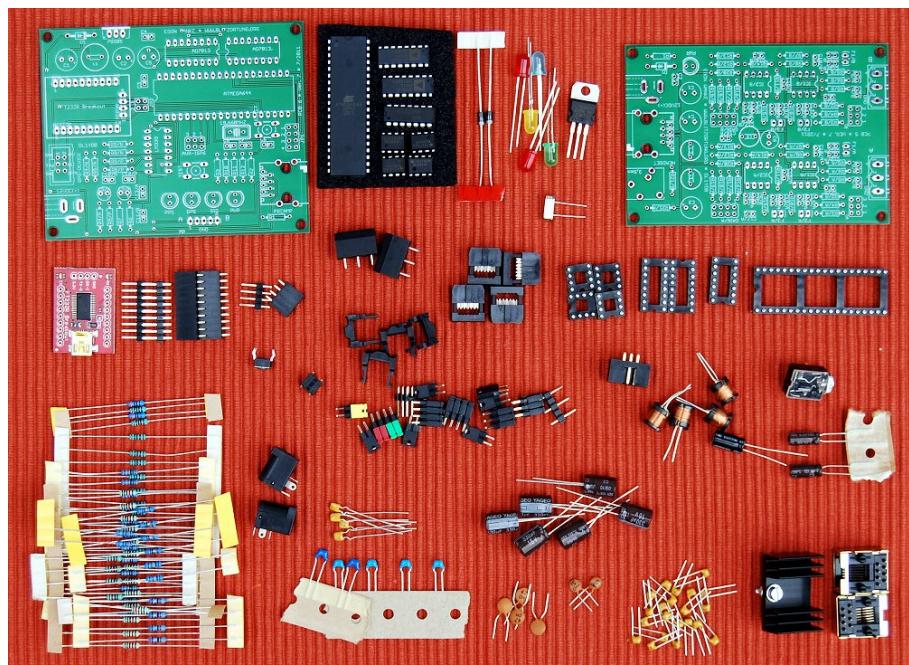


Figure 5: The amplifier kits PCB 5 Version 7 and the controller board kit PCB 6 Version 7

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.

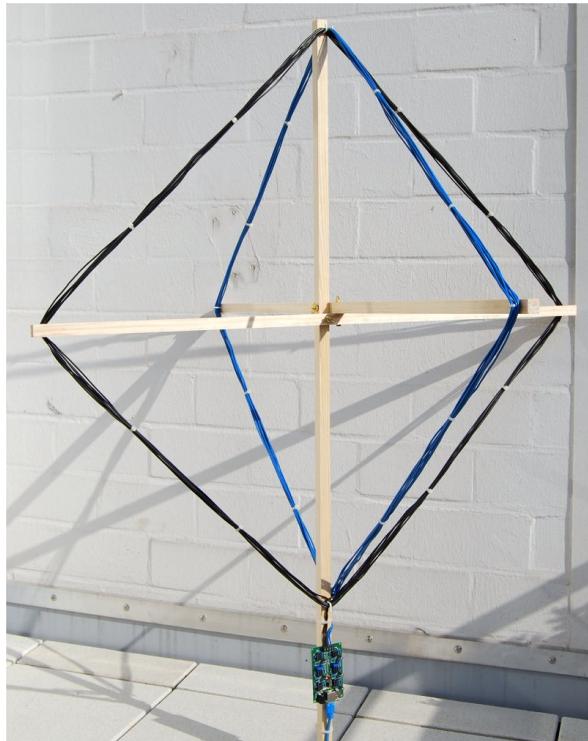


Figure 6: Two orthogonal crossed VLF loop antennas, 8 turns, diagonal size 1 m connected to amplifier PCB 3 Version 2.

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.

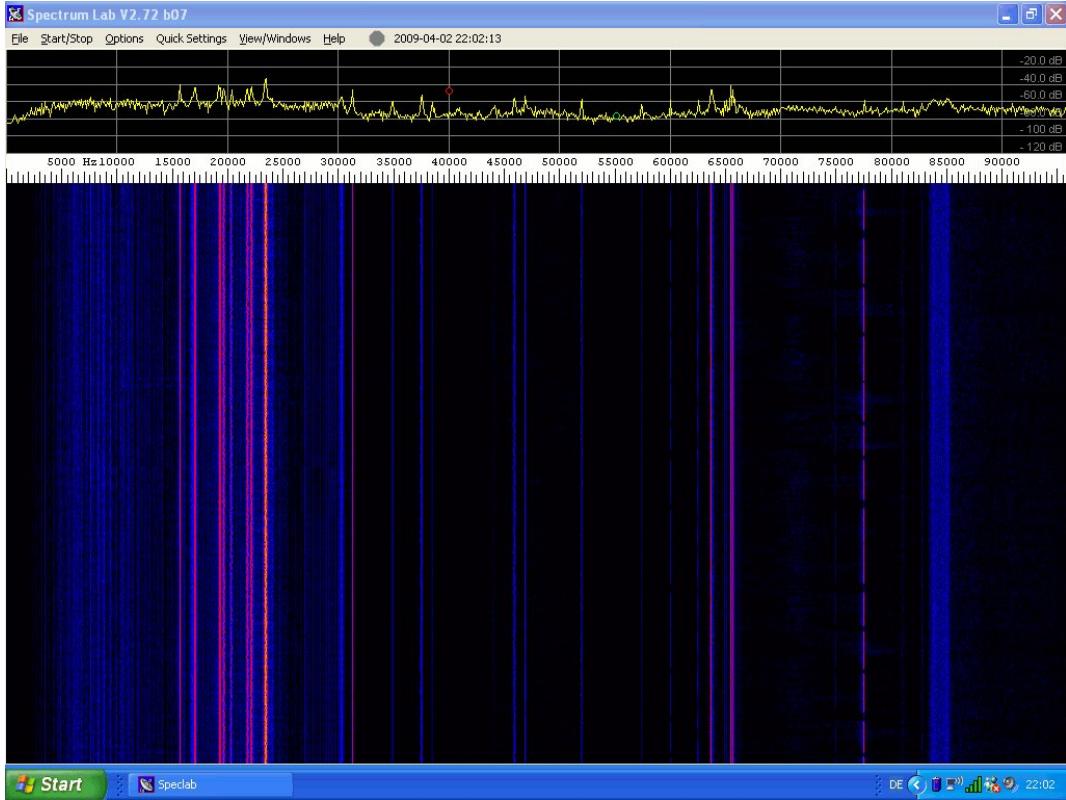


Figure 7: A spectrogram of the signal received by a 35 cm ferrite rod antenna. The signal was recorded by a Creative Professional E-MU 0202 sound card with a sampling frequency of 192 kHz. The spectrogram is made by Spectrum Lab. Vertical lines shows radio transmissions for special purpose, and do not 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 8 shows to the left a signal received by two equal sized untuned loops antennas. These loops have no additional tuning capacitor. The resonance frequency of the antenna is approximately at 1000 kHz (= 1 MHz). The used amplifier reduces frequencies of 1000 kHz by -72 dB (=4000 times). To the right of Figure 7, Loop B is connected to a parallel tuning capacitor of $1 \mu\text{F}$. Now, the tuned

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 8: 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 € in a German home improvement store.



Figure 9: 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 amplifier.



Figure 10: ©Daniel Verschueren

2.3 Coaxial cable antennas

A cheap 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 $60 \mu H$ and a self-resonance at 2 MHz.

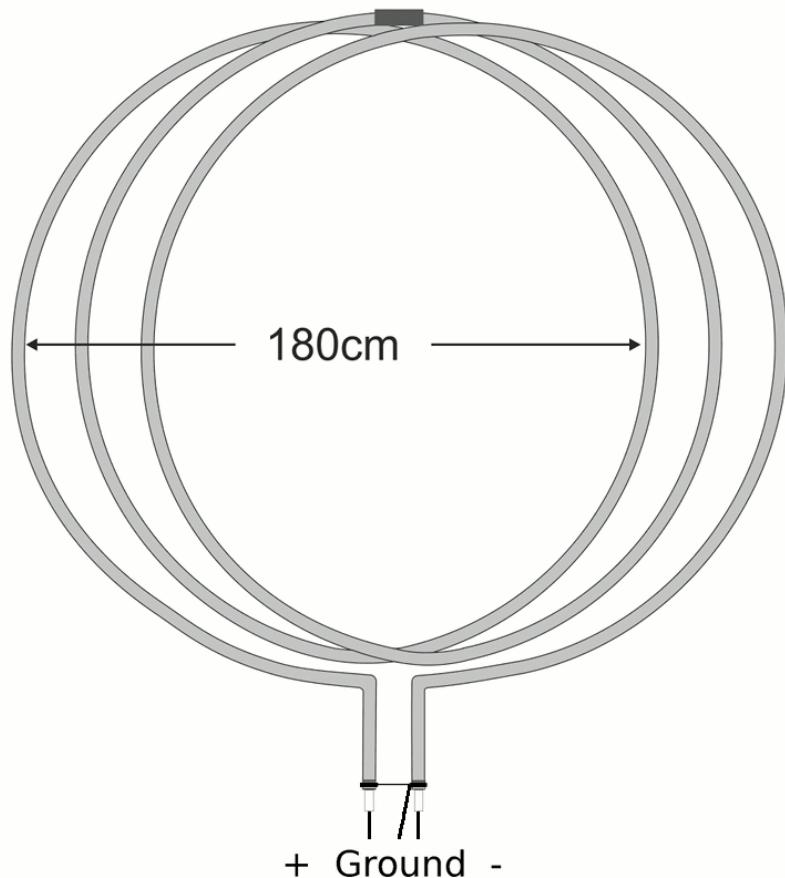
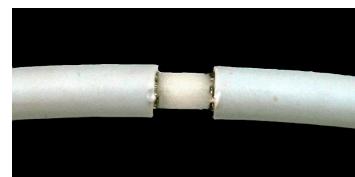


Figure 11: A coax antenna, ©Richo Andersen



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 12: Cutting the wire grid in the middle of the coaxial antenna

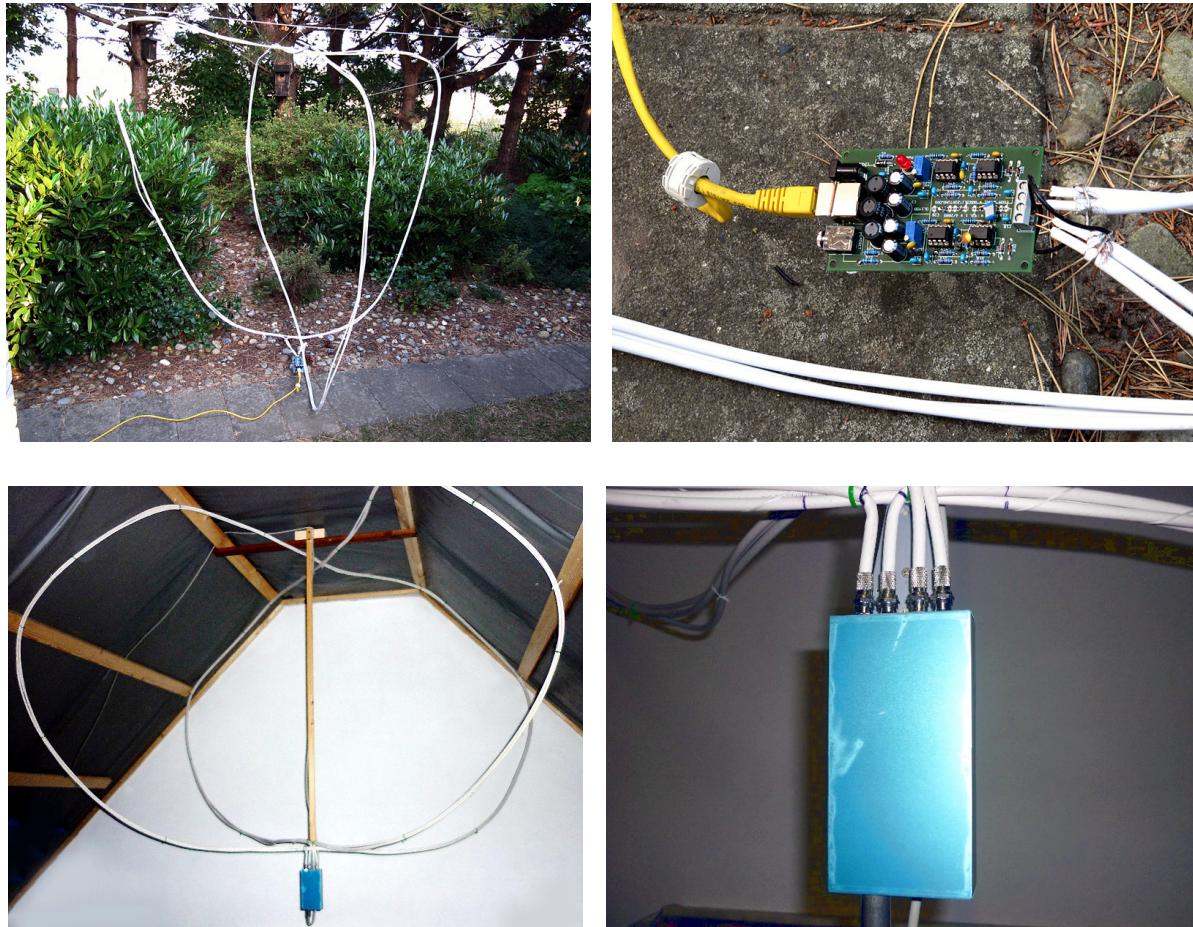


Figure 13: Connecting a coax antenna, ©Richo Andersen and Bernhard Kilimann

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>.

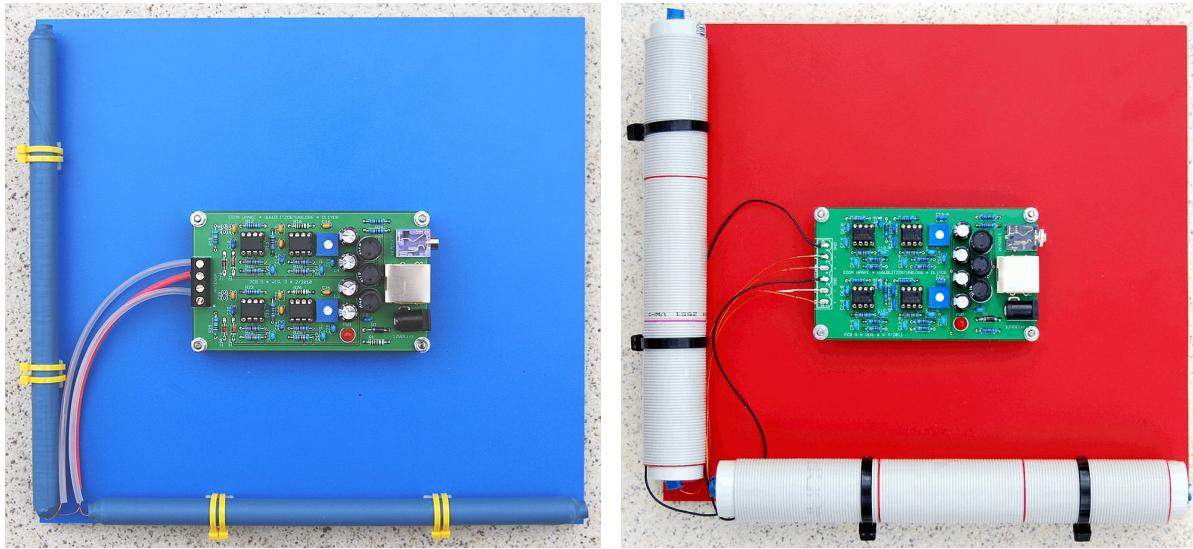


Figure 14: Two 20 cm ferrite rod antennas mounted on a PVC board connected to amplifier PCB 5 Version 1, and two 20 cm ferrite shielded rod antennas mounted on a PVC board connected to amplifier PCB 5 Version 6

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 amplifier board. The wires definitely 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 positive inputs of your amplifier and the other wire with the negative input of the amplifier. If you are using PCB 5.1, PCB 5.2, or PCB 5.3

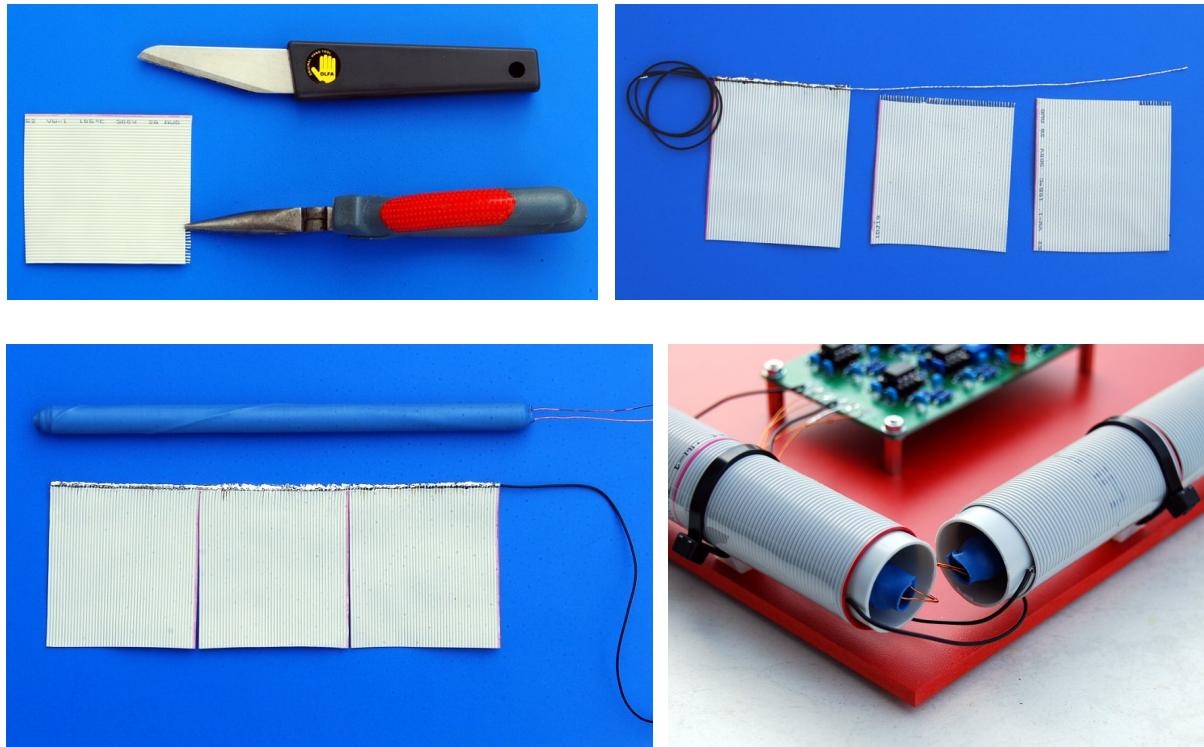


Figure 15: Shielding a ferrite rod antenna with ribbon cable

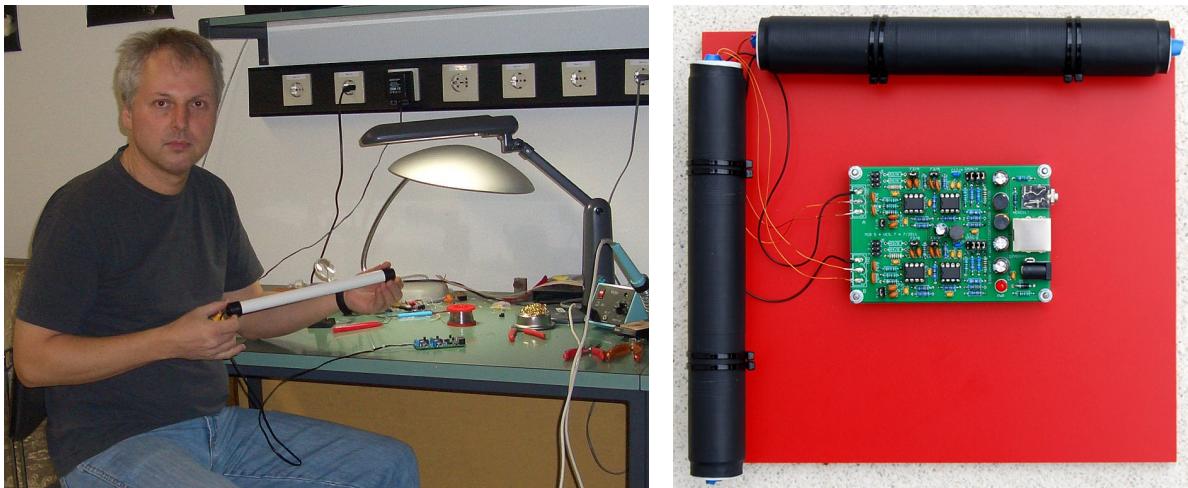


Figure 16: A 35 cm ferrite rod antenna in my hands and two 20 cm ferrite rod antennas mounted on a PVC board connected to amplifier PCB 5 Version 7

the knots should be connected to pin 1 and 4. If you are using PCB 5.4 or PCB 5.5 the knots should be connected to pin 1 and 3.

