Hardware for a WWLLN site

Introduction

The World Wide Lightning Location Network (WWLLN) consists of about 25 (eventually 50) lightning receiver sites in operation around the world. Each of these sites transmits to a central processing computer (CPC) the precise (to within a few microseconds) time of arrival at that site of the lightning strike impulse ("sferic"). With this information from all sites, and the exact (to within a few hundred metres) position of the sites, the position of lightning strikes throughout the world can be located to within a few km and within about ten minutes of the lightning striking.

Anyone in any country anywhere can build a lightning receiver to *detect* lightning from as far away as 10,000 km, but *location* of lightning by time of arrival requires at least five lightning receiver sites surrounding the lightning. Lightning radiation is strongest at about 10 kHz (30 km wavelength). At such frequencies, sferics travel across the world in the waveguide formed by the ionosphere base above and the ground (mainly ocean) below. Thus the receiving sites can be several thousand km apart, the optimum being 3,000 km.

The WWLLN is an association of all the receiving site operators who pool their data to enable world-wide lightning location. All such receiving site operators (mainly universities and research institutes) receive lightning stroke locations from the entire world on monthly compact disks (CDs) in return for pooling their data. This world-wide data, received some 2 – 6 weeks after the event, is fine for research or to compare with other phenomena. Individuals or bodies involved in prediction (e.g., severe weather) need "real-time" lightning data for which they pay according to the time, latitude and longitude windows required. This is the only source of funding to WWLLN and helps to fund direct expenses but not salaries.

There is no political restriction on membership of the association (WWLLN). It is not directly funded by any government. The people who keep the WWLLN in operation and keep the CPCs going are volunteers from different countries. In many ways, the WWLLN is like the WWW (World Wide Web), and uses the Web (as the Internet) to get the data from the sites. It is truly international. There is no membership fee and no membership contract: if a site stops pooling its data, WWLLN stops providing the processed data (the world-wide lightning location).

If evenly spaced at the optimum distance of 3000 km from site to site, the number required to cover the whole world is about 50, the number we aim for. This is nearly twice the number WWLLN has in operation at present, which are not ideally sited either, making "holes" in which lightning, if present, is not surrounded by a minimum of 5 active WWLLN sites and so is not located. We are anxious to fill these holes as we get the opportunities and finance to do so.

With limited finance we are able to lend all the hardware, including the computer and antennas, for sites of particular importance to the WWLLN. When either the WWLLN no longer requires the data, or the site operator is no longer able to provide it, the hardware is to be returned. However, many of these sites have import restrictions which make the loan unfeasible or impossible. For these we require that the site operators build their own lightning receivers. Nearly all the parts required can be obtained in the country of the site concerned.

Before you start!

If you go to much trouble and expense, only to discover that your equipment and resources are inadequate, you will be disappointed. You need to have us check at every stage.

Internet access

WWLL is "real-time". The arrival time of every sferic is transmitted on the Internet to the central processing computers (CPCs) in New Zealand and America *immediately*. The data packet containing this and the sferic energy must arrive at the CPCs within seconds. The sferic occurrence, and so the rate of data packet transmission, is about 300 per minute. The adds up to a total transmission of about 2 GB per month. This requires a permanent connection with a permanent IP address (not dynamic) to the Internet.

Before making and buying any hardware, including the computer, borrow a computer (linux, UNIX or Windows) with a permanent IP and give us an account ("wwlln") on it so that we can test the Internet and data transfer speed. The computer for testing need not be that planned for WWLL.

Adequate site

WWLLN sensors use VLF electric field antennas which can be used in built-up (urban) regions such as university and research institute campuses, provided they are mounted on the roof of buildings not overshadowed by other antennas or wires or conductors (even trees!), or by nearby buildings which are taller. Ideal VLF electric field antenna locations are near an edge or corner of the roof of a tall building, away from other antennas, metal masts or flag poles, and overhead wires. If you can test the VLF electric field in suitable sites within reach of your Internet access, so much the better, but in any case:

Please send photographs from your choice of the VLF antenna site in all directions (panorama). This means that there must be sufficient photographs to show all 360º with some overlap. This panorama should show a clear view to the horizon with no obstructions more than 10º above the horizon. Include one or two photographs of a person standing where the VLF antenna is intended to be placed. The camera should be 30m (100ft) or so from the person standing where the VLF antenna is intended to be placed so that we can see where it is to be relative to the building edge and other items on the roof.

VLF hardware to be obtained or built

Most people interested in VLF lightning location have VLF broad band receivers, VLF antennas, and VLF pre-amplifiers for these, or else they have colleagues with this experience. It is possible you have adequate VLF hardware already, so I will describe the VLF hardware you will need.

