Remembering and Honoring Paul Nicholson G8LMD: Passionate VLF Enthusiast and Master
HamSCI Workshop 2026

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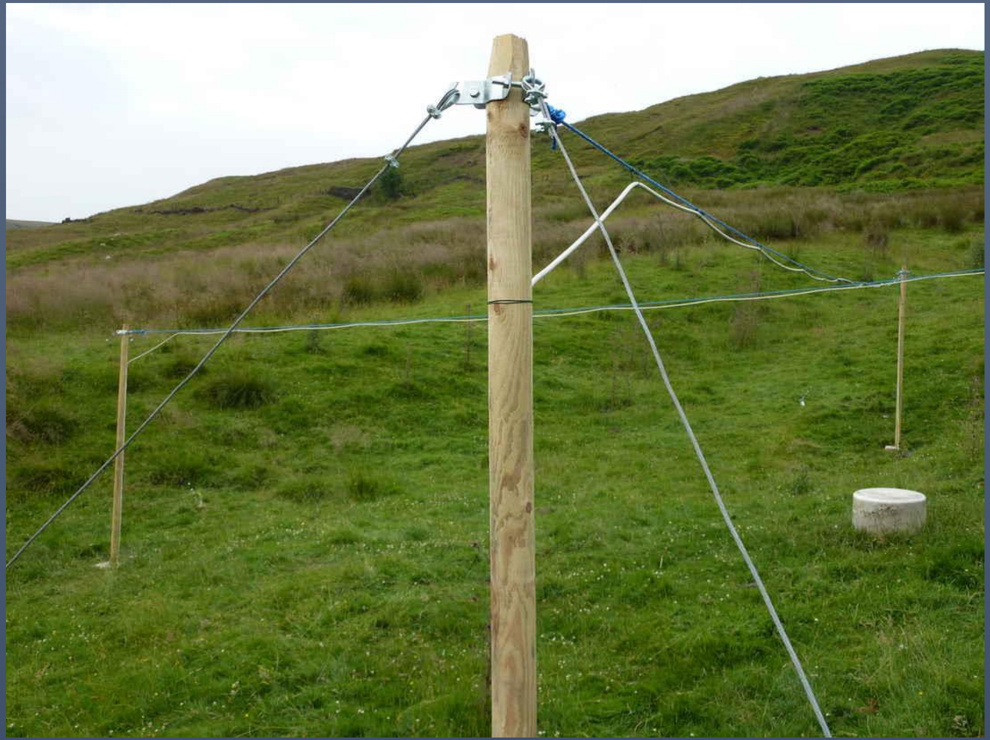
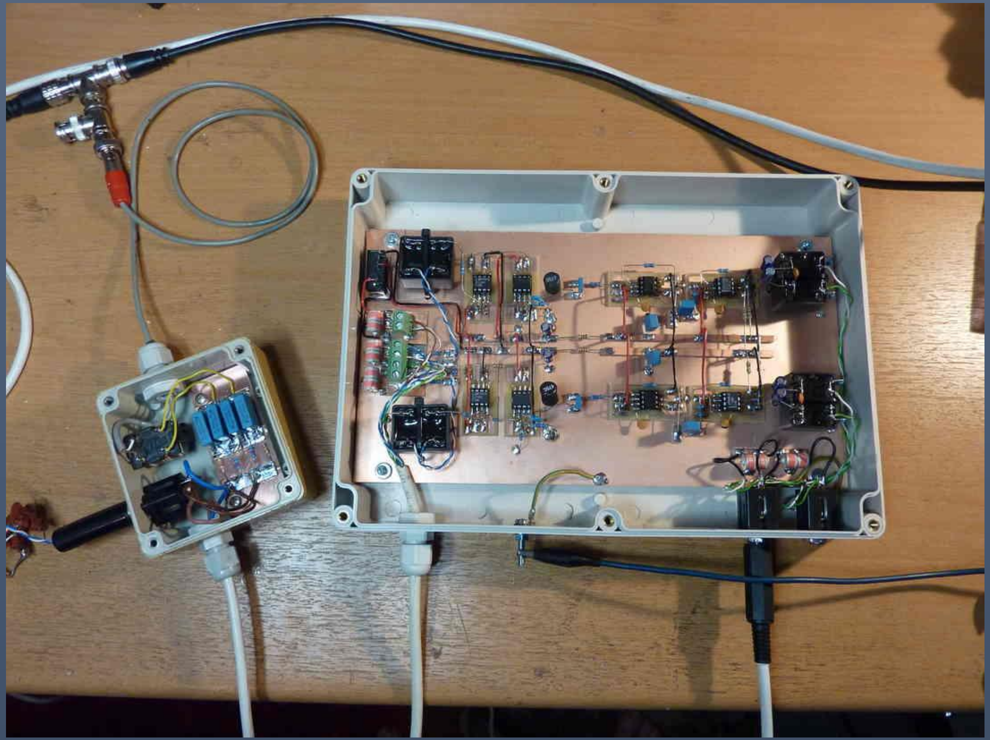
About Paul Nicholson

- Attended Sir Joseph Williamson’s Mathematical School (1970-74) in Rochester, Kent, England.
- Lived in Todmorden, England. Moved to Northumberland in 2024.
- Developed the first VLF reception techniques for amateurs and citizen scientists.
- Author of vlfrx-tools, LCnetgen, EbNaut, EbKey, and EbSynth software.
- Developed the first VLF amateur transmission modes in the 8270 Hz and 5170 Hz bands.
- Developed the Indian Lightning Detection Network, India's first domestic lightning location network that saves thousands of lives.
- Paul used his brilliant mind to make the world a better place. We must continue Paul’s work!

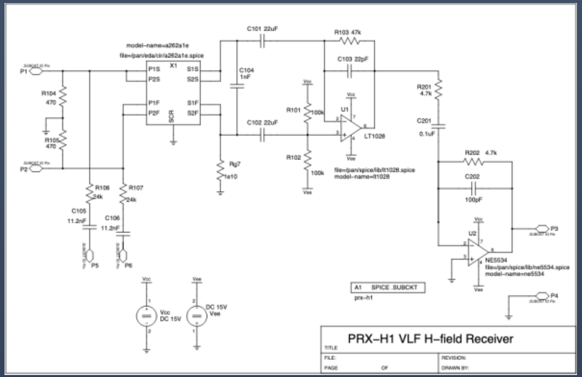
H-field Receiver at Todmorden



H-field Loops



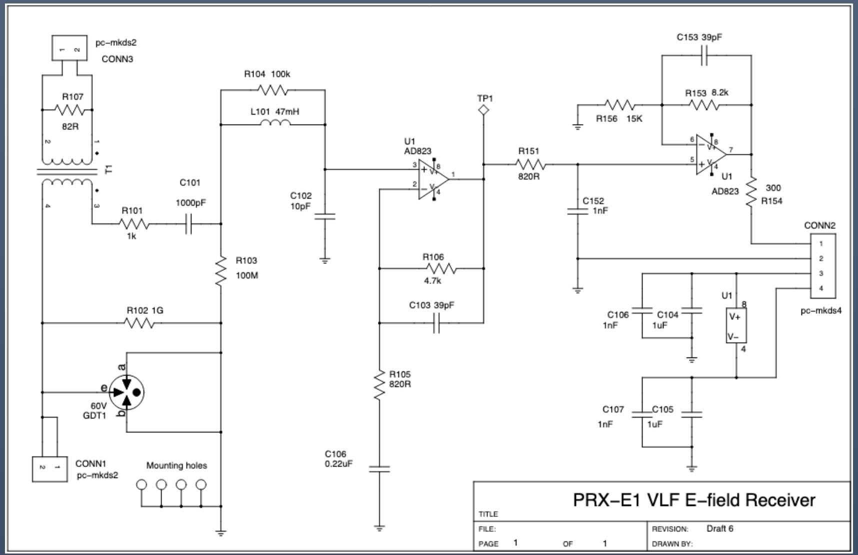
H-field Preamp Frontend, Power Supply, and Line Driver



H-field Preamp Schematic

E-field Receiver at Todmorden

E-field Antenna Installed



E-field Preamp Schematic

E-field Preamp Frontend

Power Supply and Line Driver

vlfrx-tools

VLF Receiver Software Toolkit

A modular software toolkit for timestamped signal processing and storage.