It is not easy to wind ferrite rod antennas by yourself. The quality of a ferrite rod



Figure 17: A quite location far away from VLF noises

antenna depends on the used material for the rods and on the type of the coil. A large range of rods can be found at <http://www.amidon.de>. High quality rods can be obtained much cheaper by <http://www.sfericsempfang.de>. Coil placement and the length of windings on the rods, bars, plates and tubes affect the effective permeability of the antenna. Greatest inductance will be obtained when the winding is centered on the rod rather than placed at either end. The best "Q" will be obtained when the winding covers the entire length of the rod. The spacing between the turns has also a significant effect on the "Q". The best values for the "Q" are obtained when the coil turns are spaced one wire diameter apart, with a winding covering the entire rod. This would not increase the inductance to much. Note that we have to design a ferrite rod antenna with a high "Q" but a low inductance, such that we do not get low resonance frequencies with small capacities. We do not recommend to wind ferrite rod antennas by yourself.

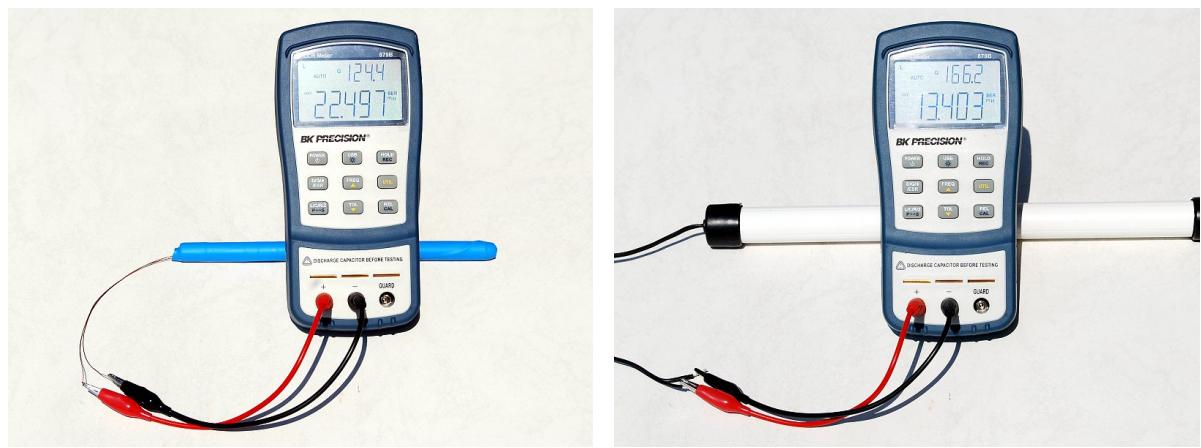


Figure 18: A 20 cm ferrite rod antenna with an inductance of 22.5 mH and a "Q" of 125 and a 30 cm ferrite rod antenna with an inductance of 13.4 mH and a "Q" of 156

Ferrite rod antennas can also be made waterproof, as the image presentations at Figure 19 and 20 show.

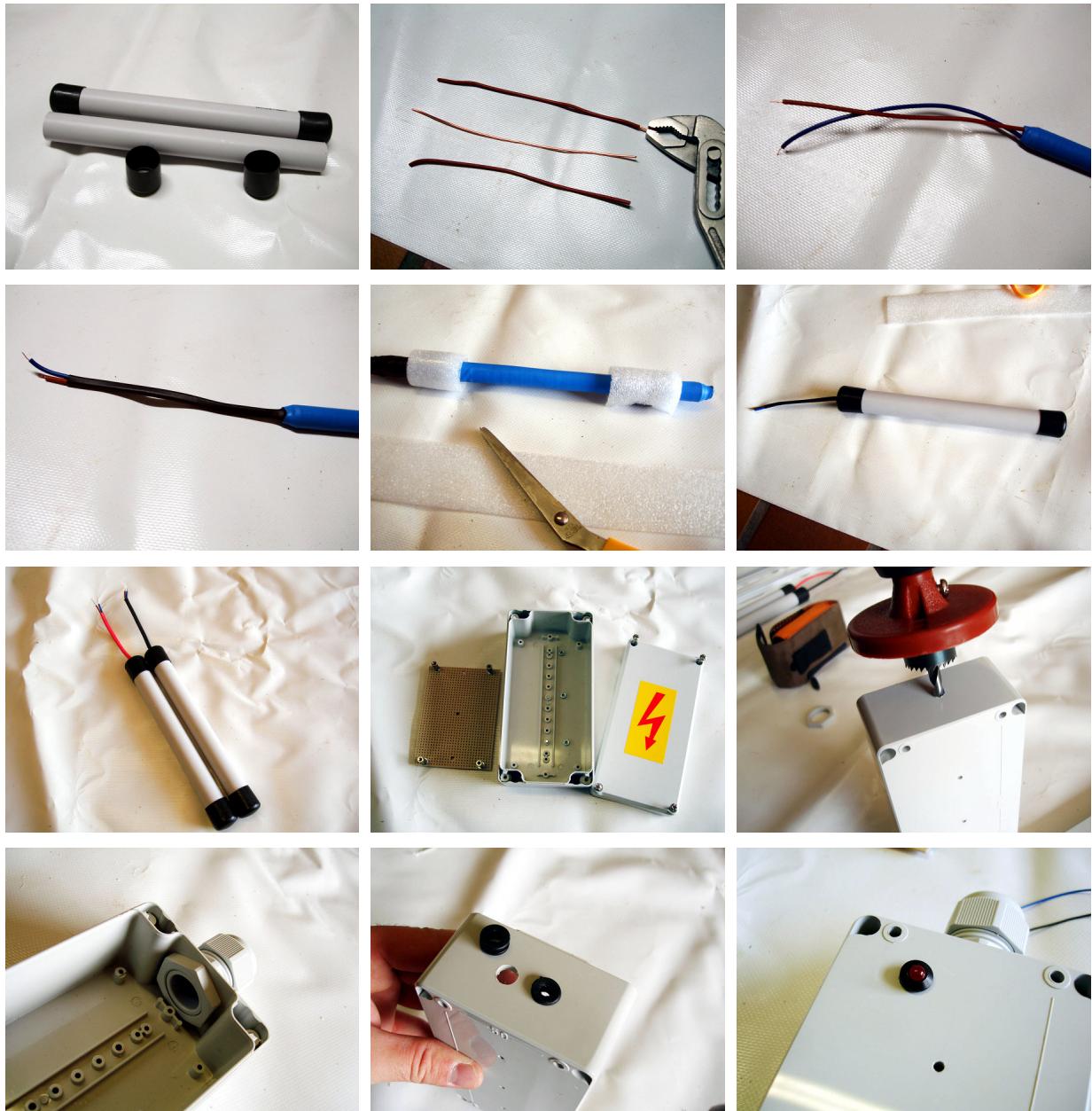


Figure 19: A guidance for building an outdoor ferrite rod antenna, ©Florian Bamberg



Figure 20: A guidance for building an outdoor ferrite rod antenna, continued, ©Florian Bamberg

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 amplifier. Note that it is important that the wire is directly connected to the input of the amplifier. If you use our 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 21 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.



Figure 21: A wire of 1 meter length used as an electrical antenna connected to amplifier PCB 5 Version 1

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

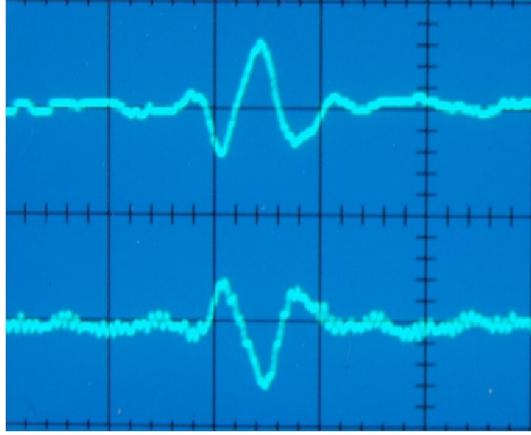


Figure 22: A signal of a lightning discharge received by an electrical antenna (above) and by a ferrite rod antenna (below)

received signals are very clean and free of any resonances frequencies. Figure 22 shows a signal of a lightning discharge received by an electrical antenna (above) and received by a ferrite rod antenna (below). However, the resonance frequencies of the ferrite rod antennas can easily be eliminated by a digital post-processing, see figure 23. 3.) It is possible to determine the polarity of the lightning discharge, if the lightning discharge was not too 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.

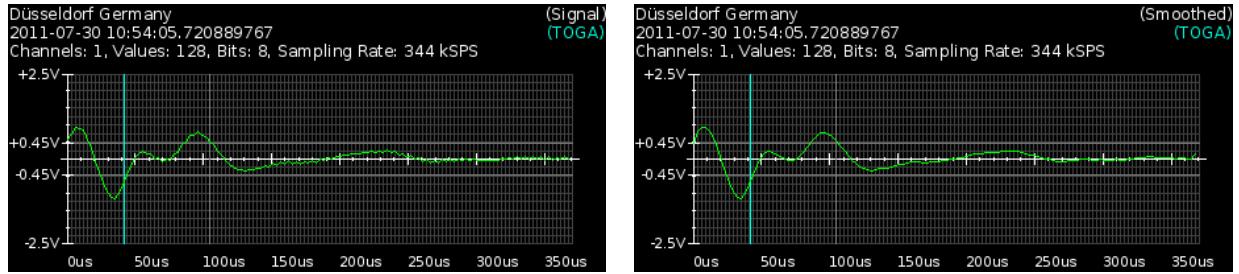


Figure 23: The original signal to the left and the Fourier transformed, filtered, and then re-transformed signal to the right

When using an electrical antenna, the **ground** of the amplifier and thus also the ground of the controller 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 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.

When using an electrical antenna, it is reasonable to connect one of the inputs of the VLF amplifier to ground and the other input to the antenna. It is also reasonable to shortcut the input by a $1 \text{ M}\Omega$ resistor to avoid electrostatic charges. Both can be done on our amplifier PCB 6 Version 7 with jumpers, see also Section 3.4.

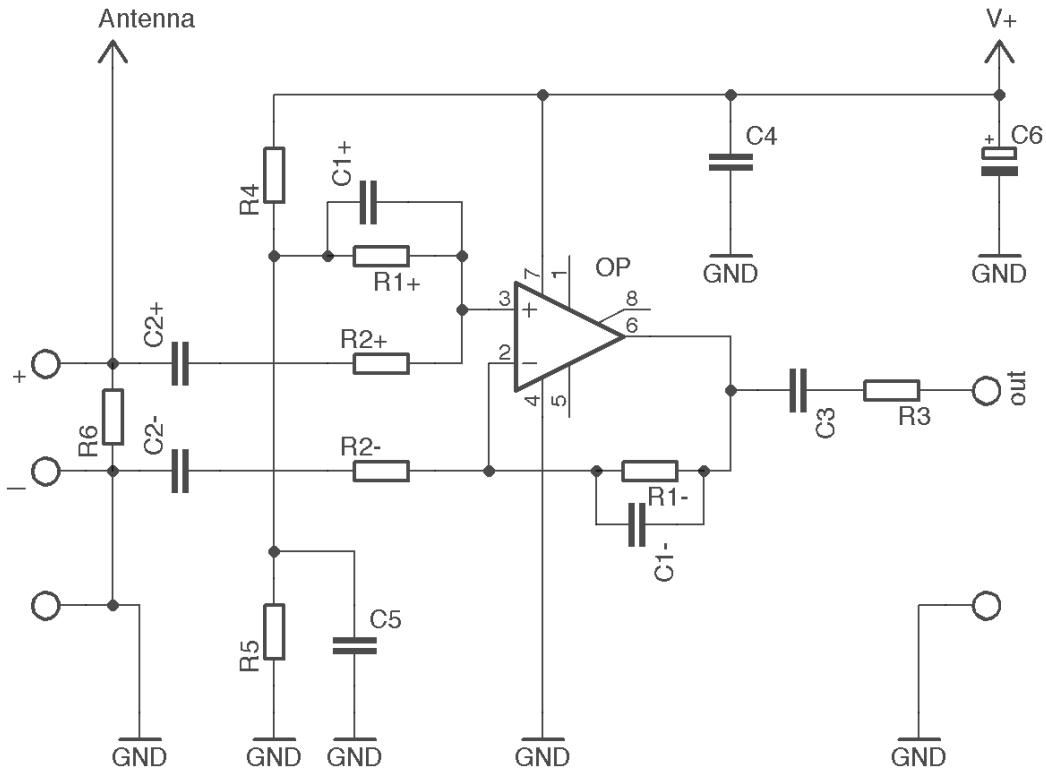


Figure 24: The setting for using an electrical antenna

3 VLF amplifier

Our VLF amplifier is realized by standard operational amplifiers (op-amps). Operational amplifiers have a high input impedance and a low output impedance. The output of an op-amp is controlled by the difference of the positive and negative input. The maximal gain of an op-amp is typically 100.000. The gain 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. The printed circuit board PCB 5 Version 7 realizes a two channel single-supply two stage VLF amplifier. For the sake of simplicity, our amplifier operates in single-supply mode with non-inverting attenuation, see Figure 32 for the complete circuit diagram. We use the two hot ends of a difference amplifier circuit as symmetric input.

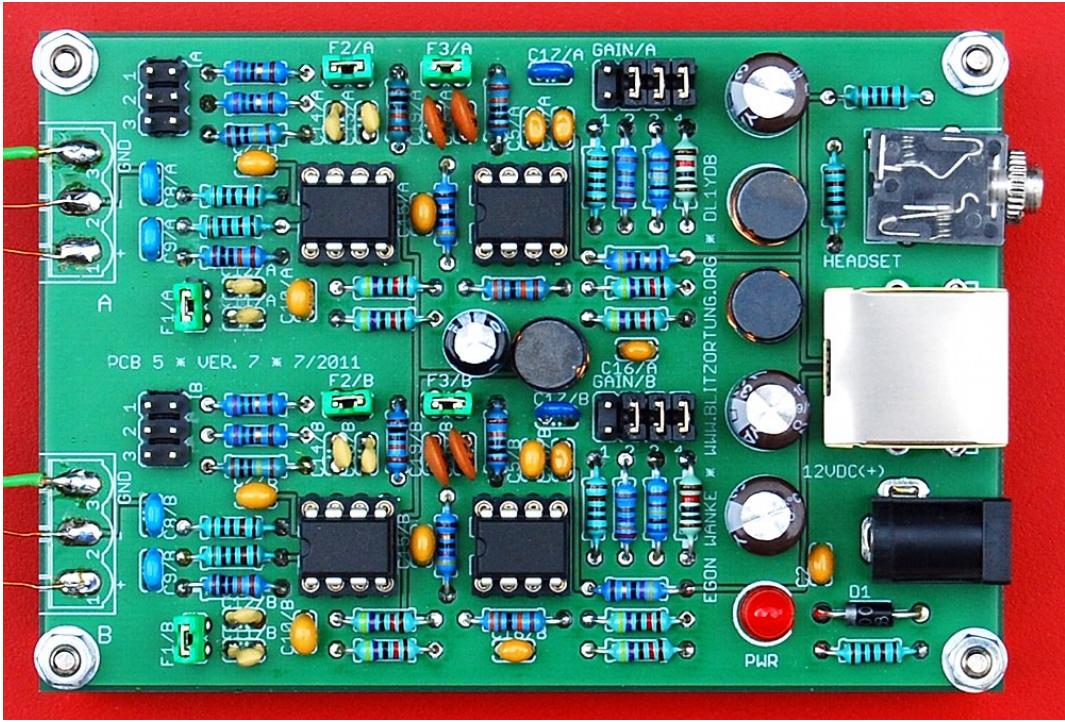


Figure 25: An assembled amplifier PCB 5 Version 7

3.1 Filter options

The amplifier uses first-order active low-pass filters with a cutoff frequency of 17 kHz or 34 kHz determined by

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

At the first stage we have $R_1=47 \text{ k}\Omega$ and $C_1=100 \text{ pF}$ or $C_1 = 2 \times 100 \text{ pF}$, respectively. In the second stage we have $R_1=100 \text{ k}\Omega$ and $C_1=47 \text{ pF}$ or $C_1 = 2 \times 47 \text{ pF}$, respectively, see Figure 26. 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. Use the cutoff frequency of 17 kHz for ferrite rod antennas and the cutoff frequency of 34 kHz for frame antennas, a coax antennas or an electrical antennas, see Figure 27.

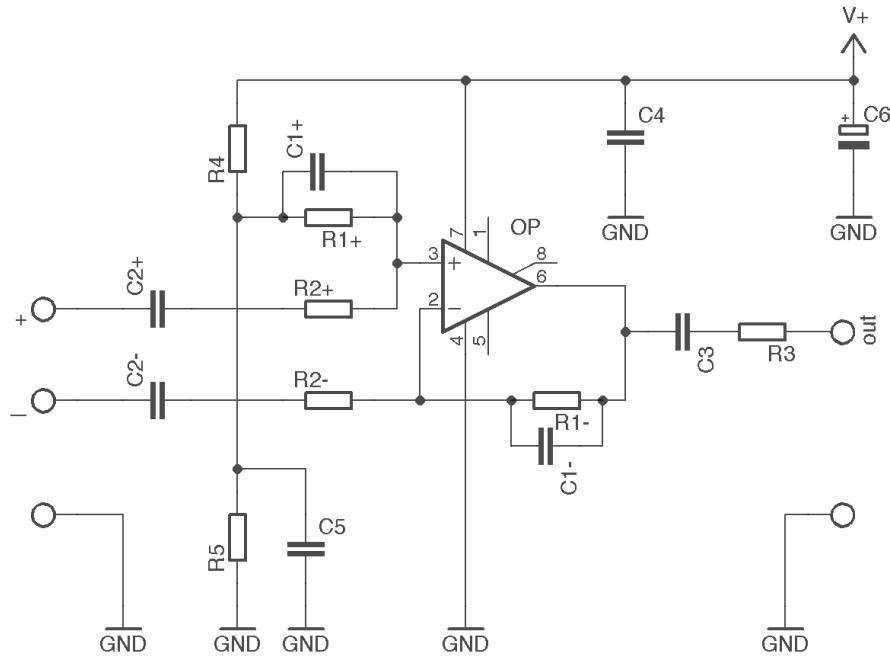


Figure 26: The first operational amplifier stage

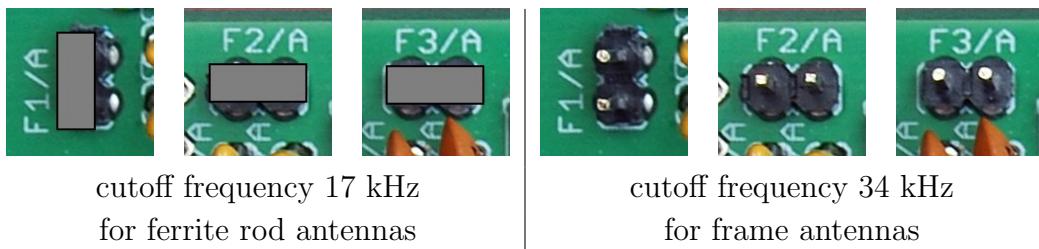


Figure 27: The settings for the Filter Jumper of PCB 6 Version 7

3.2 Gain options

The gain of the amplifier is determined by the voltage divider R_1/R_2 and can be computed by $1 + \frac{R_1}{R_2}$. The gain of the first stage is approximately 48. The gain of the second stage can be set by the Gain-Jumpers. There are 15 possible combinations to connect the four resistors R16, R17, R18, and R19 in parallel. However, the most interesting stages for the gain are those shown in Figure 28. The gain increases every stage by a factor of approximately 1.6.