VLF antenna: Most VLF researchers use loop antennas, usually as orthogonal crossed loops for magnetic direction finding. However, WWLLN requires omnidirectional (in azimuth) antennas, so uses vertical “whip” antennas which are sensitive only to the VLF electric field and so can be used in built up areas such as university campuses. Thus you must use a vertical “whip” antenna. *Constructing the VLF antenna is described near the end of this document.*

VLF preamplifier: For a vertical “whip” antenna you need to build a preamplifier having a high input impedance since the antenna impedance is almost purely capacitive at about 15 pF, which corresponds to an impedance at 10 kHz of 1 MΩ. We use a 1-MΩ resistor across the input of a very fast op-amp (AD744) set for a gain of 10. This acts as a high pass filter with a corner frequency of 10 kHz and so reduces power line interference. Note that the preamplifier must be directly connected to the antenna to avoid feeder capacitance shorting out the antenna capacitance. The preamplifier ground plane and case (if conducting) should be directly connected to the support pole (if metal), and nearby metal railing, roofing iron, etc., but *never* to the electric mains ground.

You are welcome to use our design for this.

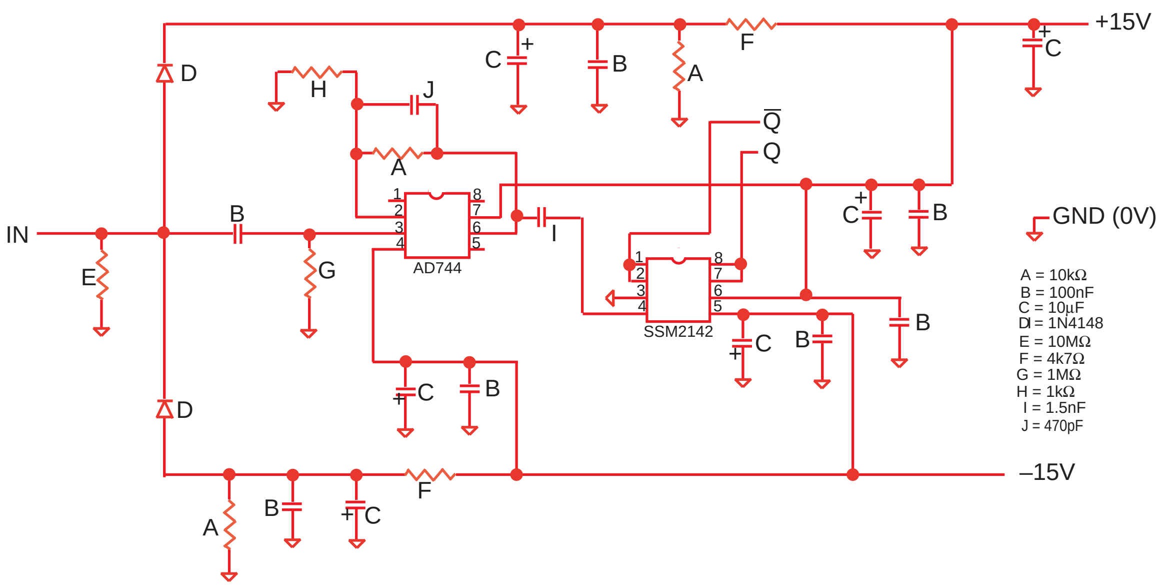

Fig. 1. Circuit diagram of preamplifier in EPS (Encapsulated Postscript) for best printing.

The two following pages show the Printed Circuit Board (PCB) in making. On the left is the negative for making the PCB using photo-sensitive, single-sided board. On the right is a photograph (actually a scanned image) of the PCB complete with all components. These components are identified by upper-case letters (as in Figure 1) added to the scanned image afterwards. The 4 polar capacitors marked “C” must be mounted the right way around. The positive pin is marked “+”. This is on the left for both polar capacitors in the top half of the picture. The two polar capacitors on the left in the lower half are rotated 90º with respect to those in the upper half. The positive pins are those towards the top of the picture.