- Command line driven, scripted processing;
- Precision timestamped capture and processing;
- Streamable packeted signal streams;
- Whistler detection;
- Signal database;
- TOGA measurement;
- Linux, FreeBSD, OpenBSD;
- Open source;
- Real-time, post-processing, or simulations;
- Distributed pipelines, built-in networking;
- SID monitoring with phase and bearing;
- Runs on PC, Raspberry Pi, BeagleBone;
- SDR-IQ and RTL2832U;

Designed for VLF radio signal processing, it also has applications for meteor forward scatter, seismographic and natural radioactivity recording, ELF and magnetometers, radio astronomy, bat detection, amateur radio, and other projects which require precision timestamps preserved through signal capture, storage, and post-processing.

The software is suitable for heavy-duty post processing of recorded data, and for remote or headless embedded data capture in industrial and scientific applications.

Download

This software is released under the Simplified BSD license.

Download the latest version: vlfrx-tools-0.9p.tgz.

Documentation

All in a single HTML page, or PDF.

Contact

Maintained by Paul Nicholson, vt12@abelian.org

vlfrx-tools Development

- Paul pioneered VLF reception techniques at home for the VLF amateur and citizen scientist.
- Developed humfilt, an open-source application that uses an active mains tracking filter to filter mains hum and harmonics and actively track their frequency as power line frequency drifts throughout the day.
- Humfilt made it possible to hear these weaker natural radio emissions at home against the background of power line hum.
- Paul would frequently mention that he listened to the VLF band through his sound system, and humfilt made that possible.

vlfrx-tools Input/Output Programs

vtcard: Read data from a soundcard
vtvorbis: Encode/decode to/from ogg/vorbis
vtflac: Encode/decode to/from flac
vtraw: Extract the audio signal from a stream
vtain: Read data from Beaglebone ADCs
vtrtlsdr: Take data from RTL2832U based dongle
vtsdriq: Take data from rfspace SDR-IQ receiver
vtdata: Read data from ASCII source
vtwavex: Extract signal from WAV file

vlfrx-tools Signal Processing Programs

vtcat: Copy input to output
vtmix: Additive mixer
vtmult: Multiplicative mixer
vtfilter: Low pass, high pass and automatic notch filter
vtjoin: Join and align two or more streams
vtresample: Change the sample rate of a stream

vtblank: Impulsive noise blanker
vtgen: Signal generator
vttime: Refine timestamp and sample rate
vtfm: Modulate or demodulate FM
vtam: Analytic magnitude

vlfrx-tools Display and Plotting Programs

vtstat: Display stream info
vtscope: Oscilloscope
vtspec: Spectrum display
vtpolar: Polar display
vtplot: Time domain plotting
vtsidex: SID data extraction
vtsidplot: SID monitor plotting
vtsidgram: Spectrograms from SID monitor
vtsgram: Spectrogram plotting

vlfrx-tools Signal Analyzers

vtcmp: Compare two channels
vtnspec: Narrow band spectrum analyzer
vtwspec: Wide band spectrum analyzer
vtsid: SID detector
vtevent: Whistler/riser event detector
vttoga: Sferic measurements
vtrsgram: Reassigned spectrogram
vtmatch: Matched filter/convolver
vtping: Meteor ping detector

vlfrx-tools Storage and Retrieval/Utility Programs

vtwrite: Write a stream to storage

vtread: Read a stream from storage

vtwait: Wait for data

vtps: List toolkit processes

vttop: Display toolkit processes

vtcardplot: Plot soundcard performance

vttimeplot: Plot timing system performance

vtdate: Timestamp conversion utility

vtspot: Geographic calculations

vtubx: Configure u-blox GPS

vlfrx-tools Documentation

VLF Receiver Toolkit - Notes

For version 0.9p of vlfrx-tools

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Spectrogram plots
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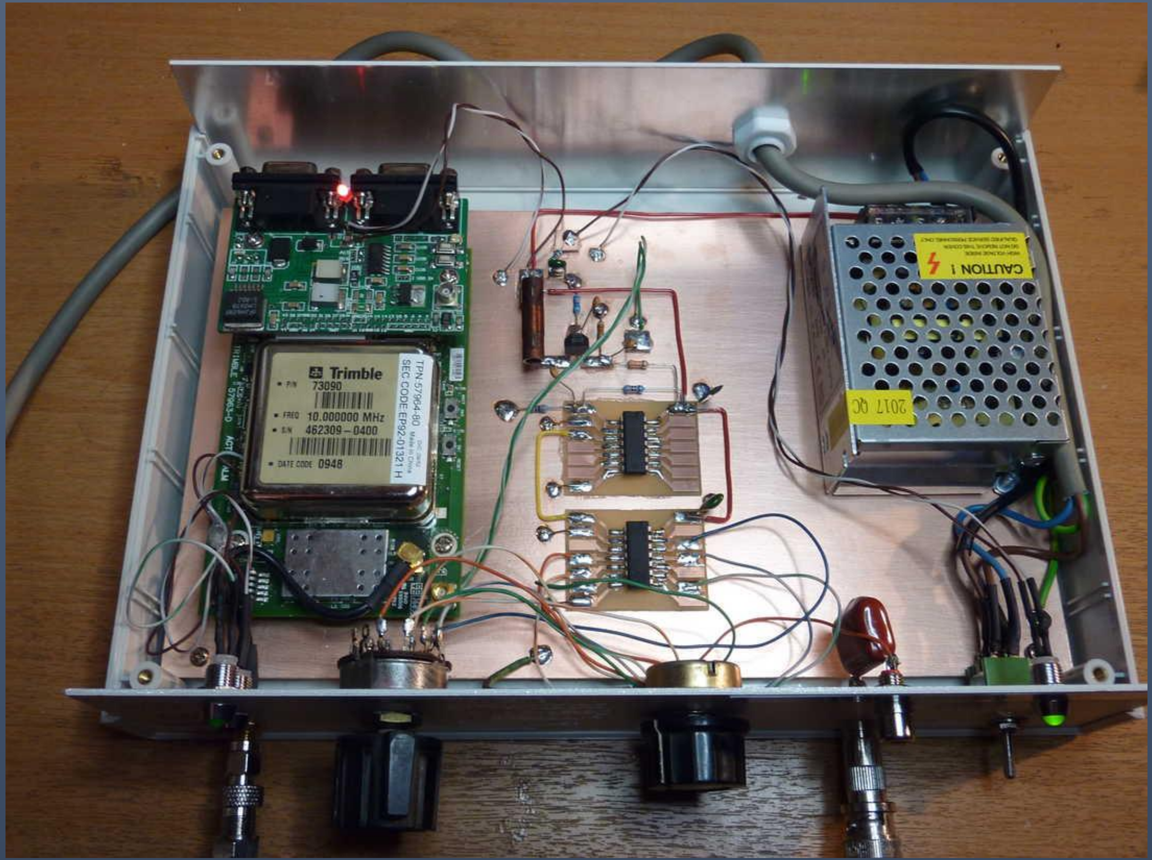
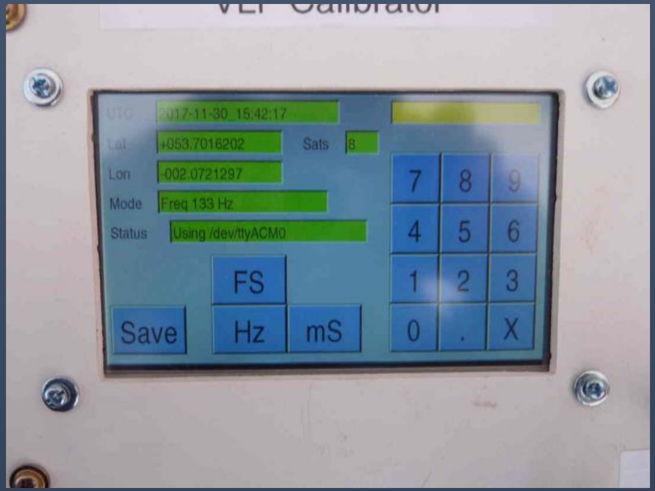
Filtering
Phase equalisation
Antenna synthesis
Polar displays
Analytic signals
Startup scripts
RTL2832U
U-blox GPS
Lightning location

System Calibration and Equipment
GPS Frequency Standard



System Calibration and Equipment: VLF Calibrator



vlfrx-tools VHF meteor scatter

GPS timestamped reception of GB3MBA using RTL-SDR

Using a low cost RTL-SDR TV receiver dongle with vlfrx-tools to monitor meteor pings from the 50.4 MHz beacon GB3MBA, with GPS precision timing using RF timing pulse injection.