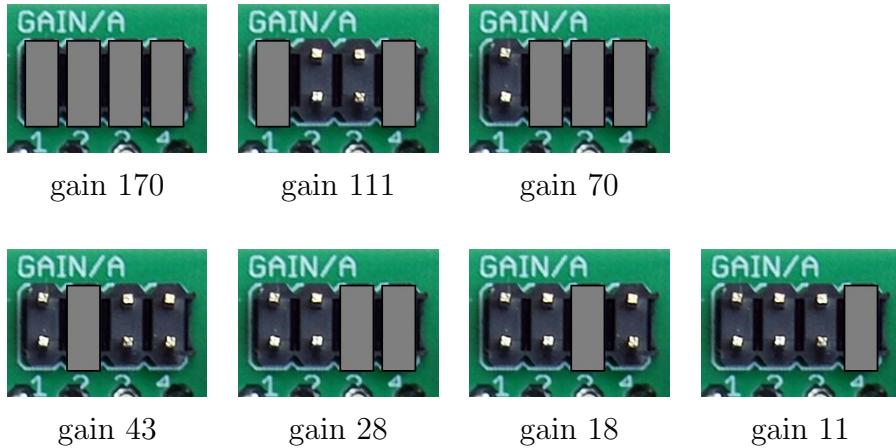


Figure 28: The settings for the Gain Jumpers of PCB 6 Version 7

3.3 Attachments

The DC jack can be used for power supply with positive polarization at the center. The power of the amplifier can also be supplied by the controller 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 can 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 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.

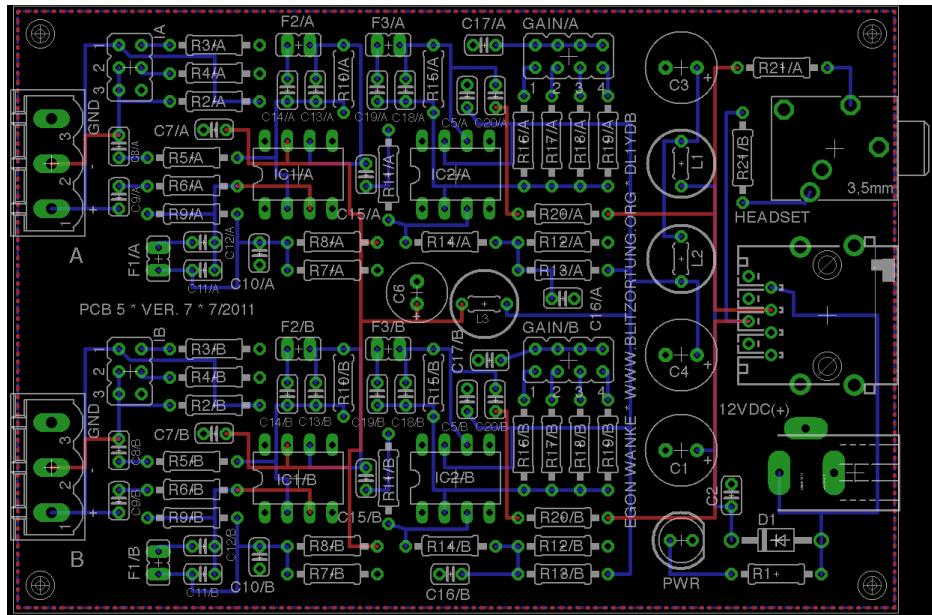


Figure 29: The layout of the VLF amplifier PCB 5 Version 7

Operational amplifier	IC1, IC2, IC3, IC4	NE5534
LED, standard	PWR	LED 5mm (red)
rectifier diode	D1	1N4001
Resistor, metal 1%	R2-A/B	1 MΩ 
	R7-A/B, R8-A/B, R12-A/B R13-A/B, R14-A/B, R15-A/B	100 kΩ 
	R9-A/B, R10-A/B	47 kΩ 
	R19-A/B	10 kΩ 
	R18-A/B	6.04 kΩ 
	R17-A/B	2.37 kΩ 
	R1, R5-A/B, R6-A/B R16-A/B, R21-A/B	1 kΩ 
	R3-A/B, R4-A/B	82 Ω 
	R11-A/B, R20-A/B	47 Ω 
Capacitor, electrolytic	C1, C3, C4	330 μF
	C6	100 μF
Capacitor, ceramic	C2, C5-A/B, C7-A/B, C10-A/B, C15-A/B, C16-A/B, C20-A/B	100 nF (104)
	C8-A/B, C9-A/B, C17-A/B	22 nF (223)
	C11-A/B, C12-A/B, C13-A/B, C14-A/B	100 pF (101)
	C18-A/B, C19-A/B	47 pF (470)
Inductor, ferrite	L1, L2, L3	470 330 mH

Table 1: The list of electronic parts for the VLF amplifier PCB 5 Version 7

We modify the 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 amplifier, please send us first the circuit diagram. It is very important that you do not include delaying parts like inductions in the signal ways. The part list of amplifier is PCB 5 Version 7 is shown in Table 1, the PCB layout is shown in Figure 29, and the complete circuit diagram is shown in Figure 32.

The output voltage of the amplifier should be between -2.5 Volt and $+2.5$ Volt. These are the reference voltages of the analog digital converter at the controller 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 unshielded ferrite rod antennas. In this cases, you can set the Gain Jumper to a gain of 70 . If you still have too much interferences, you should reduce the amplification to a gain of 43 or 28 . 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 to a gain of 111 or 170 . If the resonance frequency of your home made loop antenna is accidentally tuned at a long wave radio station you can use a parallel resistor of approximately $20\text{ k}\Omega$.

3.4 Electrical and coaxial cable antennas

When using a coaxial cable antenna, you can add the $82\text{ }\Omega$ terminating resistors by the I-Jumper as shown in Figure 30 to the right. This can additionally reduce interferences and make the signal more smooth.

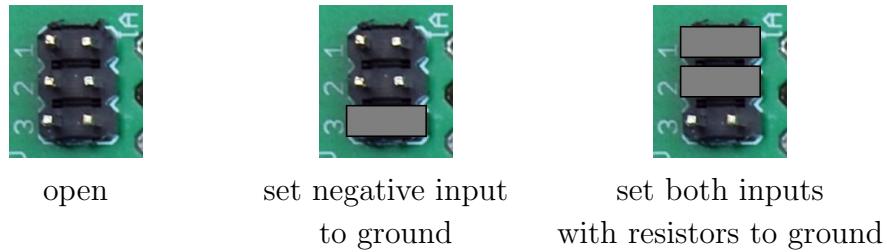


Figure 30: The settings for the I-Jumpers of PCB 5 Version 7

When using an electrical antenna, the **ground** of the amplifier and thus also the ground of the controller 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 connected to the ground wire of the electrical supply system. Usually some grounding is already given if the serial 9-ways Sub-D plug of PCB 6 Version 7 is connected to the PC. A grounding is not necessary for loop antennas.

The circuit diagram of Figure 31 shows how to connect an electrical antenna to the amplifier. The second input has to be connected to ground by the I-Jumper as show in Figure 30 in the middle. The $1\text{ M}\Omega$ resistor avoids electrostatic charges.

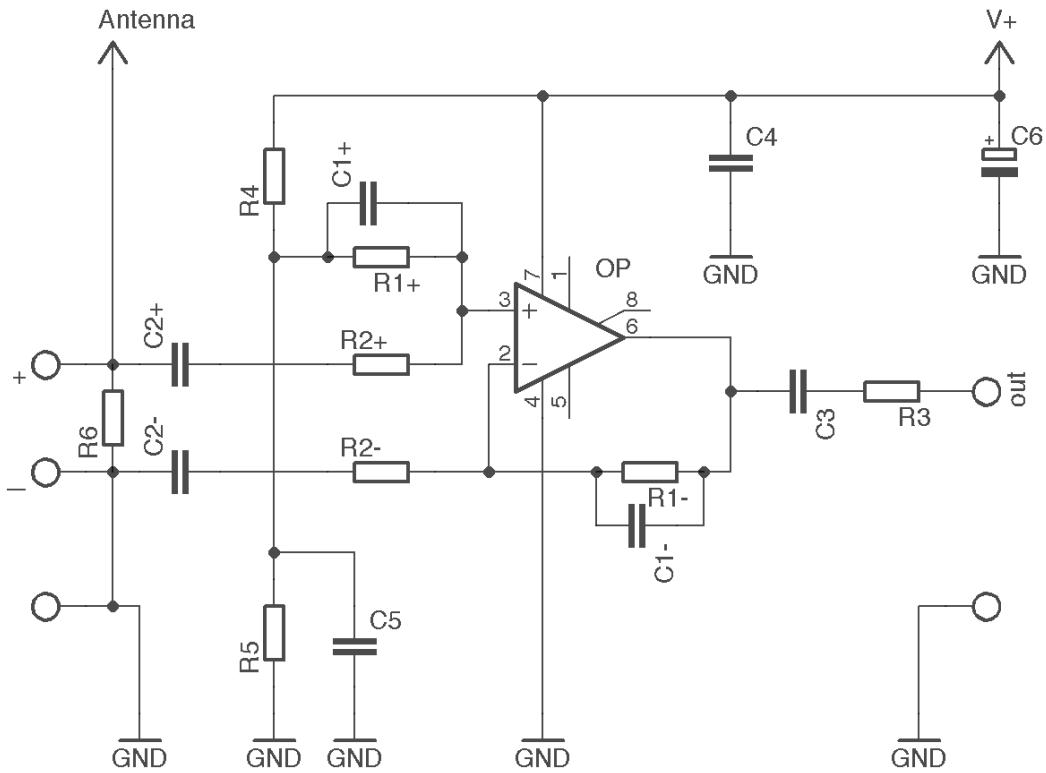


Figure 31: The setting for using an electrical antenna

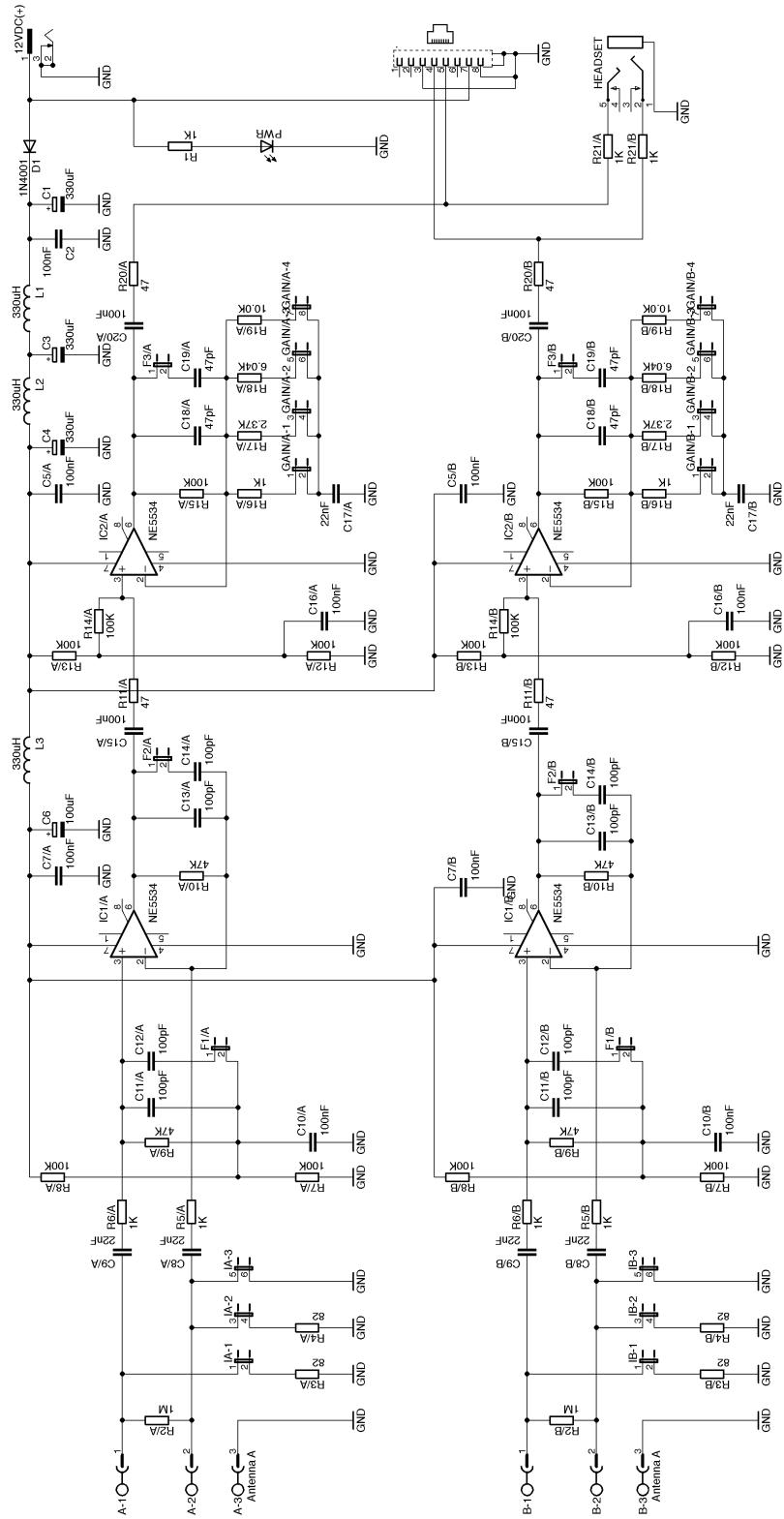


Figure 32: The circuit diagram of the amplifier board PCB 5 Version 7

4 Controller boards

4.1 The architecture

The heart of the controller boards is an Atmel 8-bit AVR micro controller ATmega644 running with a clock frequency of 19.660800 MHz¹. The boards also contain two separate 10-bit analog-to-digital converters AD7813 operating 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 samples per second. A quad comparator LM339 activates the analog-to-digital conversion, if the input signal exceed a threshold of ± 0.417 Volt. Unfortunately, the ATmega644 is not able to process and store the data as fast as provided. Therefore, we use only 8-bit conversions with a throughput of approximately 350 ksps. This is quite sufficient for our purposes.

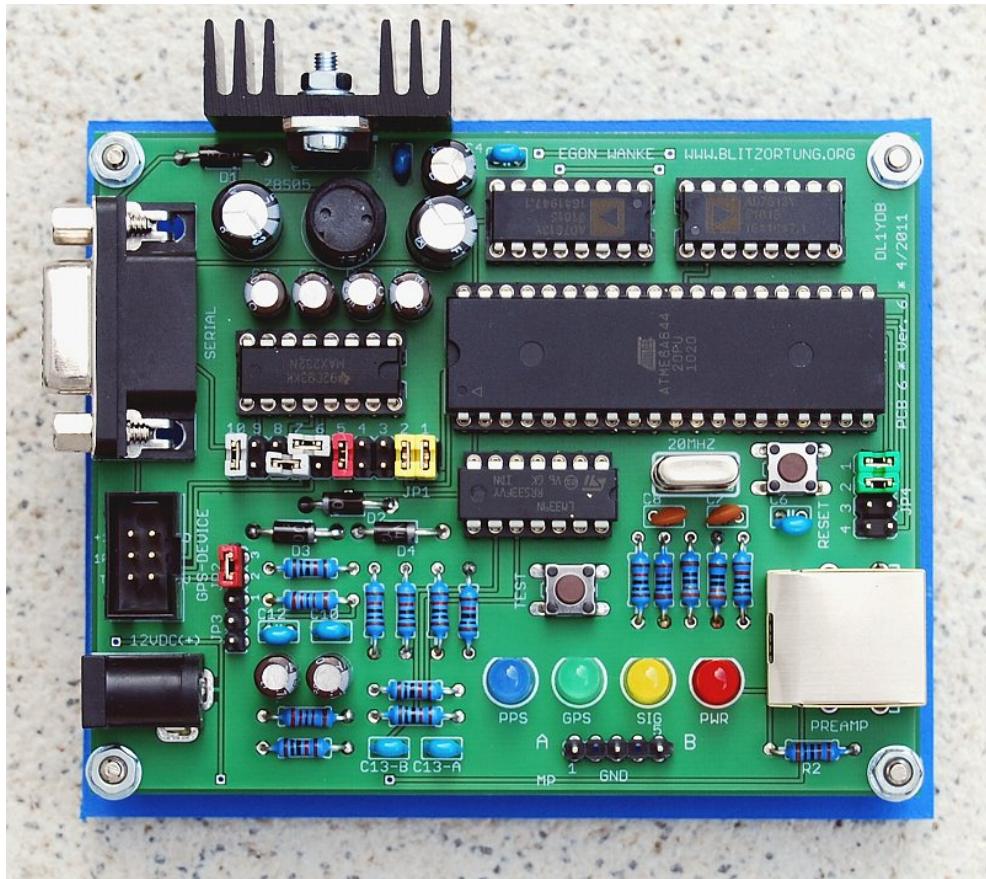


Figure 33: An assembled controller board PCB 6 Version 6

¹The PCS 6 Version 6 board still has the labeling 20 MHz. We use 19.660800 MHz to reduce the baud rate error at the serial interface. The board needs different Firmware versions for the different clock frequencies.

The micro-controller works as follows. An internal timer 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 units. One counter unit corresponds to 400 ns. If the signal from the receiver reaches the thresholds of ± 0.417 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. It outputs a data sentence for every second and for every recorded data sequence.