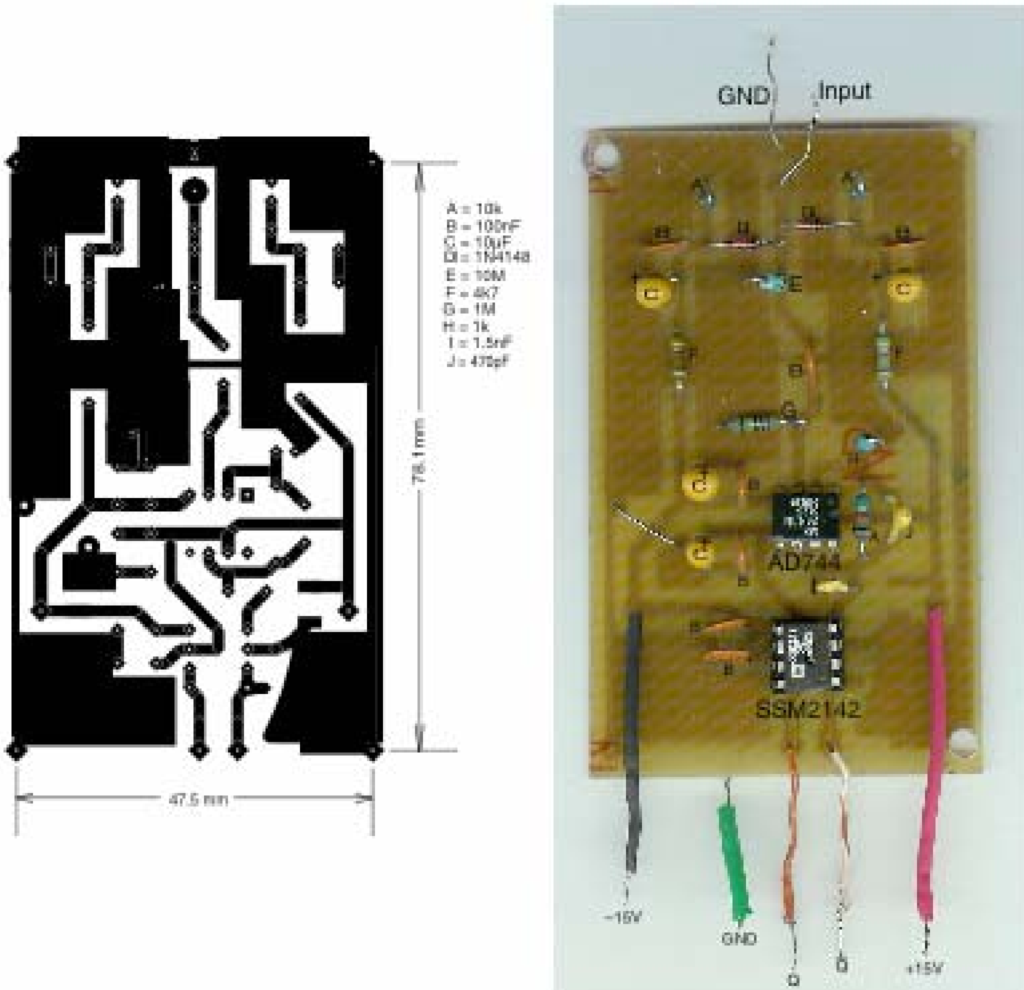

Fig. 2a. This image is the pdf version which is best for viewing on your computer screen. The VLF input is direct from the antenna or via a <u>very</u> short (< 100 mm ~ 4 inches) coax cable. The input and ground (coax sheath, if used) are the bare wires at the top of the picture. You may wish to use a low pass filter to reduce strong signals from the radio AM band and above (TV, etc). We use a simulated transmission line using only series resistance (R) and parallel (shunt) capacitance (C) in the form RCRCRCRCRCRCRCRCRCR (9 stages) where R = 18 kΩ and C = 2 pF.

The output is 2-phase ("push-pull"). The orange wire marked "Q" is the in-phase ("push") signal. The orange/white wire (Q-bar) is the anti-phase ("pull") signal. Input power is +15 V (red wire) and –15 V (black wire). The ground wire (green wire marked GND) is both the PCB ground and power zero V.