Location

Receiver is located near Todmorden UK, 53.703N,2.072W, which is 86km north-west of the GB3MBA beacon.

Antenna

The antenna is a zenith pointing turnstile antenna with a BF245 preamplifier. Located at the top of the woods about 100m from the house and connected via 100m of 75 ohm satellite TV coax. Power to the preamp is supplied at 13V through the coax using a bias T.

The turnstile antenna in axial mode is phased for left-hand circular polarisation for maximum response to meteor head reflection of the right-hand polarised beacon signal, and the circular polarisation gives an omni-directional response to the linearly polarised meteor trail reflections.



vlfrx-tools Lightning Location

Lightning location

Locating the source lightning of sferics involves two programs: `vttoga` to measure the arrival time (and possibly the bearing) of the sferics at at least three sites, followed by `vtspot` to perform the trilateration.

`vtspot` is run on a central computer which receives either baseband VLF signal, or the output from `vttoga` via some network connection. The `vttoga` may be run on the receiver sites themselves, or if the sites send the baseband signal back, it can run on the central computer. The choice depends on the available network bandwidth. If possible it is better to retrieve the VLF signal from the receiver site - it can be used for other purposes and can be monitored for quality.

The process only requires the 'H' records from `vttoga`, but the 'S' and 'T' records can also be returned if required by the application.

It is convenient to process TOGAs in batches of a few minutes duration, using the `-G` option of `vttoga`. For example

```
vttoga -G 300 -i 6 -F 6000,16000 -d /togas @filtered
```

will create a new output file in the /togas directory at every 5 minute UTC boundary, ie HH:00, HH:05, and so on. The output files will have name format /togas/YYMMDD-HHMMSS.

If the `vttoga` are running on receiver sites, the output files will need to be transferred over a network back to a central computer. The best command for this purpose is `rsync`, which uses ssh for transport. The receiver computers should have ssh keys set up so that they will accept login from the central computer without password.

TOGA files can then be transferred periodically, with a command on the central computer such as

```
rsync -a user@site1:/togas/ /togas/site1
rsync -a user@site2:/togas/ /togas/site2
...
```

where /togas/site1 is a site-specific destination directory. The `-a` option is important to preserve the timestamp of the TOGA files. Note that the source directory is terminated with / but the destination is not. The `rsync` command will transfer both completed files and partially completed files.

The retrieved TOGA files must then be presented to `vtspot` running in its 'matching' mode, using `-m` options to specify the TOGA batch file for each site. A typical `vtspot` launch script might look like

```
batch=180501-120500
OPTS=""
for site in $(ls /togas)
do
   file=/togas/$site/$batch
   [ -s $file ] && OPTS="$OPTS -m $site=$file"
done

vtspot -c0.9872 -v -o iso -o ext -f envelop=180 -f nearmax=12e3 -n6 -r1.7 $OPTS > output-$batch
```

The velocity factor of 0.9872 seems to work best for global lightning location.

The TOGA detection threshold at the receiver sites should be set so that the total rate of sferics from all the sites does not exceed about 170 per second. If the aggregate sferic rate is much higher than this, `vtspot` will not be able to reliably determine which sferics belong to which lightning stroke (too many overlaps) and the output will begin to include isolated false solutions randomly distributed over the globe. The `vttoga -r` option can be used to set the average TOGA measurement rate per site.

Successfully located lightning strokes can be listed from the output file by grepping the 'A' records:

```
grep ^A < output-180501-120500
```

and the 'G' records provide a summary of the performance of each site:

```
grep ^G < output-180501-120500
```

The output format of `vtspot` is designed to make it easy to work on the results using simple scripts.

You need a lot of receivers for lighting location to work well. At the very least, vtspot needs TOGAs from six receivers and these should surround your region of interest. Indeed, `vspot` when running in matching mode, will only output a stroke solution if it lies within a polygon formed by at least six receivers.

It often happens that you want to locate the source of a particular sferic. It is usually possible to identify the sferic manually in the VLF recording, especially if it is a prominent sferic associated with something like a TLE. In this case you can often estimate the location using only three TOGAs, which you can determine by running short samples containing the sferic through `vttoga`. The measurement set for `vtspot` would then resemble

```
vtspot T/site1/1522493298.069741 T/site2/1522493298.065848 T/site3/1522493298.069540
```

`vtspot` will always produce two solutions for a case like this because the ATD hyperbolas for the two independent baselines will intersect in exactly two places. In most cases it is clear which is the correct solution.

If you find that `vtspot` produces no output for your measurement set, then it is likely due to one of the arrival time differences exceeding the light travel time of a receiver pair baseline. Re-run with a `-v` option to see which is the problematic baseline. You may find that you have manually chosen a wrong sferic, or a TOGA measurement is poor because the sferic waveform is distorted for some reason, eg receiver overload or a multi-path effect. This often happens with a powerful stroke at short range. Your best option then is to try to measure (from a time domain plot) the earliest arrival time of each sferic, and use those instead of the TOGAs.

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Personal projects

- Todmorden VLF
- VLF live streams
- Spectrogram of 5170 Hz and 8270 Hz amateur band
- VLF software toolkit
- EbNaut, coherent BPSK for VLF
- Recent milestones with amateur radio at VLF
- LCnetgen, quasi-static modelling software
- Meteor forward scatter of GB3MBA using GPS locked RTL-SDR
- RPVLF

External projects

- Gaddings Dam, working to restore and preserve a well-known 19th century earth embankment dam.
- Indian Lightning Detection System, saving lives in India through a free lightning tracking and warning system.
- Mountain rescue search dogs, training the search dogs.

Contact

Paul Nicholson, Email: web0807@abelian.org

Todmorden VLF

Todmorden VLF was a 3-axis general purpose VLF receiver located at 53.703N,2.072W in the small village of Lumbutts on the edge of the moors about 5km south-east of the town of Todmorden in the Pennines. The receiver ran from 2005 to June 2024, with several upgrades of the electronics and software along the way.

The receiver ran continuously, capturing natural radio events and amateur radio activity through a pair of orthogonal magnetic loops and a vertical electric field probe.

The two receivers (electric field and magnetic field) were separately located in open fields bordering the moorland, about 200m apart and at least 150m from the nearest buildings or power lines. Power was supplied at DC by isolated regulating switching converters (at both ends of the feeder cable) and signal downlink was isolated by audio transformers (also at both ends) with connections made through buried armoured CAT5 Ethernet cable.

E-field Receiver

Antenna: Vertical tube 2m x 40mm, fixed on top of a 2m guyed metal pole. Effective height 1.65m, 170813a.jpg;
Pre-amp: AD823, circuit: prx-e1-1.pdf;
Line driver: LT1010, circuit: prx-t1-1.pdf;
System noise density: 40nV/m/root(Hz) at 8kHz;
Construction: Manhattan;
Antenna and pre-amp photos: 171129d.jpg, 171129a.jpg;
Line driver and power supply photos: 171129c.jpg;

The pre-amp was located inside the base of the antenna tube. The line driver and power supply were in a separate box installed several metres away and connected via multi-score screened cable. The power supply receives 48V DC via a cat-5 pair, this was converted to an isolated, filtered and regulated +/- 15V for the pre-amp and line driver.

H-field Receiver

Antenna: Each loop rectangular 20 m^2, 3 turns of heavy duty mains cable, 1.4 ohms, 375uH;
Pre-amp: LT1028, circuit (per channel): prx-h1-sim1.pdf;
Line driver: LT1010, circuit (per channel): prx-t1-1.pdf;
System noise density: 0.15fT/root(Hz) at 8kHz;
Construction: Manhattan;
Antenna photos: 1010111.jpg;
Pre-amp, line driver, power supply: 1020280.jpg;

The power supply receives 48V DC via a cat-5 pair, this was converted to an isolated, filtered and regulated +/- 15V for the pre-amp and line driver.