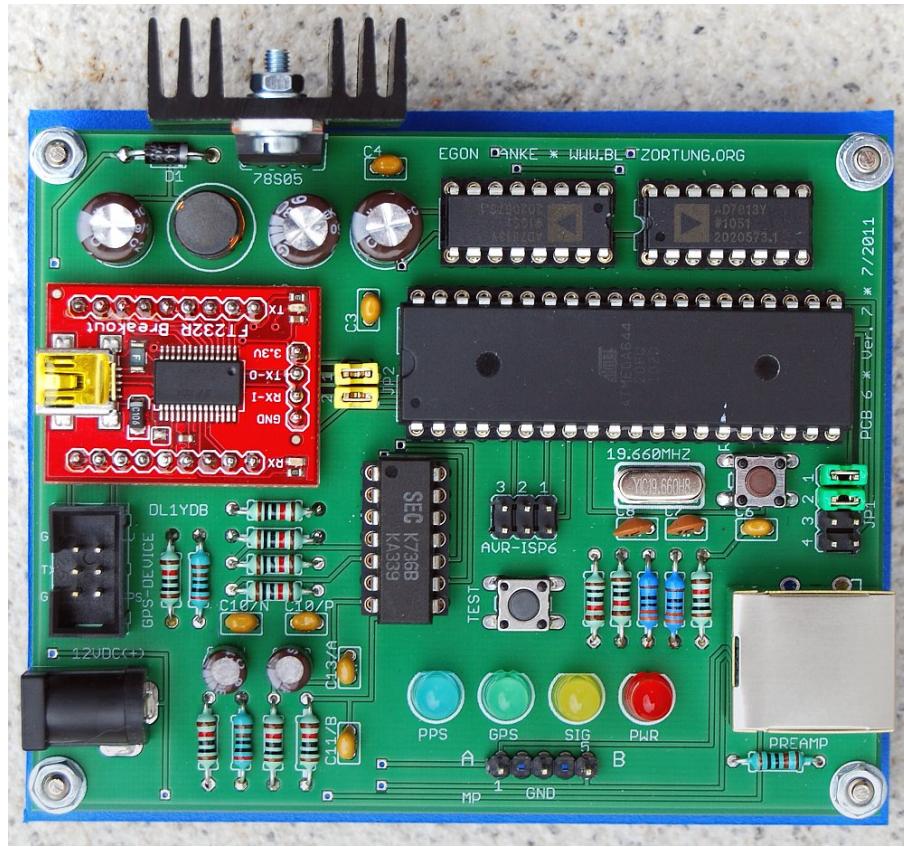


Figure 34: An assembled controller board PCB 6 Version 7

We provide two different types of controller boards, PCB 6 Version 6 and PCB 6 Version 7. PCB 6 Version 6 provides a serial RS232 interface and supports different GPS devices with 12 Volt and 3.6 to 5 Volt power supply using a TTL or RS232 serial interfaces. A dual driver/receiver MAX232 is used to convert the TTL input level into RS-232 output level and vice versa, if necessary.

PCB 6 Version 7 uses an USB to serial Breakout Board from <http://www.sparcfun.com> with a FT232RL. It supports only GPS modules with 5 Volt power supply and a serial TTL interface. The PCB 6 Version 7 board is designed to operate preferable with the EM-406A GPS module. It has additionally a 6-pin header for an AVR in-system programmer interface (ISP interface). This interface can be used to reprogram the controller.

Resistor, metal 1%	R1, R3, R4, R6, R8, R9, R10, R11, R12, R13, R14	10 kΩ	
	R5, R7	2 kΩ	
	R2	1 kΩ	
	R15, R16	330 Ω	
Capacitor, electrolytic radial, pitch 2.5 mm	C1, C2	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	
	L1	330 μH	
Inductor, ferrite	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	19.660800 MHz	
Voltage regulator	IC1	μ78S05	
Comparator	IC2	LM339	
Driver/receiver	IC3	MAX232	
Analog-to-digital converter	IC4, IC5	AD7813	
Micro controller	IC6	ATmega644 20PU	

Table 2: The electronic part list for the controller board PCB 6 Version 6

Resistor, metal 1%	R2, R3, R4/N+P, R6, R7, R8/N+P, R9/N+P, R10	10 kΩ	
	R5/N+P	2 kΩ	
	R1	1 kΩ	
	R11, R12	330 Ω	
Capacitor, electrolytic		C1, C2, C5	330 μF
		C9/N+P	4.7 μF
Capacitor, ceramic, pitch 2.5 mm	C3, C4, C6, C10/N+P	100 nF	
	C11/A+B	(104)	
	C7, C8	15 pF	
Inductor, ferrite	L1	330 μH	
rectifier diode	D1	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	19.660800 MHz	
Voltage regulator	IC1	μ78S05	
Comparator	IC2	LM339	
Analog-to-digital converter	IC3, IC4	AD7813	
USB-to-serial breakout board	IC5	SparcFun BOB-00718	
Micro controller	IC6	ATmega644 20PU	

Table 3: The electronic part list for the controller board PCB 6 Version 7

4.2 Power supply

The amplifier and the controller board can be connected by a 1-to-1 cat cable via the RJ45 jacks. We prefer a shielded Cat 5 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 10 Volt and should not exceed 15 Volt. The normal operation is 12 Volt.

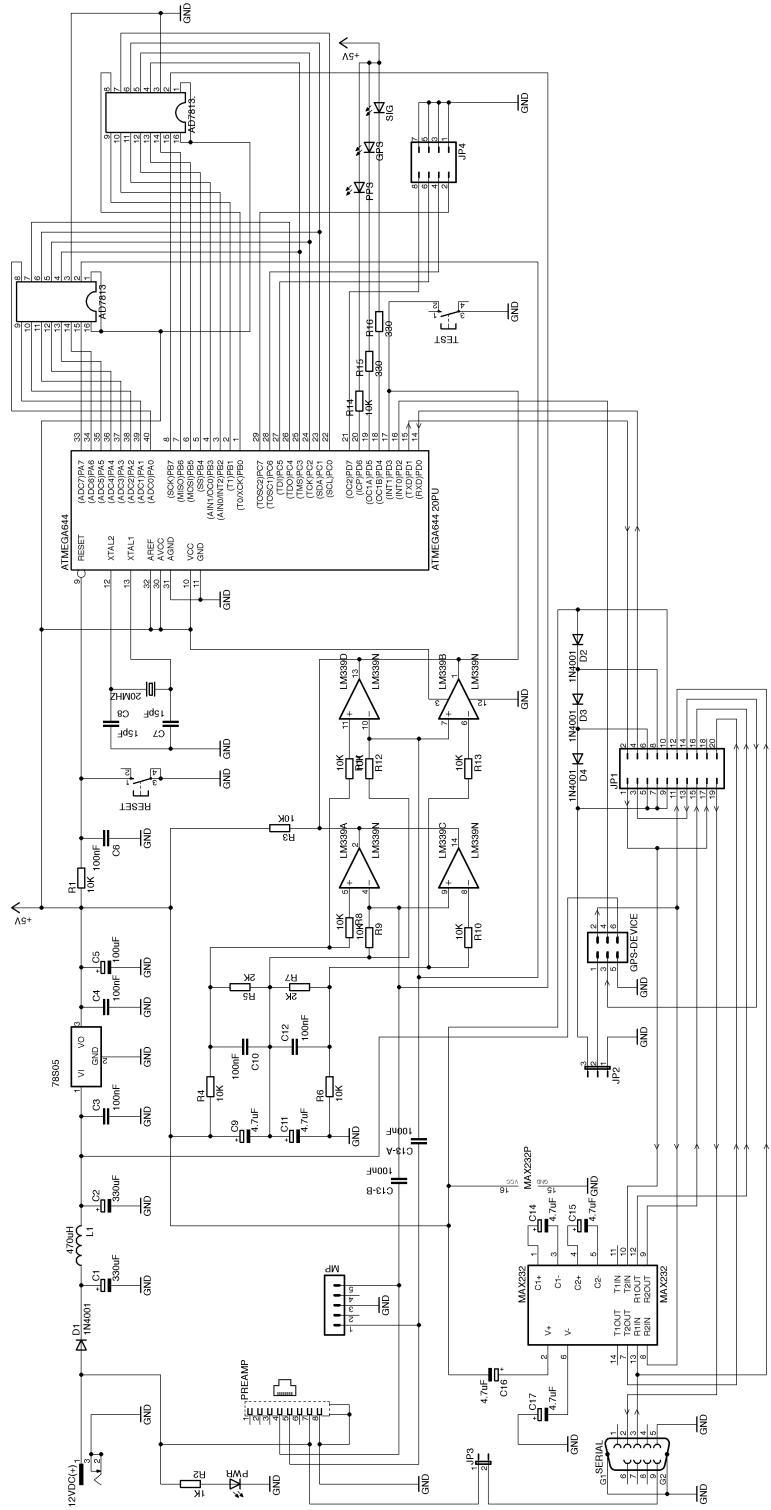


Figure 35: The circuit diagram of the controller board PCB 6 Version 6

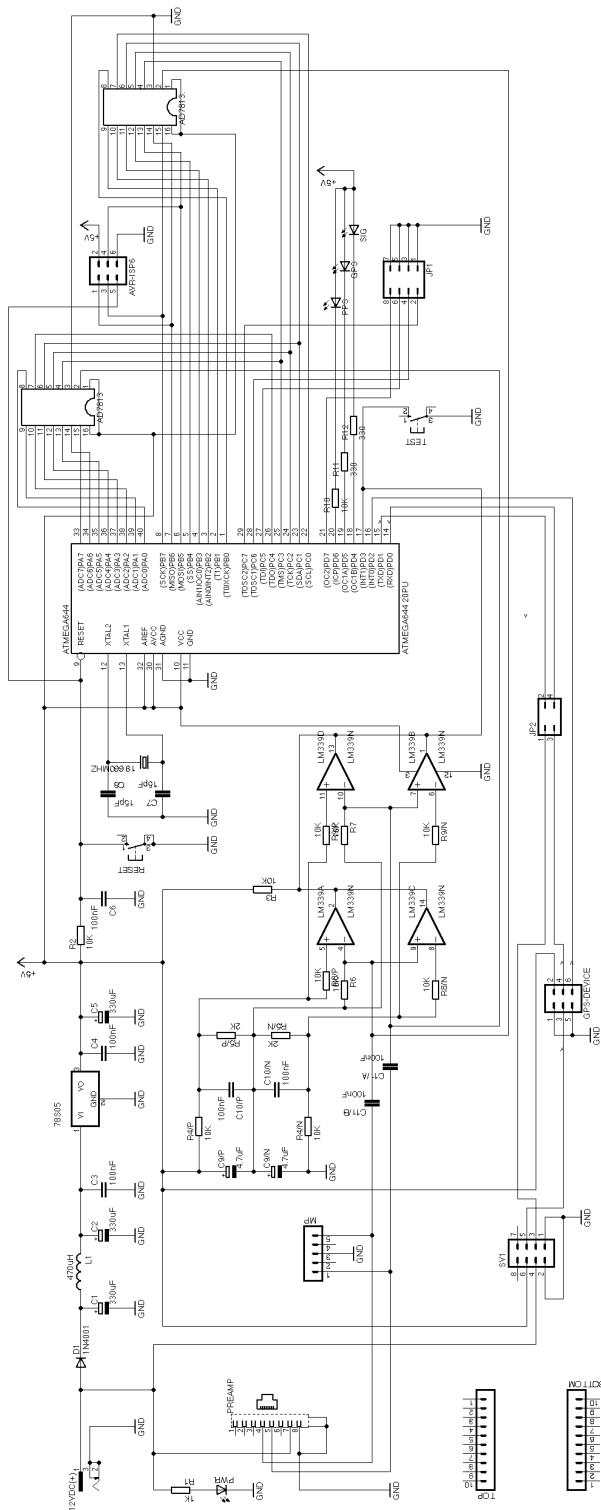


Figure 36: The circuit diagram of the controller board PCB 6 Version 7

4.3 The LEDs



Figure 37: The LEDs of the controller board

When power supply is connected to the board, then the following will happen.

- The (red) PWR LED will light and the other three LEDs will blink four times one after the other. This just indicates that the controller is running.
- The (green) GPS LED starts blinking if the controller recognizes a GPRMC data sentence from the GPS. If the (green) GPS LED remains 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 the baud rate jumper (Jumper JP4 at PCB 6 Version 6 and Jumper JP1 at PCB 6 Version 7) 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 light 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 with a view to the sky.
- The (blue) 1PPS LED will blink every time the GPS provides a 1PPS signal. This will be every second. The (blue) 1PPS LED usually starts blinking immediately after the green LED lights permanently.
- The (yellow) SIG LED will flash every time the controller outputs a data sentence containing strike signal information.

The LED series resistors R2, R14, R15, and R16 for the Version 6 board and R1, R10, R11, and R12 for the Version 7 board need to be adjusted corresponding to the illuminating power of the used LEDs. For standard LEDs, the series resistor R2(R1) for the red LED should be $1\text{ k}\Omega$, the series resistor R14(R10) for the blue LED should be $10\text{ k}\Omega$, and the series resistors R15(R11) and R15(R12) for the yellow and green LED should be $330\text{ }\Omega$.

4.4 The measuring point



Figure 38: The Measuring Point MP1 of the controller boards Version 6 and Version 7

The measuring point MP1 provides at Pin 1 and Pin 5 the two signals from the amplifier. Channel A at Pin 1 and Channel B at Pin 5. Pin 3 of MP1 is connected to the ground of the board. These pins can be used to control the 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 for PCB 6 Version 6

The jumpers at PCB 6 Version 6 have the following meanings.

1. Jumper JP1 performs several different tasks.

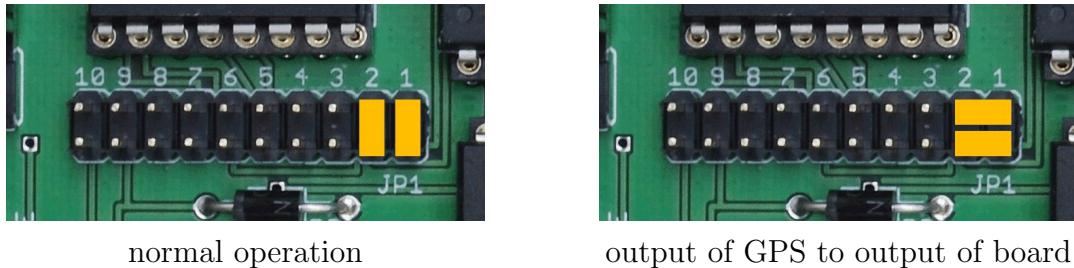


Figure 39: Setting for Jumper JP1 of PCB 6 Version 6

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 39 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 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

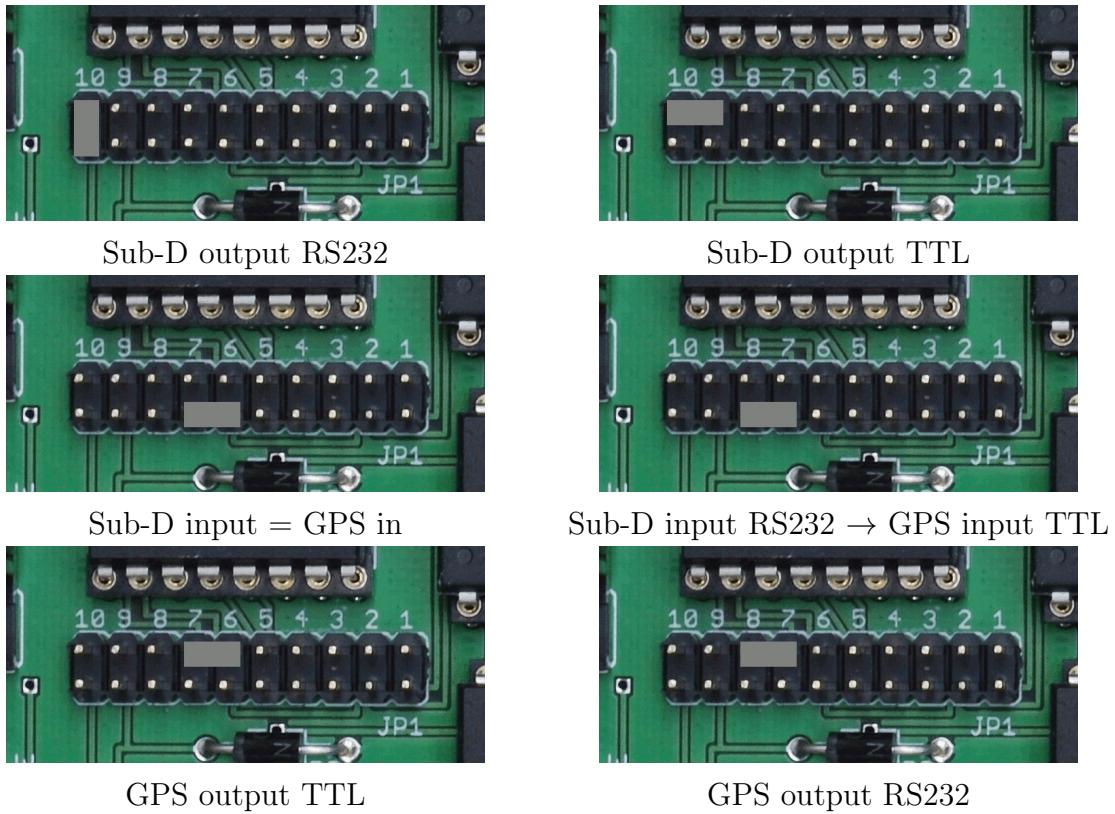


Figure 40: Setting for Jumper JP1 of PCB 6 Version 6

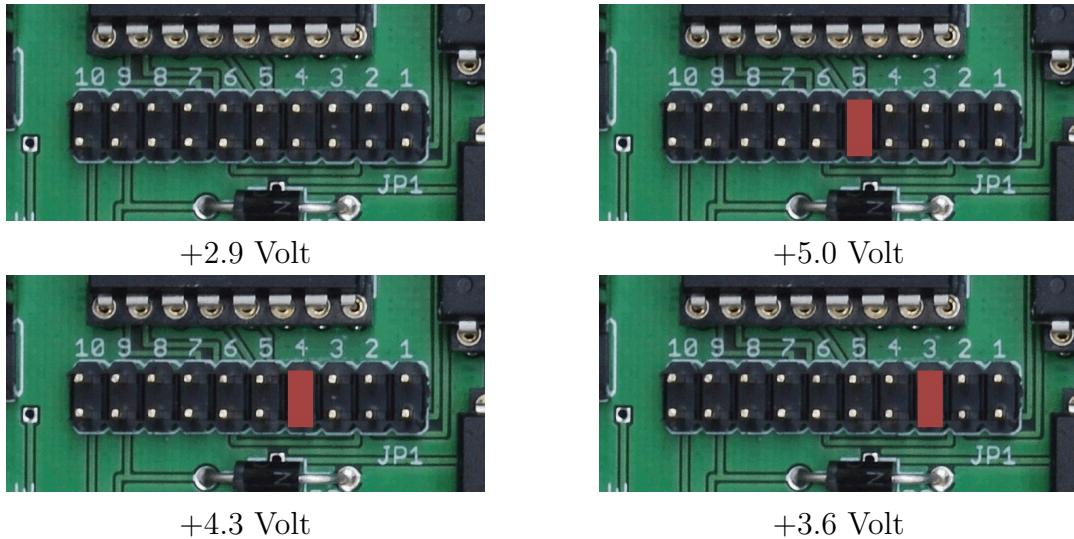


Figure 41: GPS voltage setting at Jumper JP1 of PCB 6 Version 6

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 42 to the left. JP3 allows you to connect +12 Volt to Pin 9 of the serial 9-ways Sub-D connector, see Figure 42 to the right. This allows you to power the PCBs via pin 9 of the serial connector.