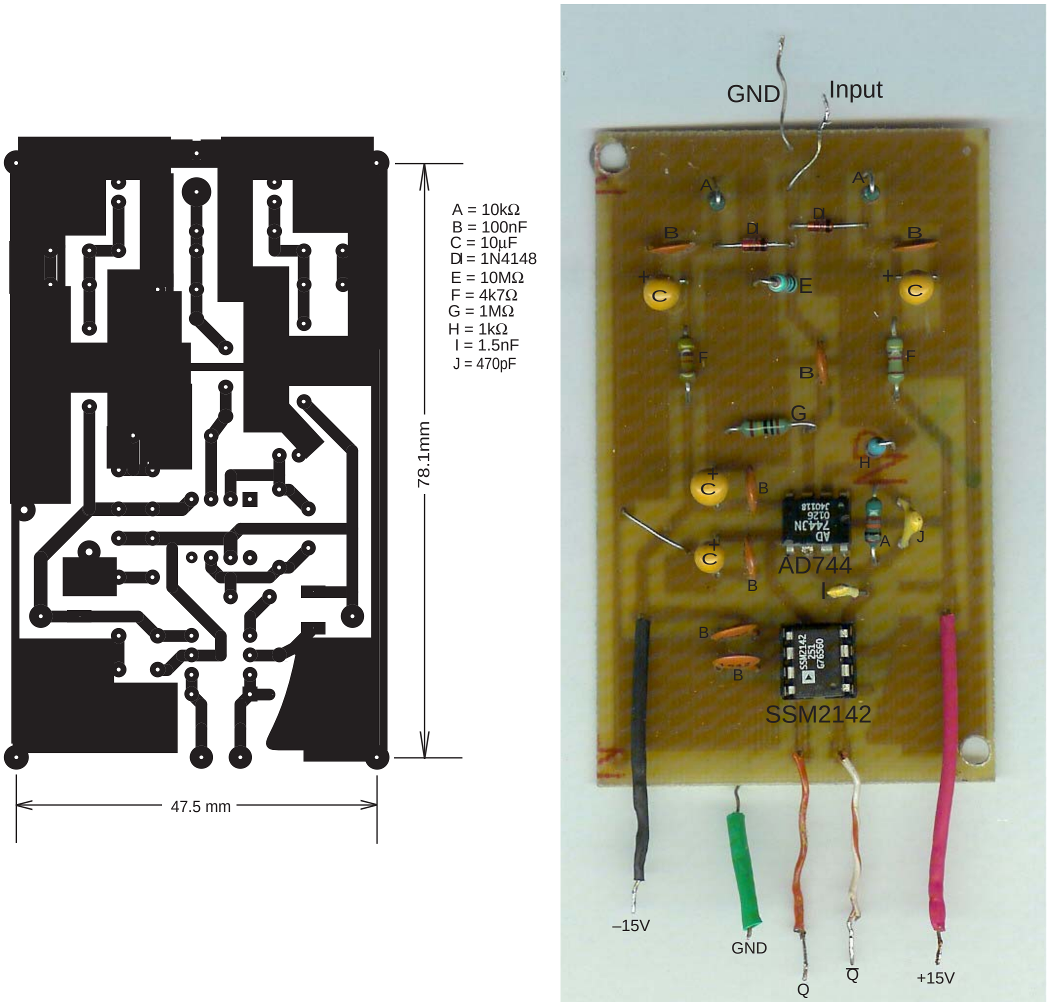

Fig. 2b. This image is the EPS (Encapsulated Postscript) version which is best for printing. It is essential to use this for printing the PCB negative to make the PCB by photo etching. On my laser printer, the two dimensions marked 78.1 mm (= 3.075 inches) and 47.5 mm (1.87 inches) are slightly (1%) larger at 79 mm and 48 mm. This is trivial for a single sided PCB with only two ICs which have only 8 pins. Note that the “land,” at 10 mm from the left hand edge and 25 mm from the bottom edge, is an “island” and must be connected to the other ground lands as shown in the image of the completed PCB as a bare wire on the upper surface of the board.

We follow the AD744 by a unity gain balanced line driver (SSM2142). The computer end of the line is fed to the sound card via a 1:1 audio transformer. The latter can be a toroidal wound power transformer having two low voltage windings.

Preamplifier power supply. This should be isolated from the computer ground. It is usually adequate to connect the power supply "common" line only to the preamplifier ground (green wire in Figure 2). If you use a toroidal wound power transformer as above in the power supply, you can expect 5 kV isolation between windings.

Computer. A Pentium III or better, with a sigma-delta stereo sound card capable of sampling at 48 kS/s and 32 kS/s (not both at the same time!), is adequate. The sigma-delta stereo sound "card" can be incorporated on the computer logic board ("mother board) or be a separate card, but it must be sigma-delta. Starting with an empty hard disk, install the latest version of "free" Red Hat linux. Name the computer "togaxyz" where "xyz" is a pronounceable word of 3 or more letters identifying your institute or city. Choose the root password to contain UPPER and lowercase letters as well as numerals. You must set a "sudo" with full root privileges with a secure password. <u>It is extremely important that you do not forget the sudo password!</u> The root password can be sent to us by email since we will change it immediately.

GPS signals. Since world wide lightning location (WWLL) depends on precise timing of the sferic arrival at a site and the precise position of the site, we require two GPS signals. One is the GPS "word" in RS232 which tells the computer the Universal Time (UT) to the nearest second as year, month, day, hour, minute and second; and the site location in latitude and longitude in degrees and minutes. This "word", in NMEA code, is fed into the computer via the COM port. The other GPS signal is the 1 pulse per second (PPS) which is fed into the computer via the sound card as one of the stereo channels (the other being the broad band VLF containing the sferics).

The hardware to provide these GPS signals normally consists of the GPS antenna, a GPS "engine" which outputs the PPS and NMEA as TTL, and the circuitry to change the NMEA into RS232. However, all these functions are performed in a single unit, the GM-44 "head" shown below:

Fig. 3. The GM-44 GPS head itself is in the middle above. It is designed for mobile use in a car, with this head on the roof and projecting through it. To the right is the thing which screws onto the head from inside the car. On the left is the 8-pin miniDIN male plug with metal locking ring.

This plugs the cable into the head. For further details, visit:
http://www.sanav.com/gps_receivers/gps_locators/gm-44.htm

The GM-44 GPS head comes with 5 meters of cable ending in a DB9 plug for a PC COM port. Attached to the DB9 plug is a short (1 meter) cable ending in another plug containing a DC/DC converter which is plugged into the car's cigarette lighter socket. This plug is shown on the right of Fig. 4 below:

Fig. 4. On the left is a line socket (not supplied) for the plug which you will need to provide if you wish to use the plug with its built-in DC/DC converter which provides +5 V output for GPS head. The input voltage on the red twin cable on the extreme left above can be anywhere between 7 V to 35 V.