Cables

The receivers were located at separate sites, about 150 metres (E-field) and 250 metres (H-field) from the house. Cat-5 ethernet cable carries 48V DC and the VLF downlink to/from each site. The VLF pairs were transformer isolated at both ends of the cable. The DC pairs were isolated at both ends via XPpower IP series devices.

A/D Conversion

The three VLF channels went through isolating transformers into three inputs of a four channel Behringer UMC404HD audio interface. The fourth input was supplied with a 10uS 1PPS from a u-blox 7M GPS module.

Signal Processing

All of the signal processing uses vlfrx-tools running on Linux PCs. The UMC404HD was read by vtcard which was sampling at 192k frames/second and gives the data an approximate timestamp derived from the system clock. The program vttime refines the timestamp using the PPS signal in channel 4, to an accuracy of around 50nS. From there, the signal was resampled to various sample rates and sent into further processing pipelines:

- vtwrite, storing about five years (22TB) of 48k/sec 3-channel data;
- vtsid, monitoring 19 military MSK and time signal broadcasts at 5-second resolution, and recording the full spectrum at 2 minute resolution.
- vtvorbis, contributing to the collection of online streams at abelian.org;
- vtnspec looking deep into the noise for amateur radio signals in the 5170 Hz and 8270 Hz bands, see fbins spectrogram;
- vtevent detecting any natural radio signals such as whistlers, see recent events;

Calibration

Both receivers were calibrated for group delay, phase, and amplitude response using a GPS-based signal generator. Group delay calibration was applied via the `c=offset` vttime option, while amplitude and phase calibration was applied in the form of equalisation maps via vtfilter. After calibration was applied, one sound card unit corresponds to 0.299V/m field strength or 1000pT flux density. This allows the three channels to be mixed to synthesise various polarisations and beam azimuths. The calibration was good enough to achieve about 30dB front/back ratio on a synthesized cardioid.

Example Signals

Auroral signals, dawn chorus, etc:

Audio 150224a.mp3;
Audio 160317a.mp3;
Audio 161029a.mp3;
Audio au170515a.mp3;

Whistlers:

Audio 160307c.mp3;
Polar spectrogram video wh180123b.avi;
Polar spectrogram video wh210326a.avi;
Polar spectrogram video aw110206a.avi (with triggered emissions);
Spectrogram, echo train, LH circular, RH circular, Vertical E-field wh110529a.png;

Sudden Ionospheric Disturbance

Effect of gamma ray burst GRB221009A on DHO grb221009a-DHO.png, on NAA grb221009a-NAA.png, on NSY grb221009a-NSY.png;

SAQ:

Audio saq211224.mp3;

Sferics

Spectrogram, EIC mode cutoffs 150822_sferic_modes_EW_25a.png;
World map, locations of sferics over 20 days pn181029a.png;

Amateur Signals:

These were well below noise in any audible bandwidth, but can be seen on narrow band spectrum and spectrogram plots.
Spectrogram. W4DEX (6194km) 141219c.png;
Spectrum. DK1IS 1071km 200nW ERP 200126f.png;
Spectrum. F5VLB 577km 5W transmit, 80nW ERP 220209a.png;
Spectrogram, five amateur signals active in 8270 Hz band 181227a.jpg;

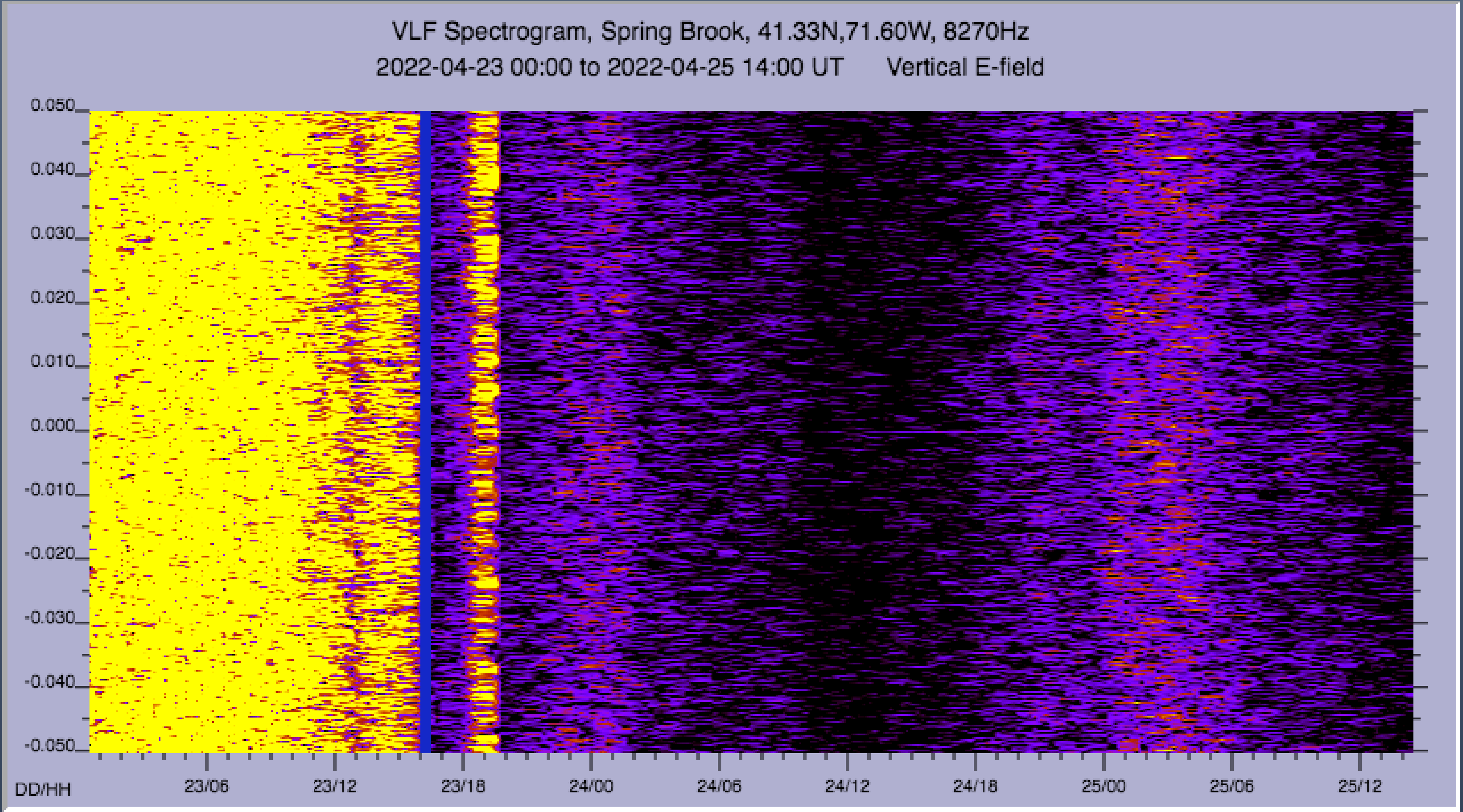
Military Signals:

Spectrogram, ZEVS 150808_zevs1.png;
Spectrum, Alpha F1 at high resolution showing the sidebands alpha.100306b.png;
Phase plot, TACAMO aircraft, 17.8kHz showing 2 minute standard orbit x178.140225a.png;