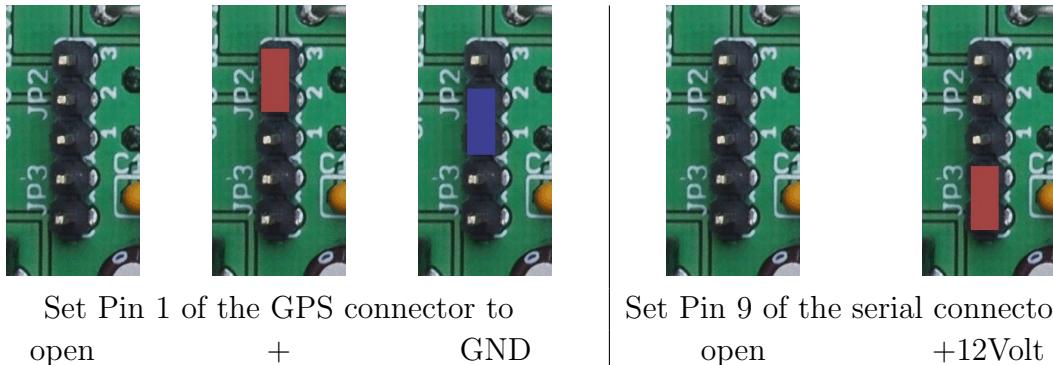


Figure 42: The settings for Jumper JP2 and JP3 of PCB 6 Version 6

3. Jumper JP4 of PCB 6 Version 6 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 Figure 43, and second, it can be used to switch between different output formats, see Figure 44.

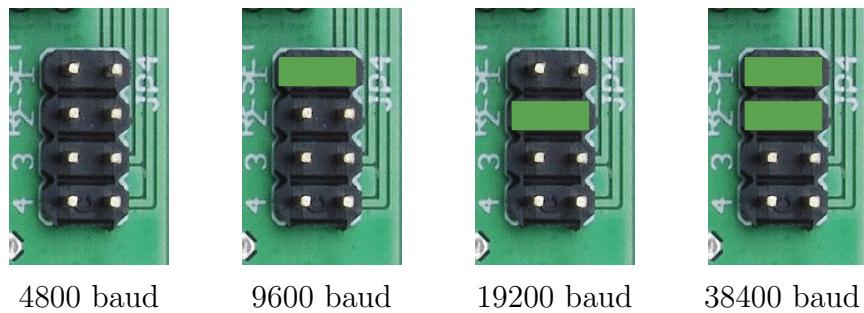


Figure 43: Setting of Jumper JP4 of PCB 6 Version 6

If this Jumper 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.

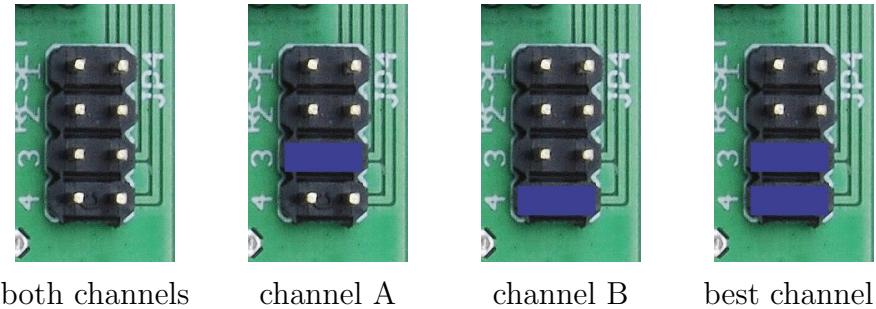


Figure 44: Setting for Jumper JP4 of PCB 6 Version 6

4.6 The jumper settings for PCB 6 Version 7

Jumper JP1 of PCB 6 Version 7 serves the same two functions as PCB 5 Version 7. 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 Figure 45, and second, it can be used to switch between different output formats, see Figure 46.

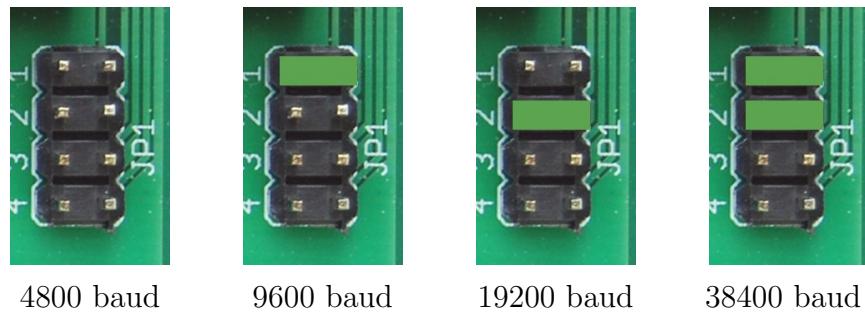


Figure 45: Setting of Jumper JP1 of PCB 6 Version 7

If this Jumper 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.

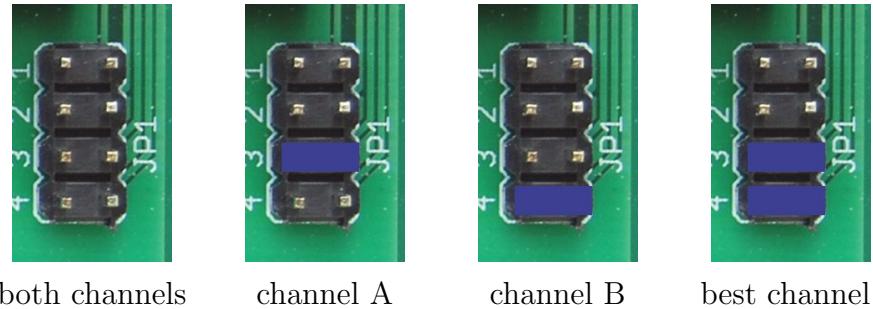


Figure 46: Setting for Jumper JP1 of PCB 6 Version 7

Jumper JP2 can be used to bypass the serial connection to/from the controller. The setting shown in Figure 47 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 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 board².

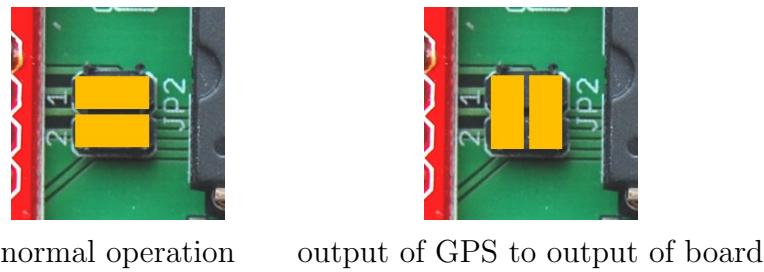


Figure 47: Setting for Jumper JP2 of PCB 6 Version 7

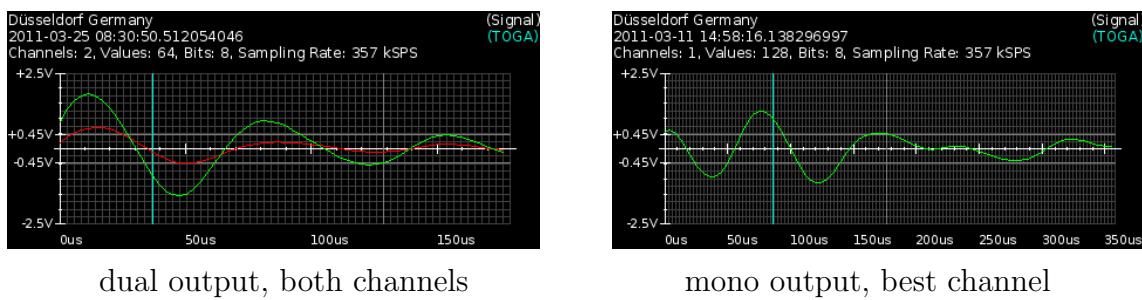


Figure 48: The different outputs

²Unfortunately, the USB controller board 6 Version 7 has a layout error which do not allow to reroute the output of the GPS device to the output of the board by turning the yellow jumpers. This is corrected in Version 7b.

4.7 Output of the controller boards

The output of the board provides data formatted NMEA 0183, Version 2.0. There are three types of sentences starting with \$BS, \$BD, and \$BM, see Table 4 and 5. A BS sentence is output every second, a BD or BM sentence is output every time one of the inputs exceeds the threshold voltages of the comparators.

Table 4: Format of the BS sentence. The information of the Time/Date field refers to the point in time of the preceding 1PPS signal. That is, the time stamp is always 1 second slow.

4.8 The GPS connector of PCB 6 Version 6

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 of the header of PCB 6 Version 6 is shown in Table 6. The power supply for the GPS receiver can be connected to Pin 6 if it works with the same voltage as the controller 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.

```

$BD,D68625,88638A61 ... 817B*75<CR><LF>
^ ^ ^
| | |
| | | Checksum
|
| 265 hexadecimal characters, 2 x 64 byte
| 0x88 = first byte channel 1, 0x63 = first byte channel 2
| 0x8A = second byte channel 1, 0x61 = second byte channel 2
|
| ...
| 81 last byte channel 1, 7B last byte channel 2
|
Counter, 24 bit hexadecimal

$BM,D68625,88938A61 ... 807F*75<CR><LF>
^ ^ ^
| | |
| | | Checksum
|
| 265 hexadecimal characters, 1 x 128 byte
| 0x88 = first byte
| 0x93 = second byte
|
| ...
| 7f last byte channel
|
Counter, 24 bit hexadecimal

```

Table 5: Format of the BD and BM sentences. These sentences transmits 64 bytes from each or 128 from one analog to digital converter. This corresponds to a time span of approximately $180 \mu s$ or $365 \mu s$, respectively. The time between two conversions is $2.850 \mu s$.

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 6: Pin assignment of the connector for the GPS receiver for PCB 6 Version 6 .

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.

4.9 The GPS connector of PCB 6 Version 7

The pin assignment of the header of PCB 6 Version 7 is shown in Table 7.

Header pin	Description
1	ground
2	+5 Volt
3	serial output TTL
4	serial input TTL
5	ground
6	1PPS input

Table 7: Pin assignment of the connector for the GPS receiver for PCB 6 Version 7

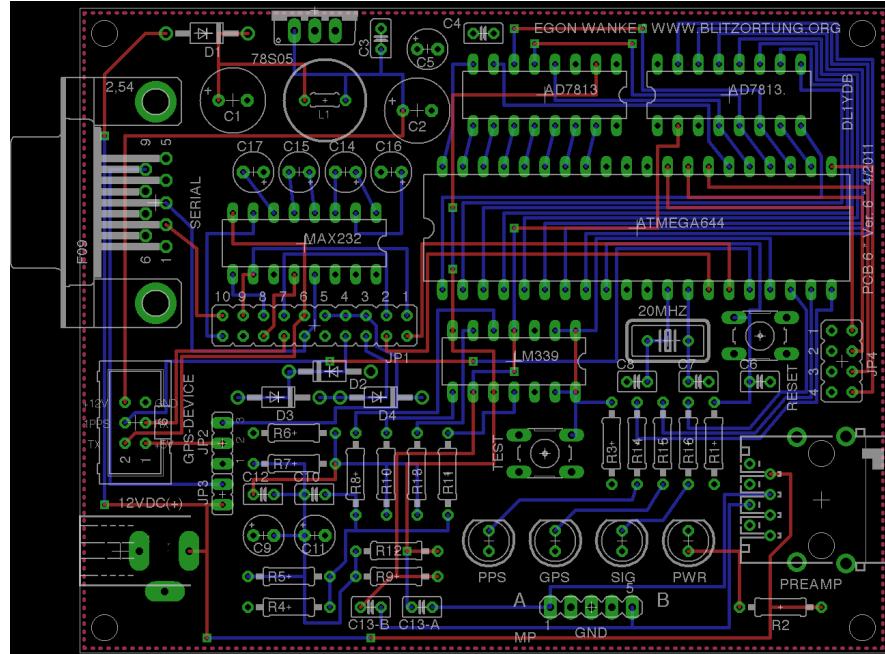


Figure 49: The layout of the controller board PCB 6 Version 6

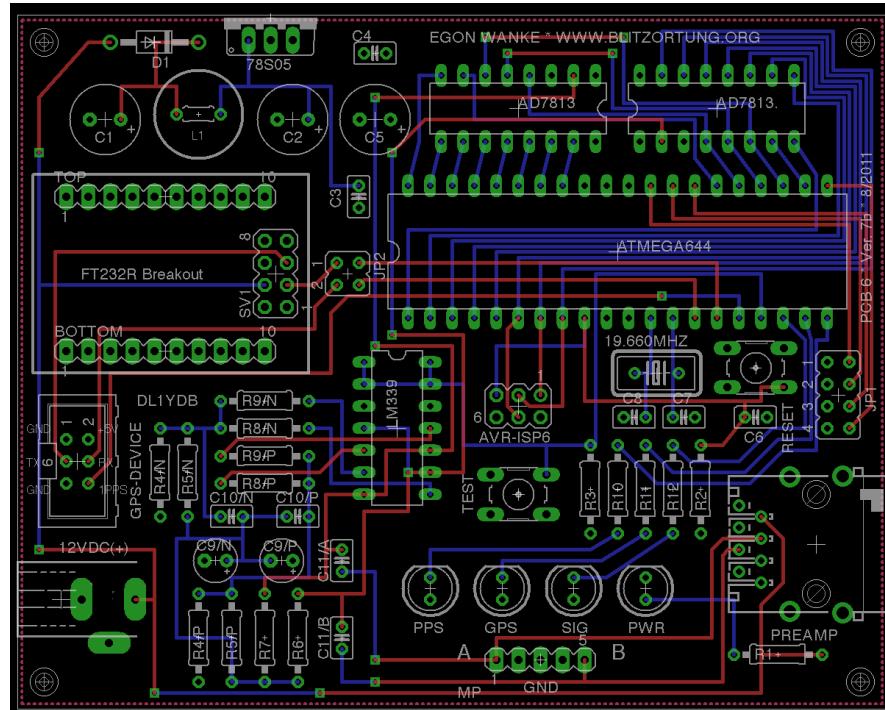


Figure 50: The layout of the controller board PCB 6 Version 7b

5 GPS receivers

The GPS devices we need for our lightning location system have to provide a one-pulse-per-second (1PPS) signal 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 controller board is carried out with 4800, 9200, 19200, or 38400 baud, 1 stop bit, and no parity. The controller board reads the GPRMC and GPGGA sentences from the GPS device. These sentences refer to the immediately preceding 1PPS output and look like shown in Table 8 and 9.

Table 8: The GPRMC data sentence

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

The GPS devices we have tested 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. If you do not already have one of these GPS devices but have to obtain one, then we advise

Table 9: The GPGGA data sentence

to choose the EM-406A GPS module, because of the following reasons.

1. The EM-406A engine module is still in production and thus can be obtained from several distributors.
 2. The price for a new EM-406A engine module is on average less than 40 €.
 3. It has an up-to-date sensitive SiRF Start III chipset and works also inside at a window.
 4. It has a serial TTL interface, which makes the RS232 to TTL conversion unnecessary. This is very comfortable, especially when using the Version 7 USB controller board. This board do not have any RS232 to TTL conversion.



Figure 51: Some GPS devices/modules providing a 1PPS signal

5.1 Connecting a GPS to the controller board PCB 6 Version 6

The **Garmin 35-HVS** and **Garmin 16-HVS** are designed to withstand rugged operating 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 controller 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. Figure 52 shows how the wires of the Garmin 16/35 HVS have to be connected to the pins of the straight header at the controller board.

Jumper JP1 of PCB 6 Version 6 has to be set such that the RS232 serial input of the controller board is routed to the RS232 input of the Garmin 16/35 HVS, the RS232 output of the Garmin 16/35 HVS is routed to the TTL input of the Controller, and the TTL output of the controller is routed to the RS232 output of the controller board, see Figure 52. Jumper JP2 has to be set such that the power on/off switch of the Garmin 16/35 HVS is connected to ground. The baud rate can be set to 19200 baud by Jumper JP4. This is the maximum speed for these old Garmin GPS devices. The Garmin 17-HVS,

Color	Description	Header of PCB 6 Ver. 6
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

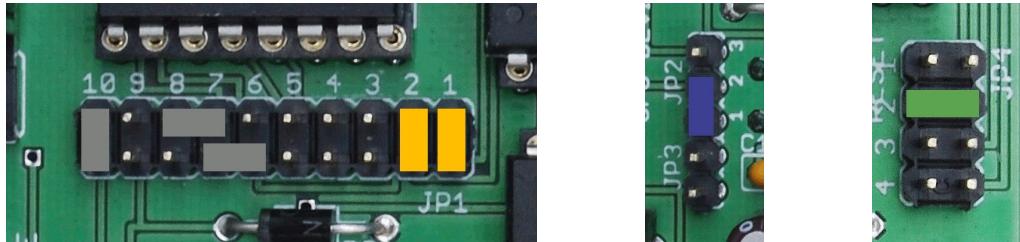


Figure 52: A Garmin 16/35 HVS connected to the controller board PCB 6 Version 6 with a transfer rate of 19200 baud

one of the more recent models, also accepts 38400 baud. The 1PPS signal 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 10: 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 new baud rate and the 1PPS mode changes take effect on the next power on cycle. That is, you have to power off and again power on the GPS device. 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 operate 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 JP2 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 controller board provided after the voltage regulator, see Figure 53.

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

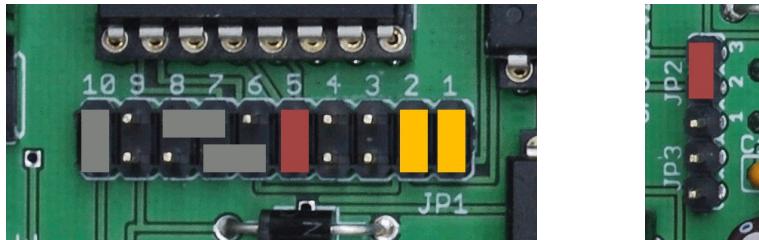
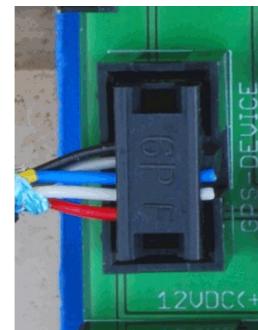


Figure 53: A Garmin 35-LVS connected to the controller board PCB 6 Version 6 with a transfer rate of 19200 baud

The old Garmin 35 GPS devices sometimes produce 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 $\pm 100\text{ ns}$ tolerance. It has also a flexible power supply of 8 Volt to 40 Volt. The power consumption is typically 1.1 W. The device can also easily be supplied by the 12 Volt power supply of

the controller 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 controller board have the following colors (if the plugs are cut off) and can be connected to the pins of the straight header as shown in Figure 54.

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

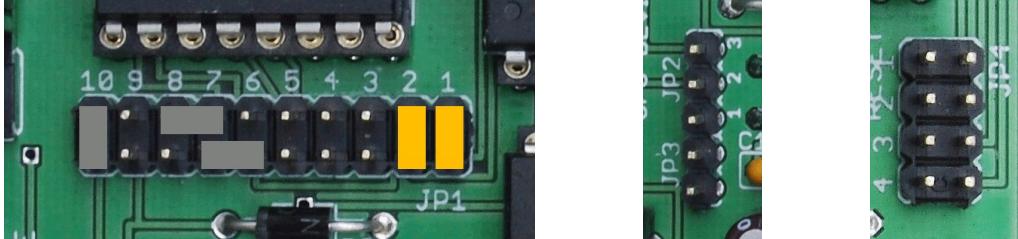


Figure 54: An AQTIME VP-200T connected to the controller board PCB 6 Version 6 with a transfer rate of 4800 baud

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. Unfortunately, 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 11: 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

of the Fortuna U2. Some of them provide an USB interface (Fortuna U2-USB). These receivers can not be used in connection with the controller board. Newer versions use a SiRF-III chip-set but do not have a free wire which we can use to lead through the 1PPS signal. We do not know whether the SiRF-III module used by the latest versions of the Fortuna U2-PS/2 also provides the 1PPS output. If somebody has find out this, please give us some feed back such that we can include this information here.