This GM-44 was originally intended for location, not timing, so although the GPS head provides the 1pps output, it is not connected to the DB9 unless specifically requested, in which case it will be connected to pin 1 of the DB9. However, you need the 1pps to go through the Delta 44 sound card, not into the COM port, so you need to make the "zero length extender" shown in Fig. 5 below:

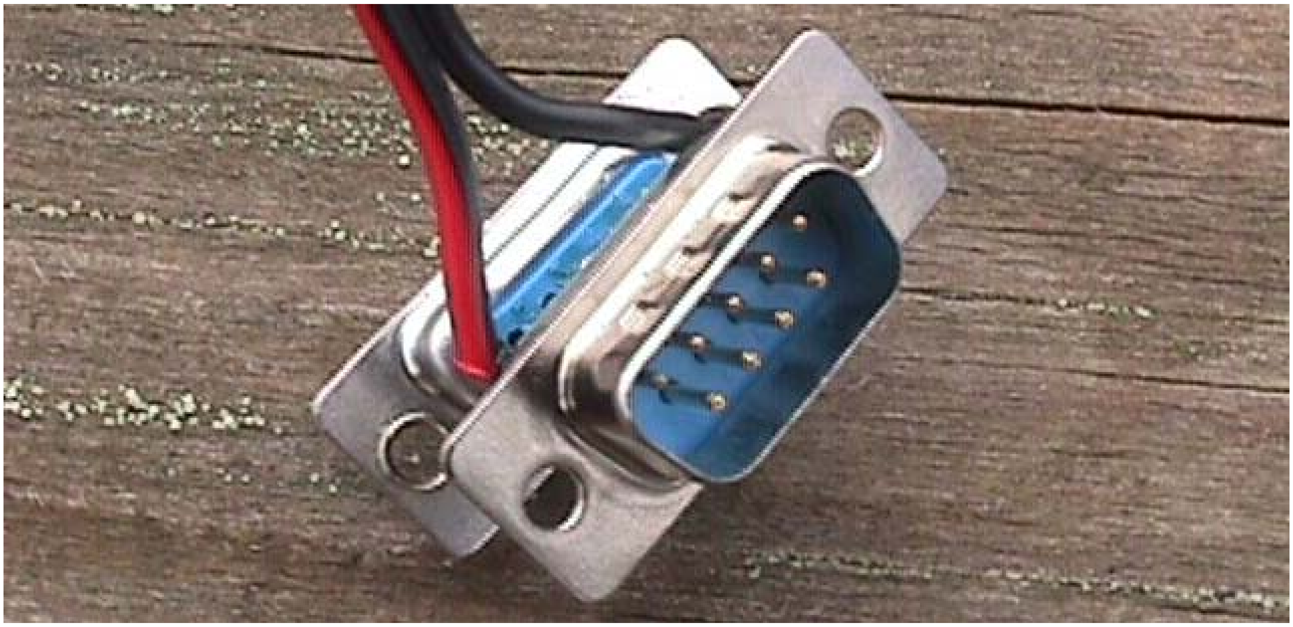

Fig. 5. This consists of a female DB9 and a male DB9 soldered back to back by the pins. Only pins 1 to 5 (upper row) need to be soldered. The male DB9 seen facing you above plugs into the female DB9 at the end of the GPS head cable. The female DB9 (facing away) plugs into the PC COM port directly or via an extender cable. The red/black conductor above, connected to pin1, together with the ground conductor (all black above) connected to pin 5, goes to the Delta 44 input #1 via an attenuator to reduce the PPS voltage from about 16 V_{pp} to about 6 V_{pp}. A 1.2 kΩ resistor in series with a 680 Ω resistor to ground is suggested.

The cost of the GM-44 head with cables and plugs is about US$220 plus freight.

Permanent installation. While the modifications above (using a “cigarette lighter” socket and making the “zero length extender” to access the 1pps signal) is adequate for initial testing, you may want a neater arrangement for a permanent set-up, particularly if you need more than 5 meters from the GPS head to your computer. Extending the supplied cables is messy because three extra cables are needed: a DB9/DB9 extender, a twin cable to the PPS and a twin cable for the DC/DC converter plug. We now describe a neater system which uses only the GM-44 head itself.

As indicated in the block diagram, you will end up with a 5-conductor cable from the GM44 GPS head to a small junction box near the PC. The length of this cable can be as long as you require, probably as much as 100 m, maybe more. This is because only low frequency signals travel in the cable. Since one of the 5 conductors is ground, the cable can be shielded quad or 2-pair, provided all conductor are identifiable (e.g., have different colours).

Connection to the GM44 is via an 8-pin miniDIN male plug you need to provide and put on the cable.

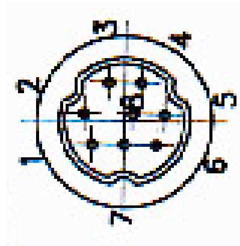

Fig 6. Front of the 8-pin miniDIN male plug. The pins appear in clockwise order (1 to 7) viewed from the front of the plug already connected to the cable so that the pins are facing you. Note that pin 8 is not in the centre but displaced to the right (towards pin 5).

You can check this interpretation by looking into the plug on the cable supplied with the GM-44. However, for the **permanent installation** described here, you do not need any of the cables supplied with the GM-44. In fact, you may be able to buy the GM-44 GPS head without any cables at a lower price.

Viewed from the **back** of the plug when soldering to the cable, the pins appear in anticlockwise (ACW) order (1 to 7).

The 8-pin miniDIN male plug is the only special plug you need which may be hard to find. The local shop in my town stocks them, but does not have the locking ring seen on the plug on the left in Figure 3. I found the locking ring was not important provided there is no significant tension on the plug.