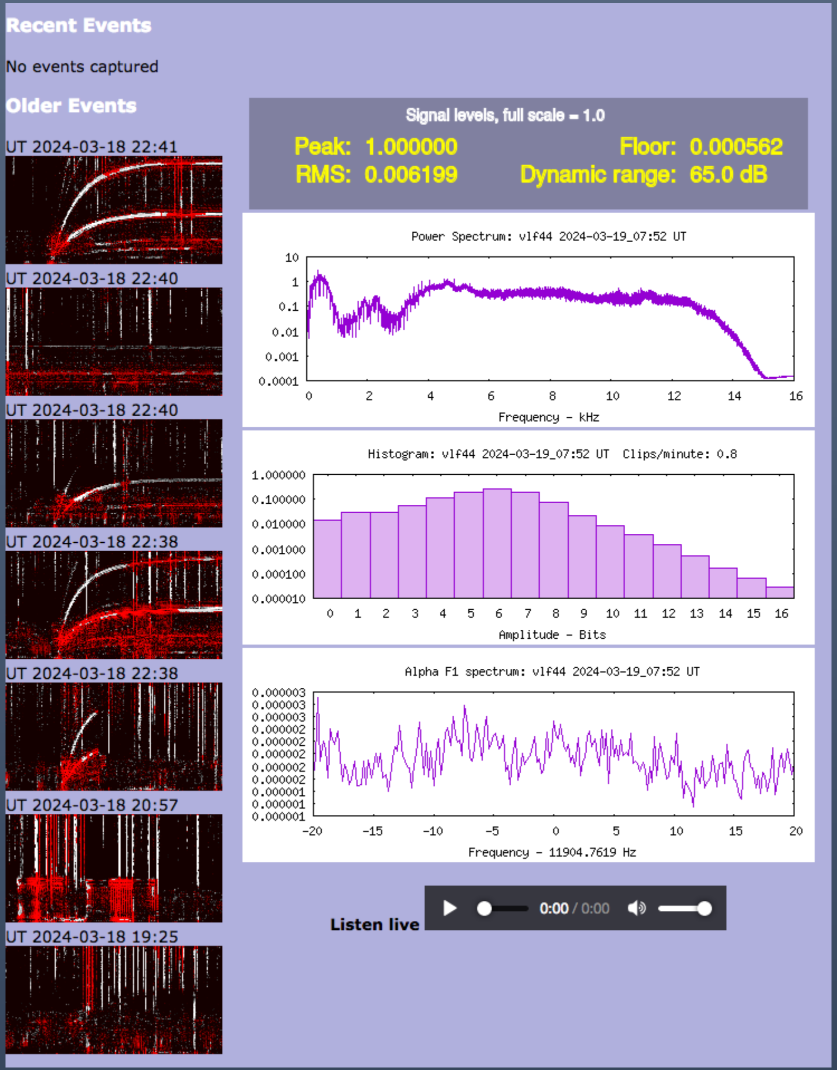
Miscellaneous, Engineering:

Histogram, annual whistler counts through one solar cycle 190509-vlf1.png;
Optimum PPS pulse width at 192k/sec on UMC404HD 191117a.png;
Intensity map, sferics as a function of distance, ground wave and successive sky wave arrivals, predicted sky waves overlaid 191207-n-all-h1.png;
Intensity map, diurnal change of background noise at 29.5kHz, one year 29499_noise_2013.png;
Intensity map, DHO diurnal, one year dho_2013a.png;
Intensity map, NAA diurnal, one year naa_2013a.png;
Whistler duct trilateration, de-dispersion of whistlers for timestamping, original 130226a.png and de-dispersed 130226c.png;
Using the Alpha hyperbolic navigation signals to locate Todmorden 131110b.png;
GPS based VLF calibration tool, u-blox 7 plus Raspberry Pi and touch screen 171123d.jpg, 171130c.jpg, set up for phase and group delay calibration 171130f.jpg;
GPS frequency standard, Trimble 10MHz GPSD-OCXO plus divider 180121a.jpg, 180121b.jpg;
Testing prototype receiver for the Indian Lightning Detection Network, 60cm tube, 40cm of which is antenna element, 20cm for pre-amp, 180924-487.jpg, pre-amp test 181222-524.jpg;
A possible but unconfirmed VLF signal from a meteor md130208a.gif;
Early development of automatic whistler detector, VLF spectrogram top, Hough transform lower left, center was the whistler reconstructed from the Hough transform peak, vsa090313.vlf3c.gif;
My office 181221.jpg;