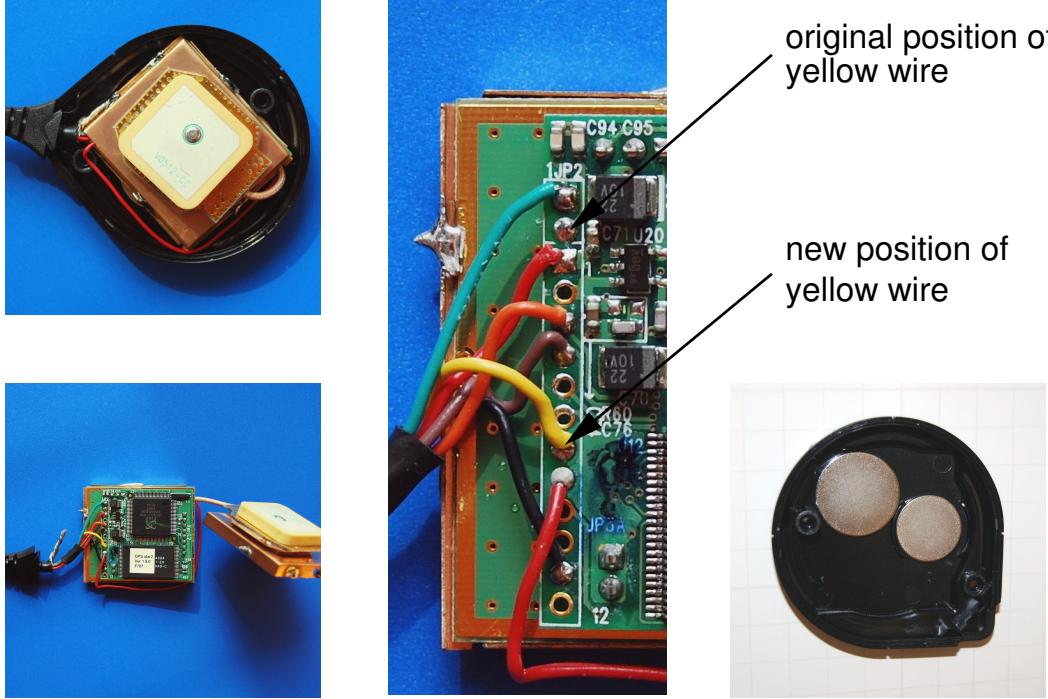


Figure 55: The modification of the old Fortuna U2/PS2 with the SiRF II module

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 55 to the left. The cap contains two slices that makes the base of the device magnetic, see Figure 55 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 55 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 pin assignment as shown at the top of Figure 56. Note that the information about the pin assignment at the folder enclosed into the original package of the Fortuna U2 is wrong!

The initialization by the tracker program switches off the data sentences GPGLL, GPGSA, GPGSV, GPMSS, GPDTM, and PGZDA. The data sentence GPRMC and

Color	Description	Mini-DIN	Header of PCB 6 Ver. 6
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 56: The 6-ways female Mini-DIN connector from the front and its connection to the header of PCB 6 Version 6

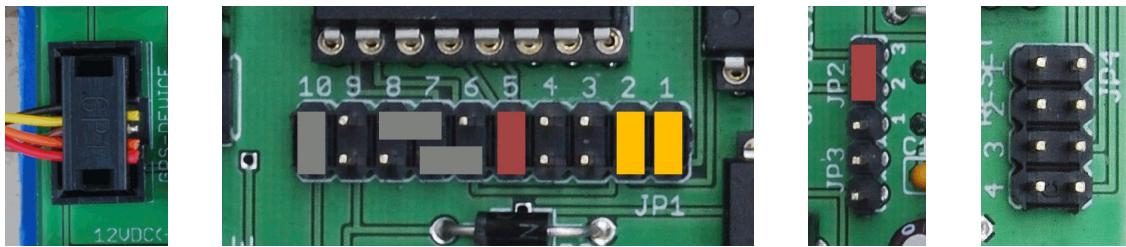


Figure 57: The Fortuna U2/PS2 connected to the controller board PCB 6 Version 6 with a transfer rate of 4800 baud

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 can switch the communication speed up to 38400 baud.

```
$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
$PSRF100,1,38400,8,1,0*3D
```

Table 12: Initialization strings for SiRF GPS devices

The device operates with a voltage of 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 controller board, you can either cut off 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 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 58 shows two examples for an integration of the module into the housings of other GPS devices. Note that the EM-406A module is not the module inside the Navilock NL-303P. We have exchanged the original module with an EM-406A module.



Figure 58: 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

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 $1\mu s$. 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 60.

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 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.

Pin	← EM-406A module	Header of PCB 6 Ver. 6 →	Pin
1	ground		5
2	+5 Volt		1
3	serial input TTL	123456	3
4	serial output TTL		2
5	ground	654321	
6	1PPS output	front	4

Figure 59: Pin assignment of the EM-406A module and its connection to the header of PCB 6 Version 6

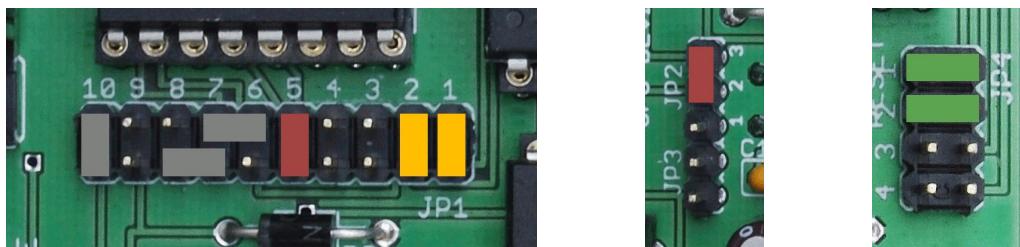


Figure 60: An EM-406A module connected to the controller board PCB 6 Version 6 using 5 Volt power supply and a transfer rate of 38400 baud

There are several further GPS devices that can be connected to the PCB 6 Version 6 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.

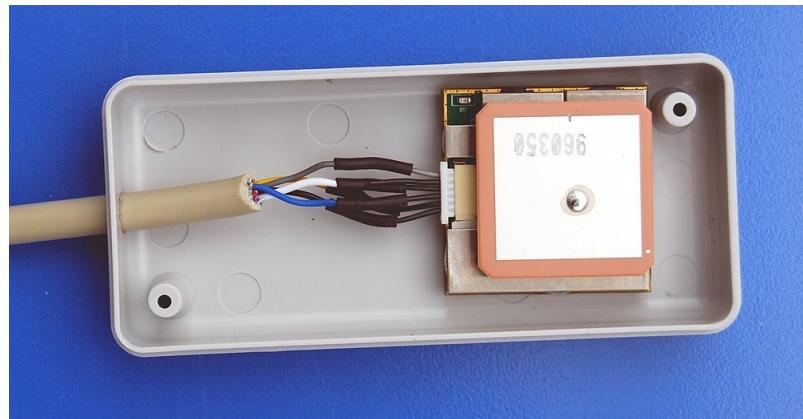


Figure 61: An EM-406A module embedded in a plastic housing

5.2 Connecting a GPS to the controller board PCB 6 Version 7

The controller board PCB 6 Version 7 has no RS232 to TTL conversion chip. You can only connect GPS modules with a serial TTL interface. The board is designed to work preferably with the EM-406A GPS module. The pin assignment of the header is the same as the pin assignment of the module, see Figure 62. Figure 63 shows a completely connected controller board PCB 6 Version 7. Jumper JP2 defines a transfer rate of 38400 baud.

Pin	\leftarrow EM-406A module	Header of PCB 6 Ver. 7 \rightarrow	Pin
1	ground		1
2	+5 Volt		2
3	serial input TTL		3
4	serial output TTL		4
5	ground		5
6	1PPS output		6

Figure 62: Pin assignment of the EM-406A module and its connection to the header of PCB 6 Version 7

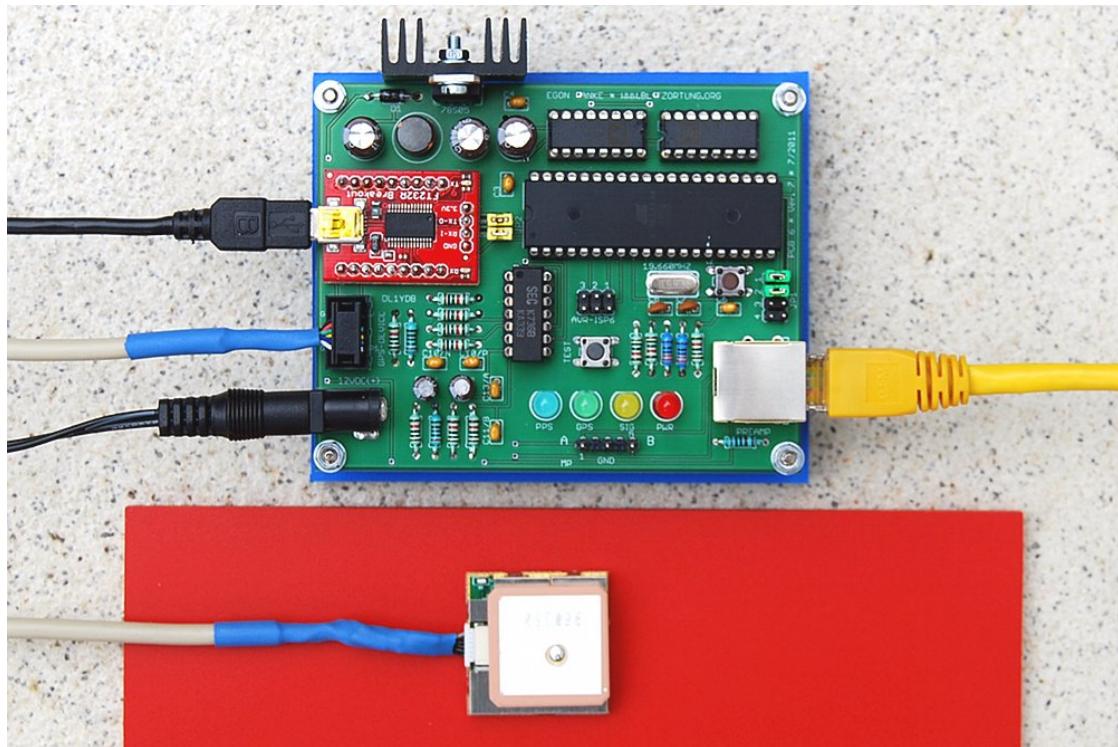


Figure 63: A completely connected controller board PCB 6 Version 7

6 Data upload

The data upload is carried out by a **tracker program**. It reads and processes the data of the controller board and sends the resulting lightning data to our computing server. We provide two types of tracker programs, one for computers running a Linux operating system and one for computers running a Windows operating system. The official tracker program for Linux is written by Egon Wanke. We only provide the C++ source code of the Linux tracker program. You have to compile the source code using any C++ compiler for your Linux system. The official tracker program for Windows is written by Edmund Korffmann. It consists of only one small executable file. You can download both tracker programs from the "Miscellaneous" page of the "Services" menu of Blitzortung.org. However, you can also use the other tracker programs written by some of the participants. Please do not write and use own written tracker programs without to get in contact with us.

6.1 The official tracker program for Windows

In this section, we briefly explain how to work with the tracker program for Windows. The current Version (at the time this text has been written) is "WT 5.02". The program consists of one small (less than 250 K) executable file named "`serial_tracker`". You can store the tracker program in any directory, also on your desktop. It should run at all Windows systems. If you are running an extraordinary Windows system, please get in contact with us. The tracker program stores the used settings in a configuration file called "`Tracker.prefs`" placed in the same directory.

First, connect the GPS device to the controller board and the controller board to your computer. Disconnect the amplifier. We recommend to set the jumper of the controller board to 38400 baud or at least 19200 baud, depending on the maximal speed your GPS device supports. Then power on the controller board and start the tracker program. Select the serial device, the baud rate, and the GPS type, as shown in Figure 64, and initialize the GPS device. If you are using a Garmin GPS device then the initialization is not carried out until the next power on. In this case, you have to disconnected and then again to connect the power supply. Now the green LED should start blinking, and after a while it should continuously light. If the green LED blinks, the controller board receives GPRMC sentences with status 'V' (= invalid), if it lights permanently, it receives GPRMC sentences with status 'A' (= active). If the green LED is off, either the baud rate of the GPS does not match the baud rate of the controller board, or something else fails. In this case, you can use the port monitor to control the serial connection with the controller board, see Figure 66. If you push the reset button of the controller board, then the micro-controller outputs its firmware version. If the firmware version text string is not listed at the port monitor, then the baud rate of the controller board does not match the baud rate selected at you PC for

the serial device. You can turn the yellow jumpers at the controller board by 90 degrees to see the output of the GPS device at the port monitor³. If the green LED is blinking and does not turn into a permanent light, then move the GPS device outside, or at least to a window side.

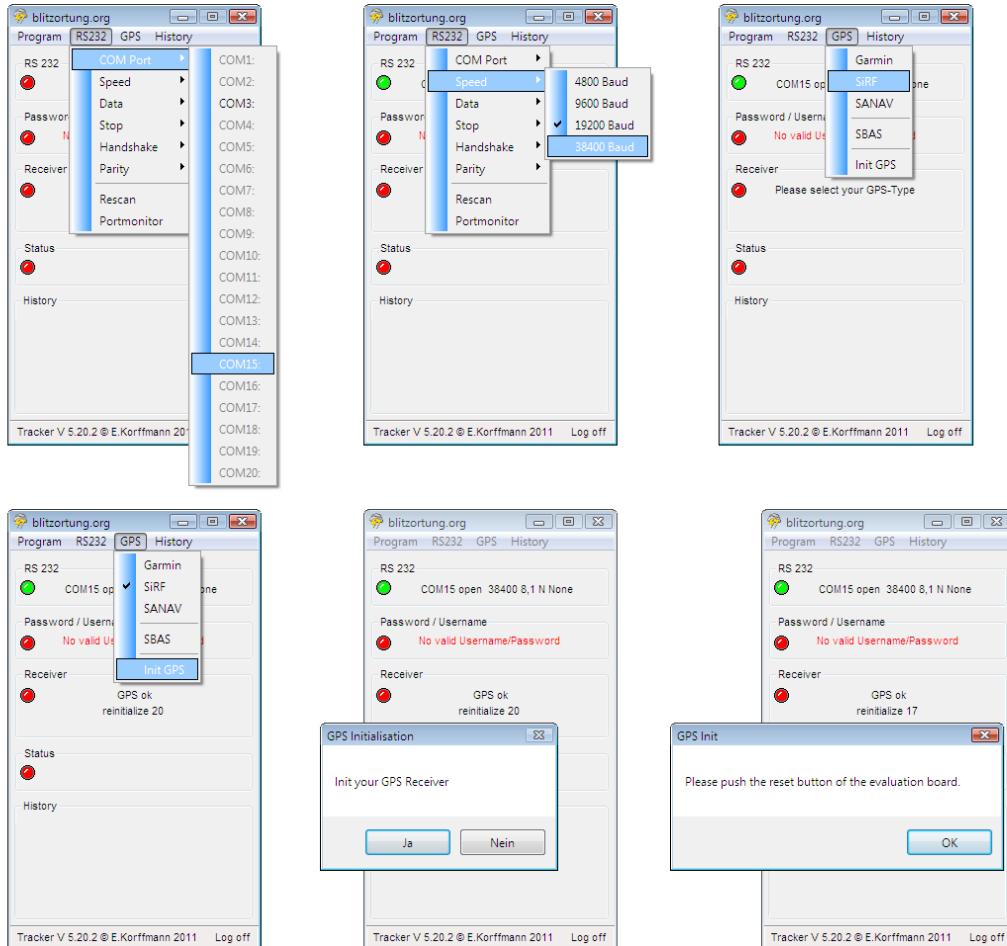


Figure 64: The initialization of the serial connection and the GPS device

Next you should insert your username and password. The username is the one you got from blitzortung.org. The password is the one you have chosen by yourself. The tracker program will not accept the password you initially got from Blitzortung.org. You have to select a new own password.

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 program window will disappear from

³Unfortunately, the USB controller board 6 Version 7 has a layout error which do not allow to reroute the output of the GPS device to the output of the board by turning the yellow jumpers. This is corrected in Version 7b.

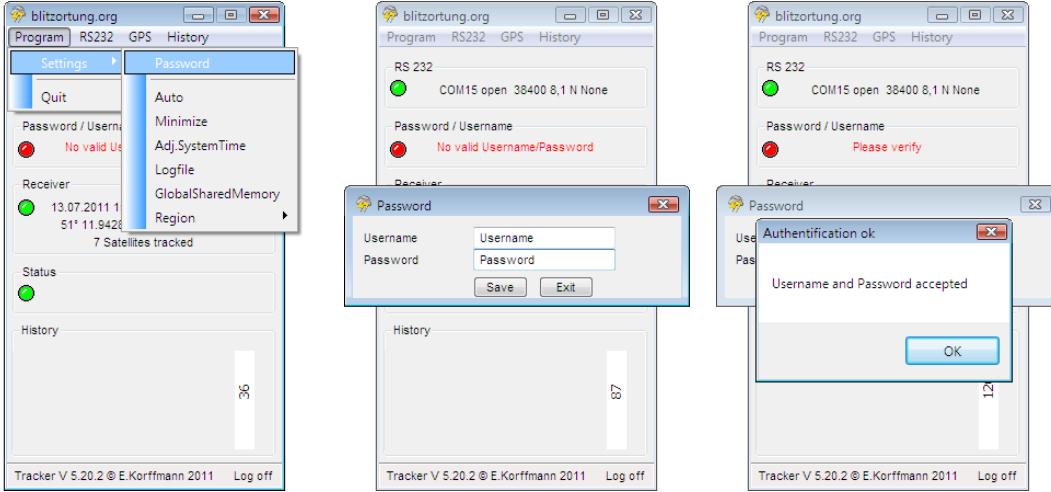


Figure 65: Inserting the password and user name

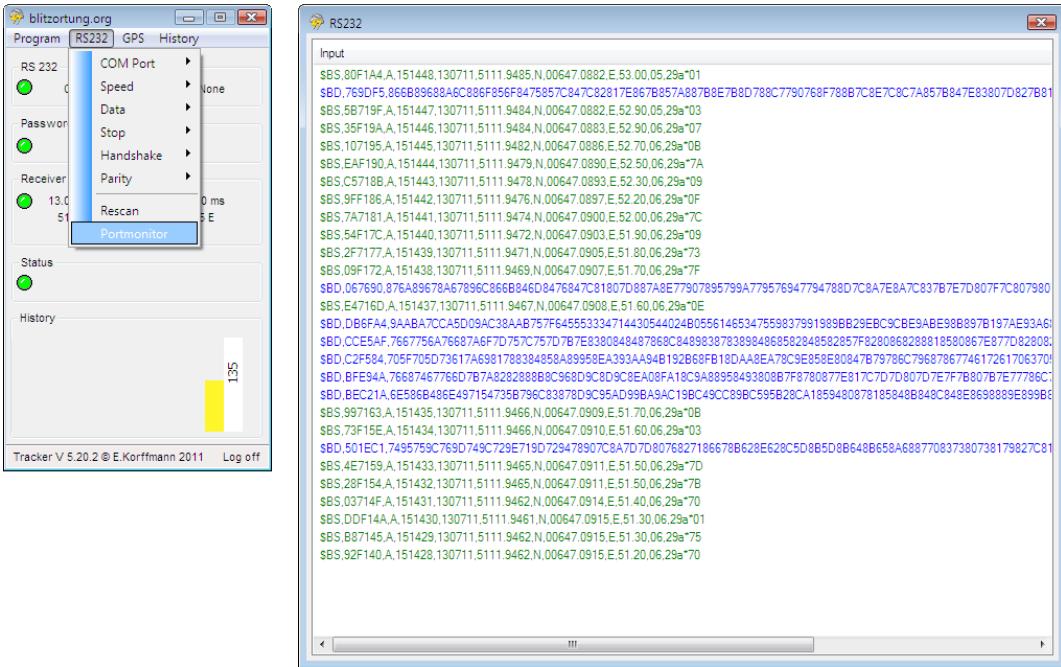


Figure 66: The port monitor

the desktop and move to you tool bar. The "Logfile" flag activates log file output, and the "Adj. System Time" option allows to synchronize the local clock by the GPS time. The "Region" menu is used to distinguish between different computing servers for different continents. At the time this document is written, there is only one region, Region 1, for Europe. Different setting for the History window can also be chosen, see Figure 67.