First slide the soft plastic cover off the 8-pin miniDIN male plug. If you were able to find a 8-pin miniDIN male plug with locking ring, thread the ring onto the cable first, followed by the soft plastic cover. If the cable is too thick for the thin end of the soft plastic cover, cut off some or all of the rings of plastic at the thin end. The soft plastic cover with some of the rings removed is shown on the far left of Figure 7 below.

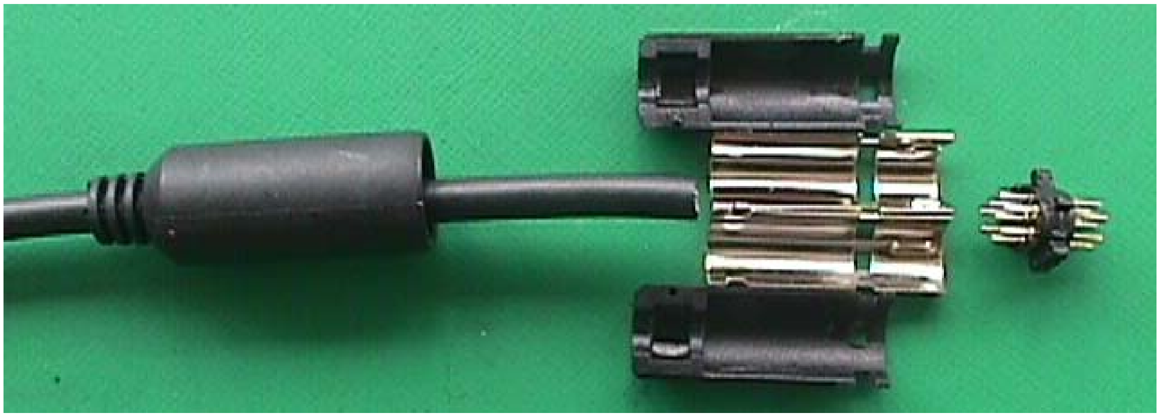

Fig 7. 8-pin miniDIN male plug disassembled, showing the soft plastic cover pushed onto cable. The metal halves are inside the hard plastic halves. The join of the former is turned 90º to the latter. The halves are reassembled after the cable is soldered to the pins and tested. In the meantime, I suggest you coat the inside of the metal halves with a thin layer of protective lacquer in case the metal halves touch a conductor.

Only 5 of the 8-pin miniDIN male plug are connected. These are shown in Figure 8:

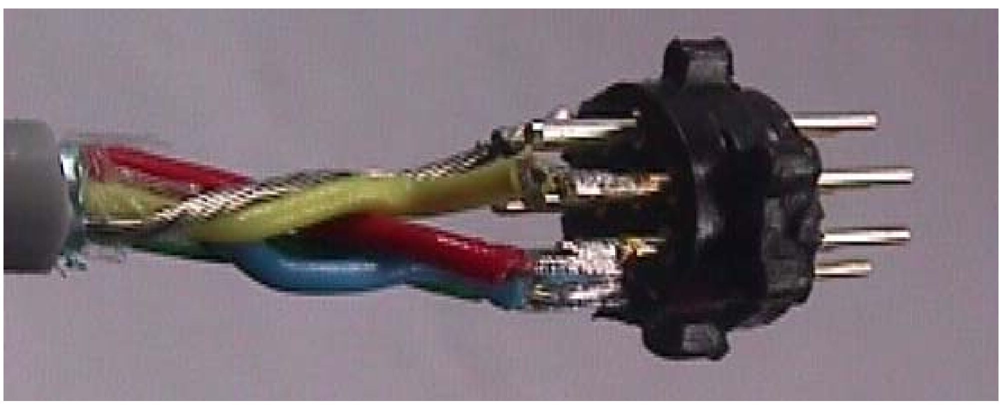

Fig. 8 showing the 5 cable wires soldered to the 8-pin miniDIN male plug. These are:

Pin 1 = TXA, which is the NMEA signal, is hidden in Figure 8.

Pin 2 = RXA (blue in Figure 8)

Pin 3 = +5 V for powering the GM-44 head (red in Figure 8)

Pin 4 = PPS (yellow in Figure 8)

Pin 5 = n/c = no connection (appears in Figure 8 with no wire)

Pin 6 = Ground (bare wire in Figure 8)

Pin 7 = n/c = no connection (appears in Figure 8 with no wire)

Pin 8 = n/c = no connection (appears in Figure 8 with no wire)

I suggest you leave the 8-pin miniDIN male plug disassembled until you have completed most of the junction box in the next section for easier testing of continuity and possible shorting. Retest after reassembling the 8-pin miniDIN male plug.

Junction box

This can be any size. It can be made of any material, conducting or non-conducting. I used a small (58x63x35 cm) polycarbonate box obtained locally. Polycarbonate is easy to work (drill holes, etc) but melts very easily if touched accidentally by your soldering iron. There is no need to copy my design. A slightly larger box would be better. The one I made is shown below (Figure 9).

Fig 11. The junction box was photographed twice to show all 4 sides. The female DB9 (labelled “To COM”) is mated with the COM port on your PC (via an extender cable). The other three (“GPS”, “+5V”, “PPS”) connectors are your choice, provided you have mating plugs. I chose connectors requiring round holes which are easier to drill. I will deal with these in order:

“GPS” The cable from the GM-44 GPS head plugs into this. I chose a 5-pin DIN socket and so used the corresponding plug. MiniDINs having 5 or more pins are smaller and have material less likely to melt during soldering.