Live Spectrogram on abelian

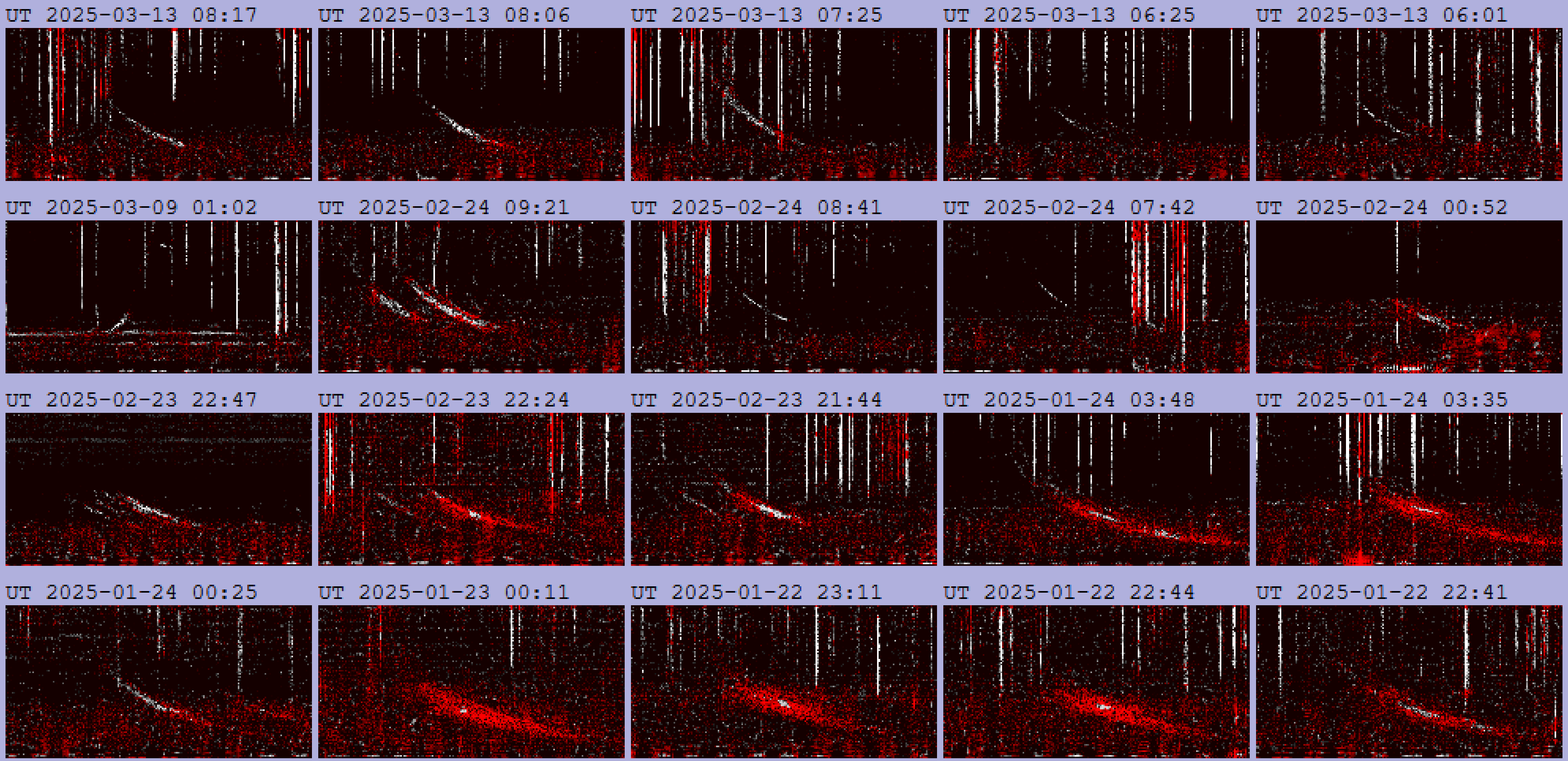


Abelian VLF Live Streaming



abelian.org vlf44 Event Gallery

Event Gallery



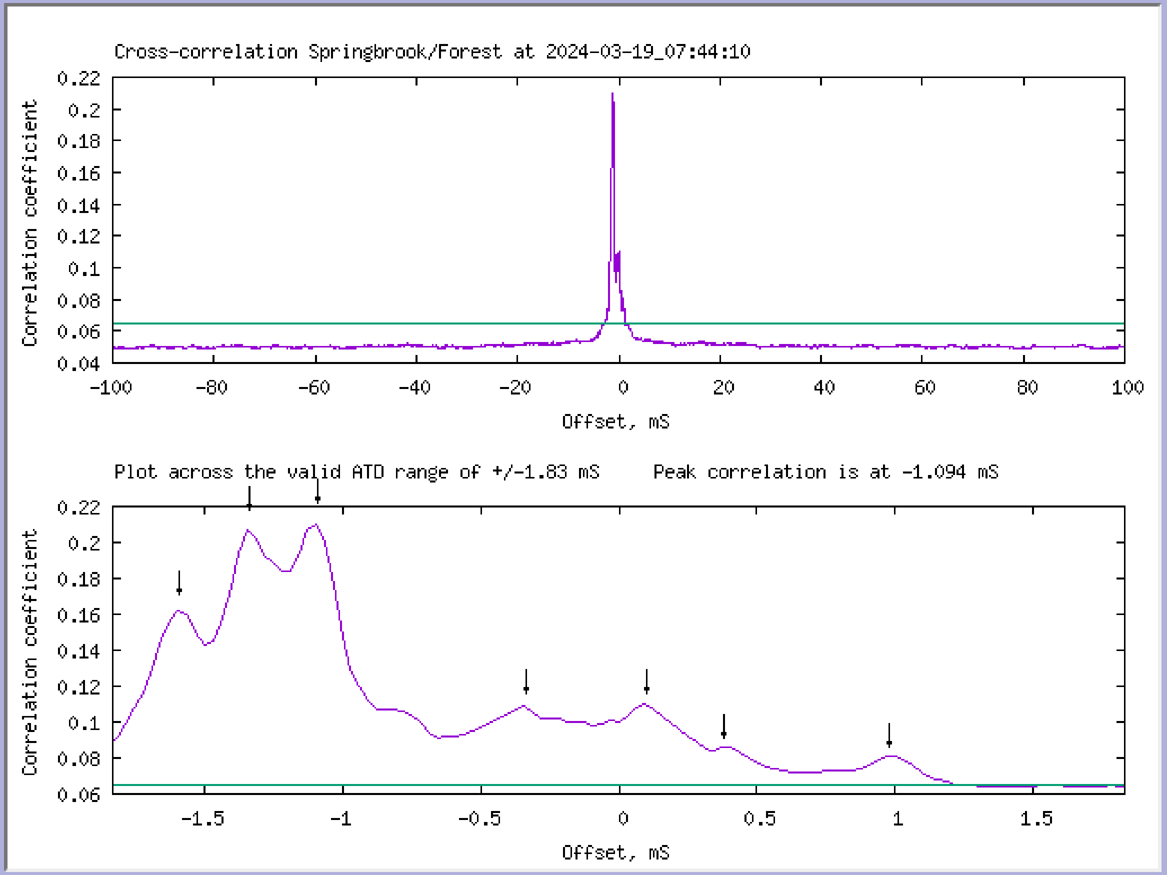
Edit events | Earlier events | Return to detail page

?stream=vlf44&id=1741853180

abelian.org vlf44 Data Uplink

Cross-correlation graphs

Updated every few minutes: Todmorden/Heidelberg Todmorden/Cumiana Todmorden/Forest Forest/Heidelberg Heidelberg/Cumiana Todmorden/Warsaw Springbrook/Forest



Red circles are the geomagnetic conjugates of the receiver sites.

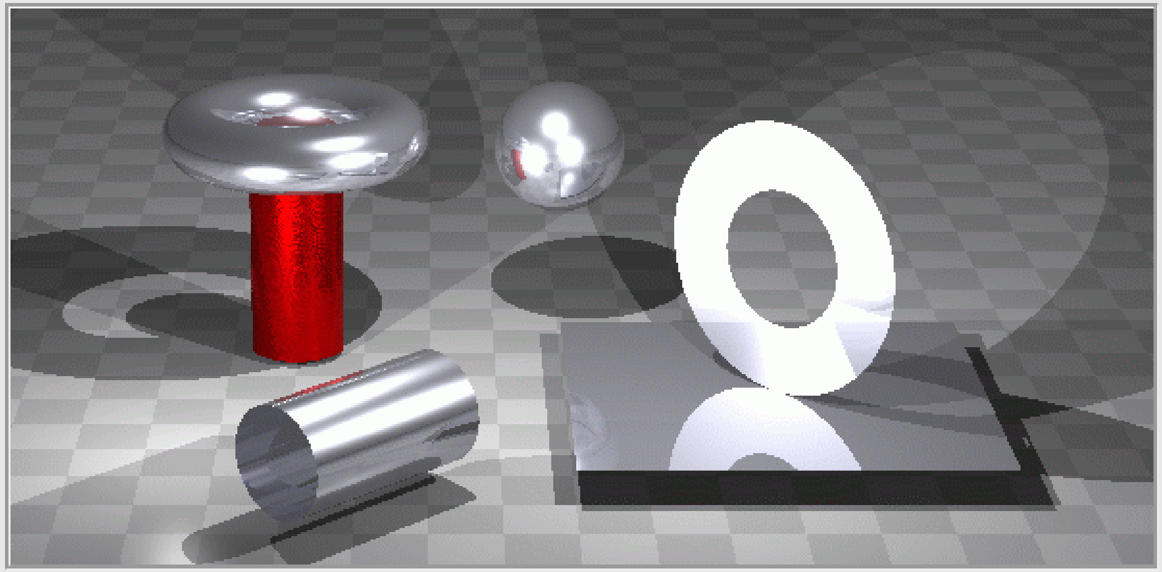
Stream	Site	Location	Operator	Conjugate	Website
vlf1	Todmorden, UK	53.703N,2.072W	Paul Nicholson	-47.014,17.072	http://abelian.org/todmorden-vlf/
vlf15	Cumiana, NW Italy	44.96N,7.42E	Renato Romero, Openlab	-30.067,14.525	http://www.vlf.it
vlf35	Forest, Virginia	37.34385N,79.28818W	Mike Smith	-60.269,-81.225	http://www.unixnut.net/efield.html
vlf38	Warsaw, Poland	52.16313N,21.03094E	Jacek Lipkowski	-42.130,35.301	https://klubnl.pl/wpr/en/
vlf39	Heathcote, Victoria	36.804163S,144.67559E	Leon Mow Radio Observatory	53.326,150.669	https://asv.org.au/ASV-Heathcote
vlf41	Heidelberg, Germany	49.443N,8.695E	Stefan Sch�fer	-38.055,20.264	http://www.iup.uni-heidelberg.de/schaefer_vlf/DK7FC_VLF_Grabber2.html
vlf44	Spring Brook Township, Pennsylvania	41.33N,75.60W	Jonathan Rizzo	-63.584,-74.699	

LCnetgen

LCnetgen Home Page

Calculates the distributed inductance and capacitance of a network of coils, wires, and electrodes of various shapes.

Generates a Spice sub-circuit representing the coils and electrodes as a detailed LCR network.



LCnetgen is open source and runs on all system supporting the gcc compiler - that means almost any computer from a Raspberry Pi to a Cray - with the exception of those running Windows.

The program uses a quasi-static field approximation and is therefore applicable only when the dimensions of the system are small compared with the free-space wavelength of the highest frequency of interest.

Applications include: Tesla coils; LF and VLF antennas; Loading coils and variometers; High voltage systems.

LCnetgen calculates:

- Self capacitance of each electrode;
- Distributed self capacitance of each coil;
- Distributed mutual capacitance between each pair of coils;
- Distributed mutual capacitance between all coils and electrodes;
- Self inductance of each coil;
- Distributed mutual inductance between each pair of coils;
- Distributed series resistance of each coil;
- Response of each coil to incident electric and magnetic fields;
- Response of each electrode to incident electric field;

LCnetgen

- Self capacitance of each electrode;
- Distributed self capacitance of each coil;
- Distributed mutual capacitance between each pair of coils;
- Distributed mutual capacitance between all coils and electrodes;
- Self inductance of each coil;
- Distributed mutual inductance between each pair of coils;
- Distributed series resistance of each coil;
- Response of each coil to incident electric and magnetic fields;
- Response of each electrode to incident electric field;

Component types:

- Spheres;
- Toroids;
- Discs and plates;
- Cylinders and cones;
- Wires;
- Solenoids;
- Loops;
- Flat spiral coils;
- Circular cross-section;
- Any polygonal cross-section;
- Incident electric and magnetic fields;
- Infinite ground plane;

Contents

LCnetgen Example Monopole E-field Antenna

LCnetgen Example 4, Monopole E-field Antenna

This is a 2.8m monopole electrode clamped to the top of a wooden post as in the adjacent photos. The pole is held upright by three ropes.

The guy ropes are modelled as three separate wire electrodes so that they are brought out to separate terminals in the Spice model. In dry weather they are practically insulators and have no effect on the antenna but when soaked they act as grounded wires.