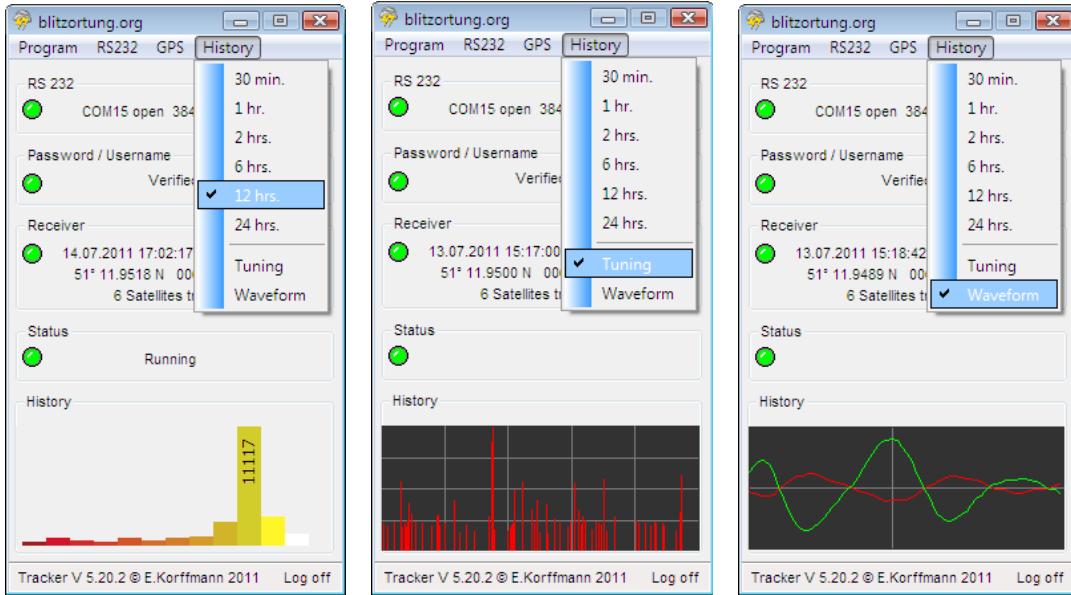


Figure 67: Different settings for the history window

6.2 The official tracker program for Linux

The source code of the tracker program for Linux can be downloaded from the "Miscellaneous" page of the "Services" menu of Blitzortung.org. The file `tracker_Linux.c` should be compiled by `g++ -Wall -lm -o tracker_Linux tracker_Linux.c` to the executable `tracker_Linux`. A short description of all options can be listed by starting the tracker program with option "`-h`", see the following screen dump.

```
> g++ -Wall -lm -o tracker_Linux tracker_Linux.c
> ./tracker_Linux -h
./tracker_Linux: [-h] [-L] [-ll file] [-lo file] [-ls file] [-vl] [-vo] [-vs] [-vi] [-e serial_device] [-s]
                  gps_type baud_rate serial_device username password
gps_type          : gps type (SANAV, Garmin, or SiRF ('-' for no initialization))
baud_rate         : baud rate (4800, 9600, 19200, or 38400)
serial_device     : serial device (example: /dev/ttyS0)
username          : username (example: PeterPim)
password          : password (example: s36r67hi)
-h                : print this help text
                  alternative: --help
-L                : write log messages to the system message logger
                  alternative: --syslog
-ll file          : write log messages to file
                  alternative: --log_log file
-lo file          : write board output to file
                  alternative: --log_output file
-ls file          : write sent information to file
                  alternative: --log_sent file
-vl              : verbose mode, write log messages to stdout
                  alternative: --verbose_log
-vo              : verbose mode, write board output to stdout
                  alternative: --verbose_output
```

```

-vs      : verbose mode, write sent information to stdout
-vi      : verbose mode, write system information to stdout
-alternative: --verbose_sent
-vi      : verbose mode, write system information to stdout
-alternative: --verbose_info
-e serial_device : serial device for input echo
-alternative: --echo serial_device
-s      : activate SBAS (WAAS/EGNOS/MSAS) support
-alternative: --SBAS

```

If the tracker is started with option **-vl**, **-vo**, and **-vi** for SiRF GPS devices using 38400 baud, it will create the following output. We have omitted some line from the complete output indicated by dots "...".

```

> ./tracker_Linux -vl -vo -vi SiRF 38400 /dev/ttyUSB0 PeterPim s36r67hi
2011-07-15 19:00:46, PID: 11524, tracker started
2011-07-15 19:00:46, PID: 11524, $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
$PSRF100,1,38400,8,1,0*3D
$PSRF151,00*0E
2011-07-15 19:00:46, PID: 11524, initialize GPS with SiRF, 38400 baud, using 38400 baud, please wait!
2011-07-15 19:00:49, PID: 11524, initialize GPS with SiRF, 38400 baud, using 19200 baud, please wait!
2011-07-15 19:00:51, PID: 11524, initialize GPS with SiRF, 38400 baud, using 9600 baud, please wait!
2011-07-15 19:00:54, PID: 11524, initialize GPS with SiRF, 38400 baud, using 4800 baud, please wait!
2011-07-15 19:00:57, PID: 11524, Ready!
$BS,B85DD4,A,192315,150711,5111.9575,N,00647.0819,E,39.20,06,29a*77
$BS,DDDDDC,A,192316,150711,5111.9574,N,00647.0820,E,39.40,06,29a*05
122880 lat: +0.000711, lon: +0.000094, alt: +0.0, acc: -19000000000 nsec, sat: 6
2011-07-15 19:00:58, PID: 11524, GPS status changed from '-' to 'A'
$BS,035DE3,A,192317,150711,5111.9573,N,00647.0821,E,40.40,06,29a*0F
245761 lat: +0.002133, lon: +0.000283, alt: +0.0, acc: -8999997966 nsec, sat: 6
2011-07-15 19:00:59, PID: 11524, GPS seconds running, 16 17
$BS,28DDEB,A,192318,150711,5111.9568,N,00647.0821,E,42.60,06,29a*03
368641 lat: +0.004266, lon: +0.000565, alt: +0.0, acc: -5666667571 nsec, sat: 6
...
$BS,A65E6B,A,192335,150711,5111.9545,N,00647.0805,E,63.40,07,29a*7B
2457608 lat: +51.199256, lon: +6.784684, alt: +54.2, acc: +224 nsec, sat: 7
2011-07-15 19:01:17, PID: 11524, Position fixed, lat: +51.199256, lon: +6.784684, alt: +54.2
2011-07-15 19:01:17, PID: 11524, 1PPS signal accuracy ok, counter: 80DE64 A65E6B, +224 nsec
$BS,CBDE73,A,192336,150711,5111.9545,N,00647.0805,E,63.40,07,29a*0F
2457608 lat: +51.199256, lon: +6.784684, alt: +54.2, acc: -183 nsec, sat: 7
$BS,F15E7A,A,192337,150711,5111.9544,N,00647.0806,E,63.30,07,29a*7E
2457608 lat: +51.199256, lon: +6.784684, alt: +54.2, acc: +224 nsec, sat: 7
$BS,16DE82,A,192338,150711,5111.9544,N,00647.0807,E,63.30,07,29a*0D
2457608 lat: +51.199256, lon: +6.784684, alt: +54.2, acc: -183 nsec, sat: 7
$BD,1E213B,6B806D82708275807B7F817F848185818480827E827F7C7E797F777E797C7C7E8080827F ... 817F*0F
$BS,3C5E89,A,192339,150711,5111.9545,N,00647.0810,E,62.70,07,29a*03
2457608 lat: +51.199256, lon: +6.784684, alt: +54.2, acc: +203 nsec, sat: 7
...

```

It is recommended to write a start/stop script for directory **/etc/init.d/** and/or **/etc/rc2.d**, such that the tracker will start automatically after a reboot. An example of

such a start script for Debian and Ubuntu Linux distributions can also be found on the "Miscellaneous" page.

The tracker program can easily be installed on a router running the OpenWrt operating system. This reduces the costs and additionally saves energy. OpenWrt is a Linux distribution for embedded devices. A list of currently supported devices can be found here <http://wiki.openwrt.org/toh/start>. You have to pay attention that the router has a serial interface or an USB port, if you are using PCB 6 Version 7. We have tested the low cost wireless router D-Link DIR-825 available in Germany for approximately 90 €. The router can easily be configured as a client in a local network.



Figure 68: Controller board PCB 6 Version 7 connected to a D-Link DSR-825 router running OpenWrt as a client bridge

6.3 The interference mode

The **interference mode** is used to reduce the amount of improper data send to the server. The tracker program enters the interference mode if it receives for more than 10 seconds every second at least one lightning data. If this happens, it is assumed that the major part of the received signals are not lightning data but interferences. During the interference mode, no further data are send to our server. The tracker program leaves the interference mode immediately after it receives no data for at least one second.

7 Location method and accuracy

The TOA (time of arrival) lightning location technique is based on the computations of **hyperbolic curves**. The emitted radio signal of a lightning discharge is traveling through the air with the speed of light. This is approximately 300000 kilometers per second, or equivalently, 300 meters per microsecond. Each received signal gets a time stamp. Let $t_A(s)$ be the time stamp for signal s from station A . Time stamp $t_A(s)$ is the Coordinated Universal Time (abbreviated UTC) in microseconds with an accuracy of $\pm 1\mu s$. The difference of two time stamps for the same signal received by two different stations and the positions of these two stations define a hyperbolic curve. Let $d_A(p)$ be the distance of a point p to station A in meter. Then the hyperbolic curve for signal s , is the set of all positions p whose distance difference $d_A(p) - d_B(p)$ in meter corresponds to the time stamp difference $t_A(s) - t_B(s)$ in microseconds converted by the speed of light into meter. That is,

$$d_A(p) - d_B(p) = (t_A(s) - t_B(s)) \cdot 300.$$

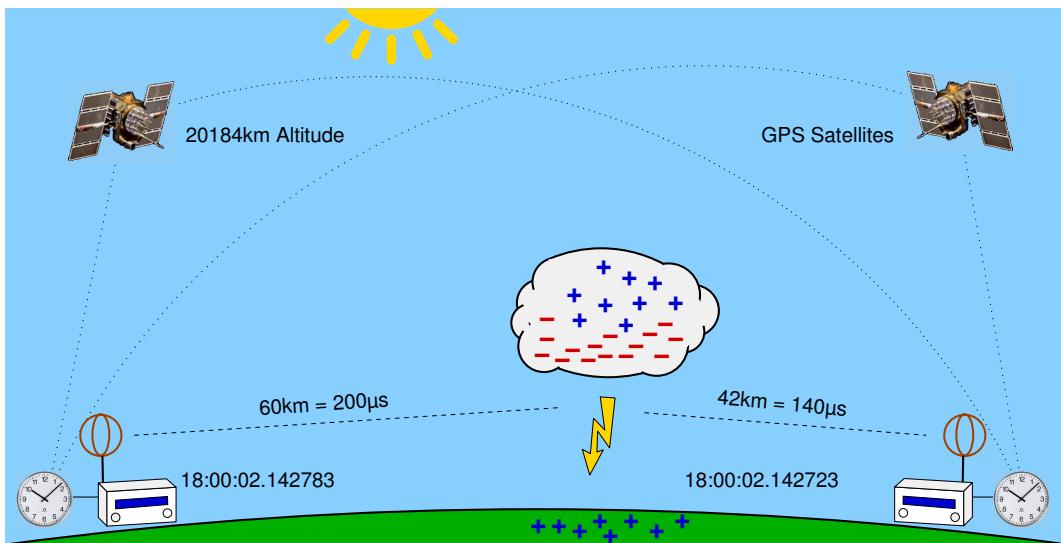


Figure 69: The receiver to the left receives the lightning signal $60\mu s$ later than the receiver to the right, because the lightning discharge is 18 kilometers more far away from the receiver to the left than from the receiver to the right.

The source of the signal has to be somewhere on this hyperbolic curve. The intersection point of three or more such hyperbolic curves defines the unique location of the source of the radio signal, see Figure 70. The computed position is then assumed to be the location of the lightning discharge. At least 4 sites not on a line are needed to define always a unique intersection point. With more than four receiving stations reporting a

time stamp for the same signal there is some redundant information available to improve the accuracy and to verify the performance.

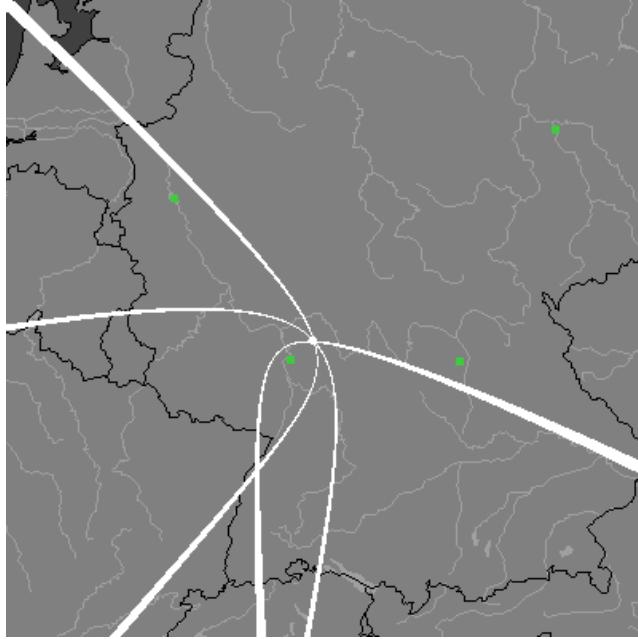


Figure 70: Three hyperbolic curves defined by the three time differences $t_B(s) - t_A(s)$, $t_C(s) - t_A(s)$, and $t_D(s) - t_A(s)$ of four sites A , B , C , and D (the green squares). The intersection of all three curves uniquely defines the location of the source of the radio signal (the white dot). The curves have a width corresponding to a tolerance of $\pm 5\mu s$. That is, the white area for signal s received by station A and B is the set of all points p for which

$$(t_A(s) - t_B(s)) \cdot 300 - 5 \leq d_A(p) - d_B(p) \leq (t_A(s) - t_B(s)) \cdot 300 + 5.$$

A time difference of ± 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 $\pm 1\mu s$ 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 $\pm 300m \cdot \sqrt{2} = 424m$. It can be much greater if the source of the signal is outside the square, see Figure 71. The argumentation of some commercial providers that their system has an accuracy of ± 300 meters, because the time stamp has an accuracy of $\pm 1\mu s$, is a naive fallacy.

The main challenge of a TOA lightning location system is to assign the received signal a unique characteristic time stamp. This is not easy, because the outline of the signal changes when it travels over long distances. One way to handle different signal forms, is to compute a time of group arrival, see [DBR02]. However, if the time stamps are

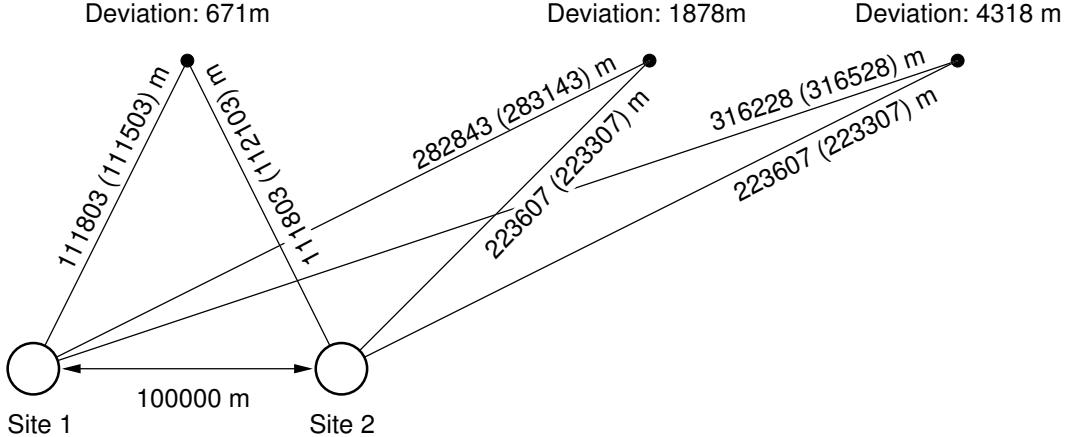


Figure 71: The deviations for an accuracy of $\pm 1\mu s$ for different cut angles

not consistently assigned, the hyperbolic curves do not intersect in a common intersection point. A collection of several nice papers about lightning detection can be found in [BSL09].

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 4 time stamps. After that a numerical method is used to minimize the sum of all squared distances to the hyperbolic curves. All our computations use spherical coordinates.

Figure 72, 73, and 74 show a comparison of the positions computed by blitzortung.org and "Blids" over Germany, Belgium, and Poland. Blids is a lightning information system in Germany. Figure 75 shows the used color code for the age of the discharges.

References

- [DBR02] R.L. Dowden and J.B. Brundell and C.J. Rodger. VLF lightning location by time of group arrival (TOGA) at multiple sites. *Journal of Atmospheric and Solar-Terrestrial Physics*, 64(7):817-830, 2002.
- [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.