“+5V” This is from your power adaptor (a small power supply like a large power plug which plugs directly into your wall socket). It is for powering the GM-44 GPS head. The current is < 2 mA but the voltage must be regulated. Make sure the plug matches the socket: 2.1 mm and 2.5 mm plugs and sockets look the same!

“PPS” This is the 1 pps output from the GM-44 GPS head. This signal needs to go to the sound card along with the VLF signal. The PPS signal comes from this junction box, whereas the VLF signal comes from the VLF preamplier via the 1:1 transformer. As explained above, the VLF preamplier is mounted with the VLF antenna, far from the 1:1 transformer and isolated power supply which will be in your lab with the computer, etc. The sound card Line Input is stereo and requires a 3.5 mm stereo phone plug. The best way to get the PPS and the VLF signals into the sound card Line Input is via an adaptor cable like that below:

Fig. 10 shows the adaptor cable which is twin shielded wire. Both twin shielded conductors end in the 3.5 mm stereo phone plug. At the other end, the twin shielded conductors are split with each one ending in an RCA plug. In the bottom right hand corner is a converter to convert the RCA plug to a BNC plug. The red RCA plug has one already. If such converters are not locally available, use RCA sockets on the junction box and the output of the 1:1 transformer. On the adaptors I buy here in NZ, the red RCA plug is the one for the PPS.

Fig. 11 shows the junction box wired and with all 4 cables connected. The white component connected (by red wire) to the +5 V input is a fuse which will blow if the power is the wrong polarity. To the right of the junction box is the +5 V adapter. This has a switch mode power supply which provides a regulated 5 volt output. Since the current drawn by the GM-44 is very low, an unregulated power adapter would deliver a much higher voltage which may destroy the GM-44. If you use a multivoltage adaptor like this, it is a good idea to use adhesive tape to prevent accidental setting to a higher voltage.

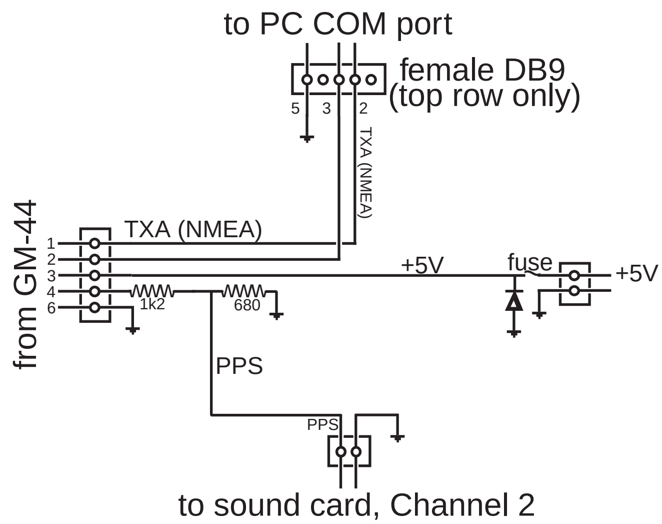

Fig. 12 is a circuit diagram (schematic) of the junction box showing the four sockets (one each side) in the same relative position as in Figure 11. Only the output socket to the PC COM port is specified (it must be a female DB9 to mate with the COM port), so only it has the pin numbers specified. The pin numbers shown on the outside of the 5-pin socket for the plug of the cable from the GM-44 GPS head refer to the pins of the 8-pin miniDIN male plug at the other end of this cable. The wire from pin 2 of the 8-pin miniDIN male plug which connects to the DB9 pin 3 is the RXA. While not used currently, it may be used in the future.

NOTE: The two diagrams, Figures 1 and 12 are EPS (encapsulated postscript) files which show poorly on your screen but very well when printed on a laser printer.

Constructing the VLF antenna

The first few WWLL stations were set by the author personally, using locally available materials to make the VLF antenna. Instead of using four splayed wires inside a plastic pipe, as described later in this section, a single thick cable was used at Singapore (Fig. 13) and at Osaka (Fig. 14), the cable in the latter being looped at the top to reduce the thunderstorm-induced field. At MIT (Fig. 15) we used a large diameter plastic pipe, containing splayed out wires similar to those in Fig. 17, into which the support pipe (copper in this case) fitted. Note the preamplifier, just below the plastic pipe, bound to the support pipe using a metal strap like that supplied. Unlike that in Fig. 21, the tightening screw is on the pipe site as suggested above. It also helps to bend the strap at the corners of the preamplifier. At Tainan in Taiwan (Fig. 16), we used a 3-m length of dry bamboo sealed in heat-shrink tubing onto which we wound the antenna wire. Another form, not shown in the pictures below, used an amateur radio antenna designed for VHF transmission. Note that a λ/4 monopole resonant at 10 kHz would be 7500 m (25,000 feet) tall, so any feasible VLF antenna is a tiny fraction of a wavelength. Thus the dimensions are not critical. However, the antenna impedance is very high (almost pure capacitance at ~ 15 pF) so avoid stray capacitance to ground.