Similarly the wooden support post becomes a conductor when wet, so this is represented in the model by a cylinder electrode.

We want to calculate the effective height and corner frequency of the antenna when connected to a preamp with 100M input resistance.

Input file

The input file monopole.in is listed below. Note the use of trig functions to position the guy wires at 120 degree intervals around the post.

```
electrode {

   name antenna

   cyl {
      end1 0.08, 0, 2.2
      axis 0,0
      length 2.8
      radius 22e-3/2
      tiles 2000
   }
}

electrode {

   name ground

   disc {
      center 0,0,0
```

EbNaut

EbNaut Coherent BPSK

A UT synchronous coherent BPSK mode for use at VLF and low LF enabling communications close to the channel capacity.

The mode uses low rate long constraint length terminated convolutional codes cascaded with an outer error detection code. Encoded symbols are sent UT synchronously with transmit and receive frequencies locked to an atomic standard. Decoding is performed by a soft-decision Viterbi decoder which employs the Soong-Huang serial tree trellis list decoding algorithm. The outer code selects the correct solution from the Viterbi output list. Constraint lengths up to 25 are used, with list sizes up to 200,000.

The long duration phase-stable paths which occur at VLF can be exploited to send messages within 1 dB of the theoretical limit. EbNaut has been used to achieve the first transatlantic amateur communication below 9kHz.

Except in the vicinity of the transmitter, the signal is invisible on a spectrogram. Consequently, transmissions must be announced in advance and the receiver must know the frequency and start time, and which code setting and symbol period to expect.

Software is available for Linux and Windows. It it written in C and is open source under the BSD 2-clause license.

Measured performance at various levels of E_b/N_0 for the rate 1/16 constraint length 25 code, with list size 50,000.

Message length	E_b/N_0	Success rate
25 characters	-0.5 dB	85 %
	-1.0 dB	63 %
12 characters	-0.5 dB	87 %
	-1.0 dB	70 %
5 characters	-0.5 dB	84 %
	-1.0 dB	74 %

Contents

Background

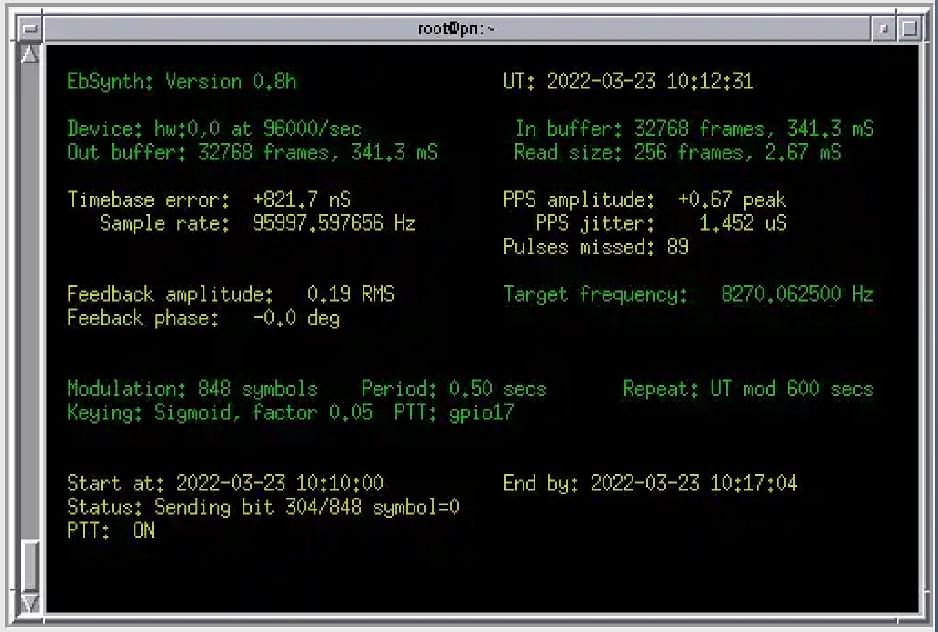
Developments in error correction techniques have led to the common use of turbo codes and low density parity check codes which can both perform usefully at E_b/N_0 below -0.5dB. This performance is only achieved with large block sizes (of order several thousand bits). For block sizes typical of short amateur radio exchanges (a couple of hundred bits), they are not effective.

Recent experiments show that convolutional codes using long constraint lengths, when combined with list decoding, can produce a useful success rate on short messages down to E_b/N_0 of -1.0 dB. Successful decodes can be obtained with over 60% probability at this signal level using a code complexity which is within reach of modern PCs. For general communications, a 40% message failure rate would be considered very bad. A network connection such as WiFi suffers badly with only a couple of percent of lost packets. But a radio amateur

EbSynth

Frequency Synthesizer

This frequency synthesizer program uses a stereo soundcard to generate a precise carrier or BPSK signal from a GPS 1PPS or reference frequency. The soundcard output can be used directly at VLF or can be multiplied or mixed up to LF. When a PPS is used the output has an absolute phase, maintained across reboots and soundcard reset.



The program makes use of a feedback signal which is used to compensate for variable phase shift in the transmitter and antenna.

You will need:

- Linux PC with motherboard, USB, or PCI soundcard,
  or
  a Raspberry Pi (2B, 3B or 4B) with audioinjector stereo or octo HAT.
- GPS module with 1PPS output.

Software

The program is open source under the BSD 2-clause license.
Download the source code from http://abelian.org/ebnaut/ebsynth.c and compile with

```
gcc -std=gnu99 -Wall -O3 -o /usr/local/bin/ebsynth ebsynth.c -lasound -lncurses -lfftw3 -lm -lpthread
```

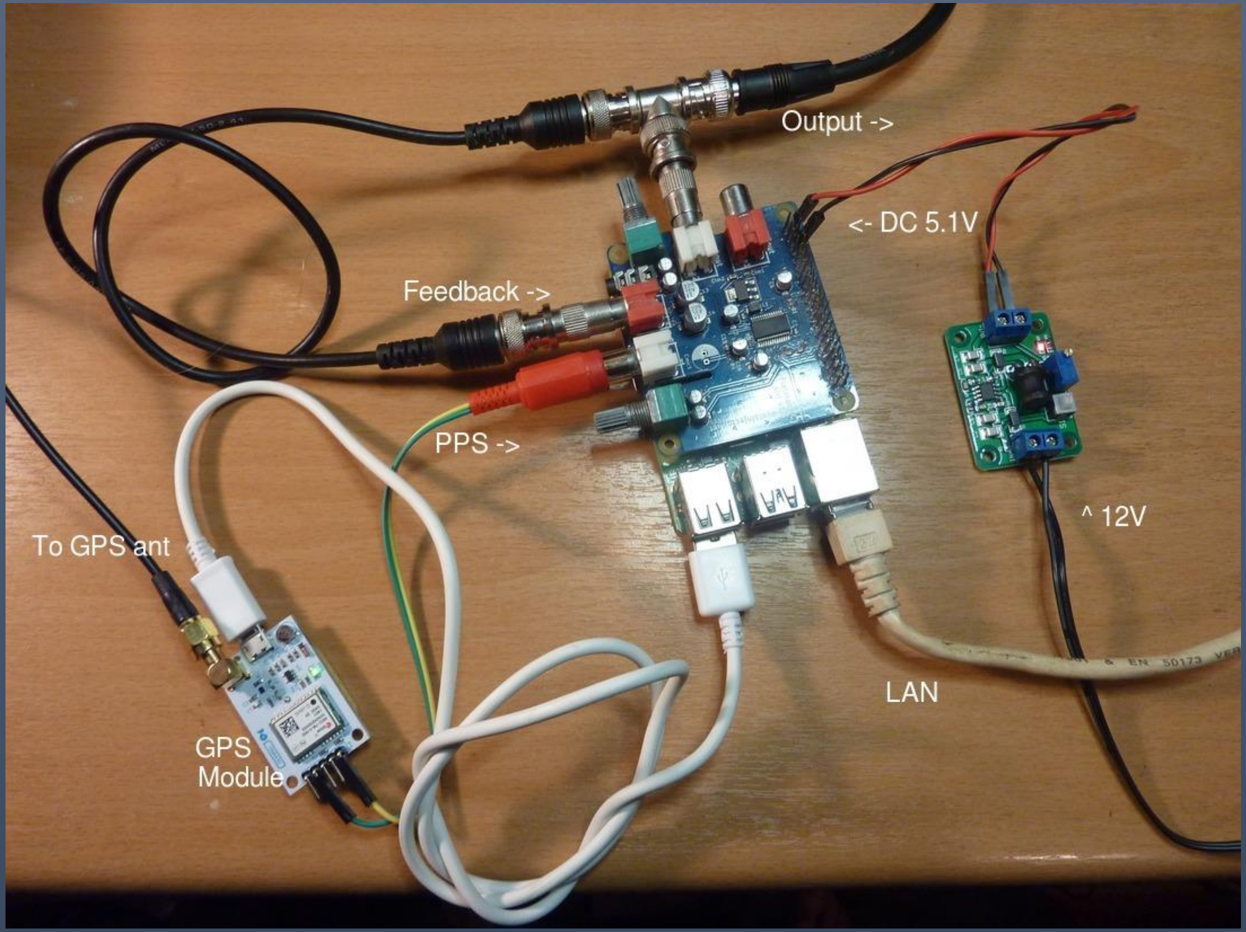
and you might need to prefix that with sudo if you are not running as the superuser. If you get a complaint about ncurses, you'll have to install the ncurses development package. On Ubuntu do