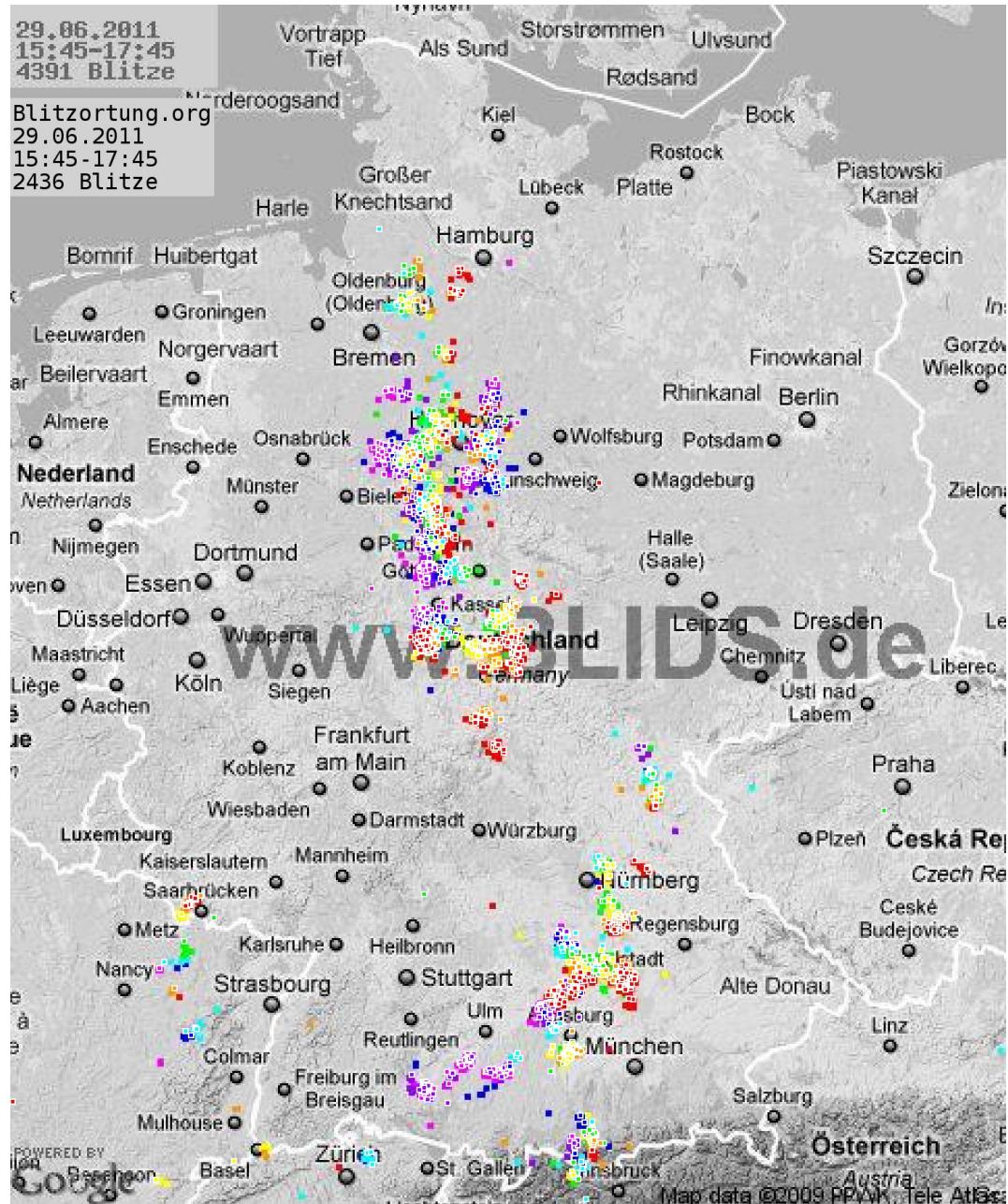


Figure 72: A comparison of the positions computed by blitzortung.org (the white framed colored squares) and Blids (the colored squares) in Germany

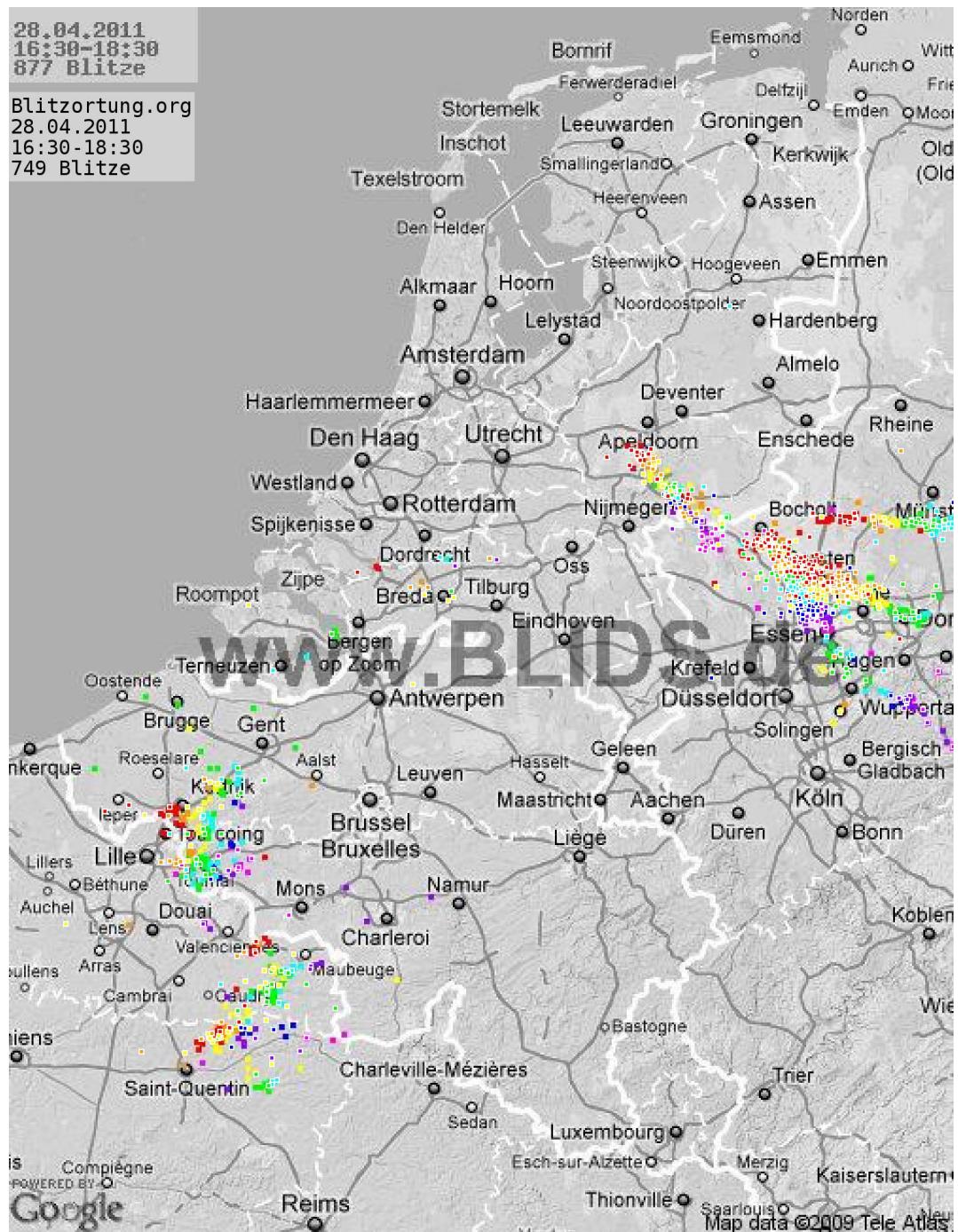


Figure 73: A comparison of the positions computed by blitzortung.org (the white framed colored squares) and Blids (the colored squares) over Belgium, the Netherlands, and Luxembourg

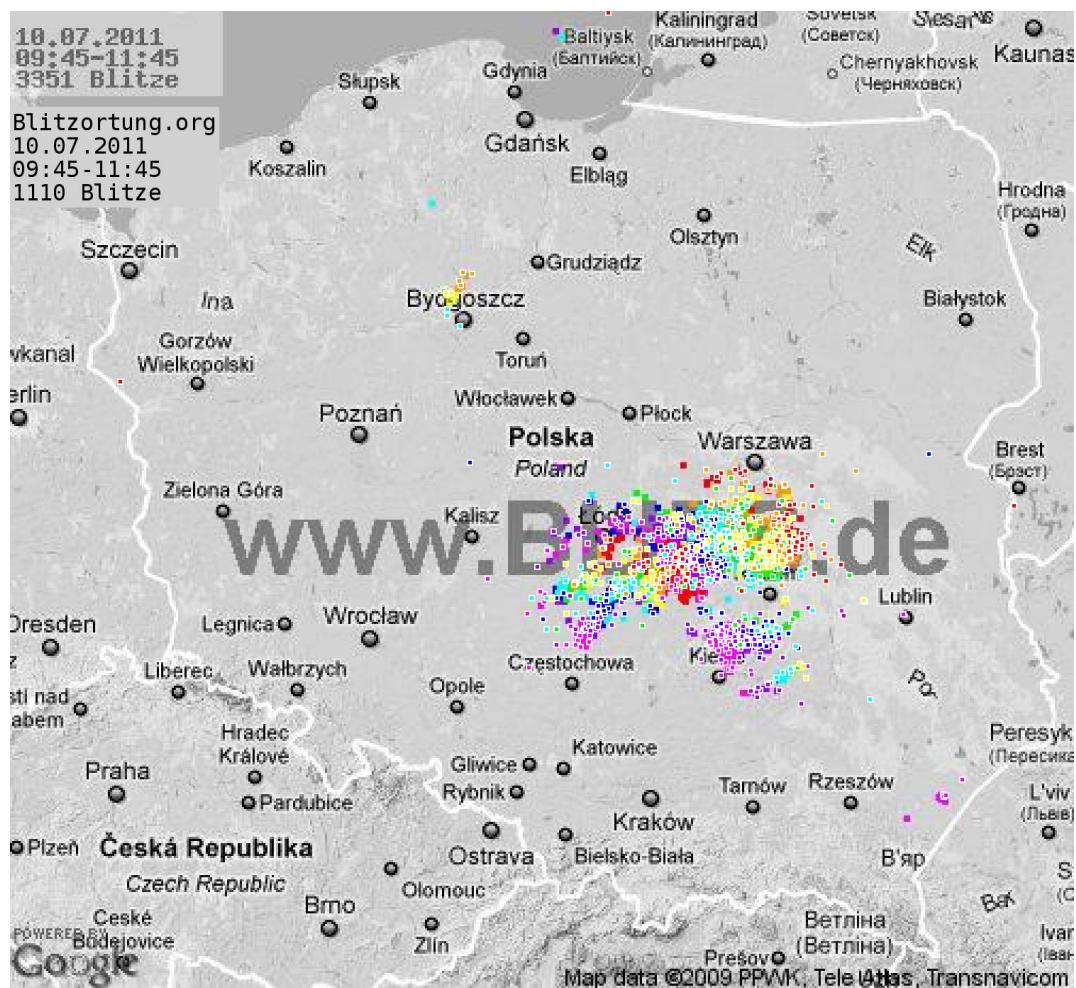


Figure 74: A comparison of the positions computed by blitzortung.org (the white framed colored squares) and Blids (the colored squares) over Poland

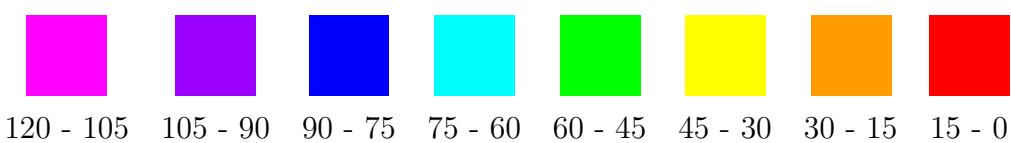


Figure 75: The Blids color code for the age of the lightning discharges in minutes

8 Prices and how to get the material

We only offer the two PCBs and the programmed ATMega644 micro-controller. We do not offer completely assembled kits. You have need 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 your country. In exceptional cases, we deliver complete kits (not assembled) if the parts are very difficult to get in certain countries. In this case, we sell everything at cost prices without profit-making intentions. We only sell parts to persons who promise to take part to the network. You will receive our bank account information and PayPal address 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 13, 14 and Table 15 show the prices for the parts of the complete kits for PCB 5 Version 7, PCB 6 Version 6 and PCB 6 Version 7 in Germany at the time this document was written.

The prices for shipping the kits from Germany are

7,00	€	with DHL (max 5 kg)	within Germany
17,00	€	with DHL (max 5 kg)	to European countries (European Union),
30,00	€	with DHL (max 5 kg)	to European countries (not EU)
35,00	€	with DHL (max 5 kg)	to USA/Canada, and
40,00	€	with DHL (max 5 kg)	to all over the world.

Additionally you need a GPS device providing a 1PPS output, for example, the EM-406A module for approximately 40 €, and a VLF antenna, for example, a ferrite rod or a loop antenna. Suitable ferrite rod antennas can be obtained from <http://www.sfericsempfang.de>, order number SKS 200 BL (approximately 22 €each).

Please remember: Blitzortung.org is a community of volunteers with noncommercial interests. We spend our free time to buy the necessary parts here in Germany, pack them into a parcel, and ship it to you. We do all this just as a favor, there is no extra charge. Since we are no salesmen, we do not write invoices for the material and service (only on occasional exception, if the users will try to get back the appropriate amount through official channels).

If you want to build your own station, first write an email to the author of this document.

Part	approximate Price
Semiconductors	
4× NE5534	4× 0,40 €
1× 1N4001, rectifier diode	1× 0,05 €
1× LED, 5 mm, red	1× 0,10 €
Σ	1,75 €
Capacities	
3× 330 µF, 16 V, electrolytic 8×11 mm, pitch 3.5 mm	3× 0,10 €
1× 100 µF, 16 V, electrolytic 5×11 mm, pitch 2.5 mm	1× 0,10 €
13× 100 nF, ceramic, pitch 2.5 mm	13× 0,10 €
6× 22 nF, ceramic, pitch 2.5 mm	6× 0,10 €
8× 100 pF, ceramic, pitch 2.5 mm	8× 0,10 €
4× 47 pF, ceramic, pitch 2.5 mm	4× 0,10 €
Σ	3,50 €
Inductors	
3× 330 µH, ferrite, pitch 5 mm	3× 0,50 €
Σ	1,50 €
Resistors	
2× 1 MΩ, metal 1%	2× 0,10 €
12× 100 kΩ, metal 1%	12× 0,10 €
4× 47 kΩ, metal 1%	4× 0,10 €
2× 10 kΩ, metal 1%	2× 0,10 €
2× 6.04 kΩ, metal 1%	2× 0,10 €
2× 2.37 kΩ, metal 1%	2× 0,10 €
9× 1 kΩ, metal 1%	9× 0,10 €
4× 82 Ω, metal 1%	4× 0,10 €
4× 47 Ω, metal 1%	4× 0,10 €
Σ	4,10 €
Further material	
1× PCB 5 Version 7	1× 10,00 €
1× RJ45 jack, 8 ways, shielded	1× 0,60 €
1× DC jack, PCB, 2.1 mm	1× 0,20 €
1× Jack socket, PCB, 3,5 mm	1× 0,25 €
2× Terminal block, PCB, 3 way, pitch 5 mm	2× 0,30 €
4× IC socket, 8 ways	4× 0,20 €
1× Pin header, 14×40 pins	1× 0,25 €
20× Jumper	20× 0,10 €
1× Power Supply, 12 V, stabilized	1× 6,00 €
Σ	20,70 €
Σ	<u><u>31,55 €</u></u>

Table 13: Approximate prices of the parts for the amplifier kit PCB 5 Version 7 including a power supply

Part	approximate Price
Semiconductors	
1× ATMega644-20PU	1× 6,50 €
2× AD7813	2× 8,85 €
1× LM339	1× 0,20 €
1× MAX232	1× 0,45 €
1× 78S05	1× 0,40 €
4× 1N4001, rectifier diode	4× 0,05 €
1× LED, 5 mm, red	1× 0,10 €
1× LED, 5 mm, yellow	1× 0,10 €
1× LED, 5 mm, green	1× 0,10 €
1× LED, 5 mm, blue	1× 0,30 €
Σ	26,05 €
Capacities	
2× 330 μ F, 16 V, electrolytic 8×11 mm, pitch 3.5 mm	2× 0,10 €
1× 100 μ F, 16 V, electrolytic 5×11 mm, pitch 2.5 mm	1× 0,10 €
6× 4.7 μ F, 100 V, electrolytic 5×11 mm, pitch 2.5 mm	6× 0,10 €
7× 100 nF, ceramic, pitch 2.5 mm	7× 0,10 €
2× 15 pF, ceramic, pitch 2.5 mm	2× 0,10 €
Σ	1,80 €
Inductors	
1× 330 μ H, ferrite, pitch 5 mm	1× 0,50 €
Σ	0,50 €
Resistors	
11× 10 k Ω , metal 1%	10× 0,10 €
2× 2 k Ω , metal 1%	2× 0,10 €
1× 1 k Ω , metal 1%	2× 0,10 €
2× 330 Ω , metal 1%	2× 0,10 €
Σ	1,60 €
Further material	
1× PCB 6 Version 6	1× 10,00 €
1× Crystal, 19,660800 MHz	1× 0,30 €
1× RJ45 jack, 8 ways, shielded	1× 0,60 €
1× DC jack, PCB, 2,1 mm	1× 0,20 €
1× Straight Header Connector jack, 6 ways	1× 0,25 €
5× Header Connector plug, 6 ways	5× 0,25 €
1× Pin header, 1×40 pins	1× 0,25 €
12× Jumper	12× 0,10 €
2× Mini switch	2× 0,15 €
1× Sub-D plug, PCB, 9 ways	1× 0,35 €
1× Cooling device, TO220	1× 0,50 €
1× IC socket, 40 ways	1× 0,65 €
3× IC socket, 16 ways	3× 0,35 €
1× IC socket, 14 ways	1× 0,30 €
1× Connection cable, Sub-D, 9 ways	1× 2,00 €
1× Network cable, RJ45/RJ45, 10 m, CAT5	1× 3,00 €
1× 1 m ribbon cable for shielding ferrite rod antennas	1× 2,00 €
Σ	24,20 €
Σ	54,20 €

Table 14: Approximate prices of the parts for the controller board kit PCB 6 Version 6 including connection cables

Part	approximate Price
Semiconductors	
1× ATMega644-20PU	1× 6,50 €
1× Breakout Board for FT232RL USB to Serial	1× 12,00 €
2× AD7813	2× 8,85 €
1× LM339	1× 0,20 €
1× 78S05	1× 0,40 €
1× 1N4001, rectifier diode	1× 0,05 €
1× LED, 5 mm, red	1× 0,10 €
1× LED, 5 mm, yellow	1× 0,10 €
1× LED, 5 mm, green	1× 0,10 €
1× LED, 5 mm, blue	1× 0,30 €
Σ	37,45 €
Capacities	
3× 330 μ F, 16 V, electrolytic 8×11 mm, pitch 3.5 mm	3× 0,10 €
2× 4.7 μ F, 100 V, electrolytic 5×11 mm, pitch 2.5 mm	2× 0,10 €
7× 100 nF, ceramic, pitch 2.5 mm	7× 0,10 €
2× 15 pF, ceramic, pitch 2.5 mm	2× 0,10 €
Σ	1,40 €
Inductors	
1× 330 μ H, ferrite, pitch 5 mm	1× 0,50 €
Σ	0,50 €
Resistors	
11× 10 k Ω , metal 1%	11× 0,10 €
2× 2 k Ω , metal 1%	2× 0,10 €
1× 1 k Ω , metal 1%	1× 0,10 €
2× 330 Ω , metal 1%	2× 0,10 €
Σ	1,60 €
Further material	
1× PCB 6 Version 7	1× 10,00 €
1× Crystal, 19,660800 MHz	1× 0,30 €
1× RJ45 jack, 8 ways, shielded	1× 0,60 €
1× DC jack, PCB, 2.1 mm	1× 0,20 €
1× Straight Header Connector jack, 6 ways	1× 0,25 €
5× Header Connector plug, 6 ways	5× 0,25 €
1× Pin header, 1×40 pins	1× 0,25 €
6× Jumper	6× 0,10 €
2× Mini switch	2× 0,15 €
1× Cooling device, TO220	1× 0,50 €
1× IC socket, 40 ways	1× 0,65 €
2× IC socket, 16 ways	2× 0,35 €
1× IC socket, 14 ways	1× 0,30 €
1× Connection cable, A-/Mini-B-USB	1× 2,00 €
1× Network cable, RJ45/RJ45, 10 m, CAT5	1× 3,00 €
1× 1 m ribbon cable for shielding ferrite rod antennas	1× 2,00 €
Σ	22,90 €
Σ	63,85 €

Table 15: Approximate prices of the parts for the controller board kit PCB 6 Version 7 including connection cables

9 Acknowledgement

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