Fig. 13. Singapore

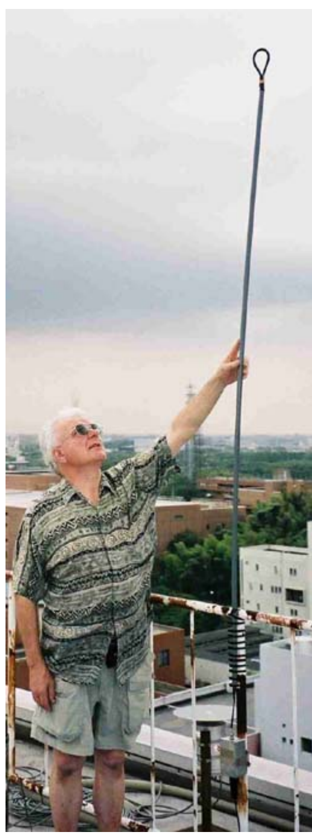

Fig. 14. Osaka,

Fig. 15. MIT Cambridge, USA

Fig.16. Tainan

Fig 17. Antenna top

Fig 18. Antenna bottom

Here is a version which hangs inside a plastic tube. It consists of 2 lengths of wire (6 m each) threaded through a pill bottle as shown in Fig. 17. Choose a 3.5-m plastic pipe with an internal diameter of about 100 mm (about 4 inches) so that the effective width of the antenna is not restricted by the pipe diameter. A larger diameter is OK, but the diameter must be at least 30 mm to fit the pill bottle. The antenna is suspended inside the pipe with the fishing line in the lid as shown in Fig. 17 (the fishing line is barely visible except near the top of the picture).

The bottom ends of the four wires are joined together and attached to the end of a very short length (< 100 mm) of coax cable previously fitted with a BNC (or similar) connector as shown in Fig. 18.

The fishing line holds the pill bottle below the top of the plastic pipe (Fig. 19) when the BNC plug pokes out of the bottom of the plastic pipe (Fig. 16.). The plastic pipe can be fixed to a steel pipe with the 2 supplied cable ties (Fig. 21). The overlap of the steel pipe should be just enough for adequate rigidity because the steel pipe "shorts out" the VLF electric field we want to measure. About 30 cm (1 foot) should be enough. Mount the preamplifier on the steel pipe using an electrician's stainless steel band for very good electrical contact.

Then attach the plastic pipe with the antenna inside, and attach the BNC plug to the preamplifier. Slide the preamplifier up so that the bottom of the plastic pipe rests on the preamplifier to protect the BNC socket from the weather. The fishing line should then be pulled up so the pill bottle is near the top of the pipe, but use a gentle pull so the black wire is not tight because we want it to splay out inside. Jam the end cap on, trapping the fishing line (Fig. 19).


Fig. 19. Cap on antenna pipe to keep rain out and to trap fishing line holding the antenna


Fig.20. Preamplifier slid down to allow antenna BNC connection to preamplifier BNC


Fig. 21 Preamplifier slid up so that antenna pipe rests on the preamplifier

The cap on the antenna pipe (white in Fig. 19), if bought with the pipe, is very close fitting. Do not glue it on, else you will have to cut the pipe with a hack saw if you need to get at the antenna. If you unable to find the proper cap for your pipe, use a jam jar (or a can) and duct (or "Duck") tape to both trap the fishing line and to prevent the jam jar from falling off.

Fig. 20 shows the preamplifier slid down the steel water pipe to expose the bottom of the antenna which ends in a BNC connector. Connect this to the preamplifier then slide the preamplifier back up the steel water pipe so that the BNC connection is fully covered by the antenna pipe.

Fig. 21 shows the antenna pipe strapped to the steel water pipe with the two black cable ties supplied. You could use more than two, but do not use white ones which become brittle in UV sunlight. They should be well separated: one near the top of the steel pipe and one near the bottom of the plastic antenna pipe, **not** as shown here for the photo!

Fig. 21 also shows the stainless steel strap (bright thing pointing to the right) for holding the preamplifier to the steel water pipe. **Before tightening the screw**, make it as tight as possible using hand vices or pliers levered against the pipe or preamplifier. It is probably better to slide the band around so that the screw is on the pipe side. If, after tightening the screw the full amount, the preamplifier is still too loose, you may need to remove the band and the kinks made by the screw to try again.

The stainless steel strap has a second screw for connecting the grounding cable (thick black cable in Fig. 21). This cable should connect to a large expanse of metal such as a safety hand rail around the roof and should **never** be connected to the ground wire of the electrical supply system.

Siting the VLF antenna

Note that all the VLF antennas shown above (Figs 13-16) are mounted on the **edge** of the roof of a tall building. The VLF electric field is much larger at an edge, or (even better) at a corner, than at the centre of a flat roof. The antenna must not be under or even close to other conductors (not even trees) which are grounded at VLF and so tend to shout out the VLF electric field. A passive TV antenna, grounded only to the TV on a floor below, can be a severe source of interference if it is near the VLF antenna.

(END)