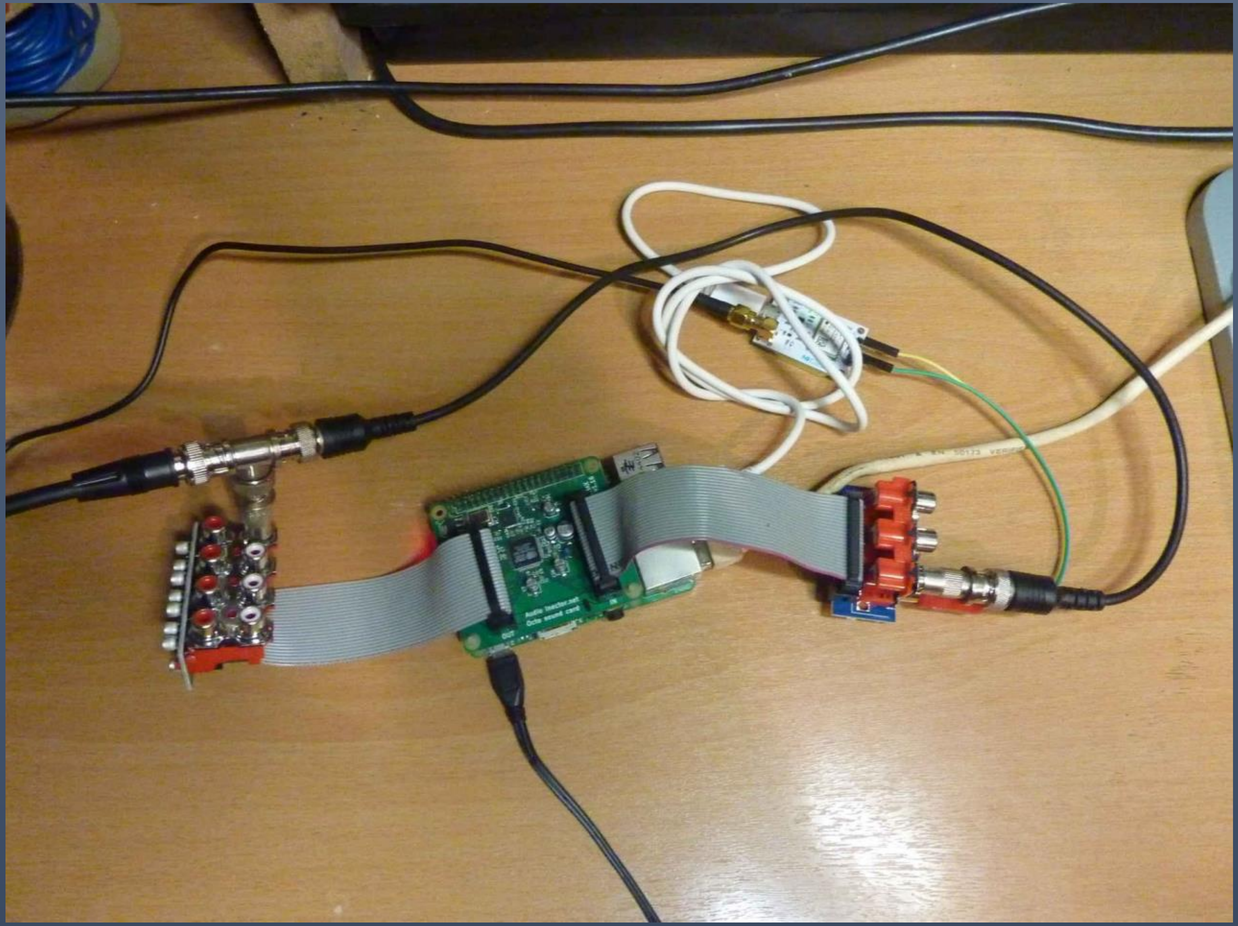
```
apt-get install libncurses5-dev
```

The command `ebsynth -? | less` gives you a summary of the command syntax.

For the Raspberry Pi, a pre-installed 32 bit operating system based on Raspios Lite 2021-05-07 'Buster' is available. There is an image for the Audioinjector Stereo: http://5.9.106.210/ebsynth-0.8h-ai.zip
and an image for the Audioinjector Octo: http://5.9.106.210/ebsynth-0.8h-octo.zip
The images contain ebsynth 0.8h, vlfrx-tools 0.9j and ebnaut 1.1, and the OS is configured for headless operation with Wi-Fi and Bluetooth disabled. IP is set by DHCP, see your router's DHCP client list for hostname 'ebsynth'. Log in as root via ssh, password is 'pi'. Change the password and install your workstation's public ssh key into /root/.ssh/authorized_keys. Run `./set-mixer` to set up the mixer on the Audioinjector Stereo. The Octo has suitable default mixer settings.

EbSynth Hardware Setups





Accomplishments by VLF Amateurs

Some recent milestones with amateur radio experiments at VLF.

With a couple of related experiments at LF and MF. Send any corrections and additions to vlf1611@abelian.org

Referring to the spectrum below 10kHz, Roger Lapthorn G3XBM wrote (RSGB *Radio Communication*, April 1975):

> " Amateurs should not ignore its potential as an area for experimental work requiring little equipment to get started and presenting a subject with a difference to work on"

Interested in getting involved? Sign up to the VLF_group on groups.io, https://groups.io/g/VLF. The group covers natural radio (whistlers, aurora, etc) but is also the main forum for amateur radio transmitting and receiving.

/

YYYY-MM-DD	From	To	Frequency Hz	QRB km	Chars	Notes
2025-03-14	VO1NA	F5WK	8270.000277	4038.5		First transatlantic VLF detection in France. Carrier detection in 4 hour integration. https://groups.io/g/VLF/message/31798
2024-06-06	DL3JMM	vlf	5270.03	1079.2	7	Final message in 57km band to Todmorden, 'TU PAUL' by 8K19A 10 second symbols, Eb/N0 +6.0 dB. https://groups.io/g/VLF/message/31205
2024-06-05	DF6NM	Todmorden UK	8270.0025	1028.4	3	Final EbNaut into Todmorden in 36km band. 8K19A with 15 second symbols, the message 'BYE' at Eb/N0 +1.3 dB. https://groups.io/g/VLF/message/31199
2023-05-07	DL7NN	DL3JMM/A	95.001	26		Carrier detection via triangular loop (side length 4m), S/N 25dB in 2.8 mHz. https://abelian.vvsindia.com/tmp/ZEVS_95Hz_07.05.23_01.JPG
2023-02-05	DL3JMM	ILDN/Prayagraj	5170.03	6379	5	New distance record for message decode in 58km band. EbNaut 8K19A with 30 second symbols. Eb/N0=-0.9db, improved to +2.5dB during next three nights. https://groups.io/g/VLF/message/29746 https://groups.io/g/VLF/message/29753 https://groups.io/g/VLF/message/29759
2023-02-03	DL3JMM	ILDN/Kolkata	5170.03	7067		Record distance for carrier detection in 58km band. https://abelian.vvsindia.com/vlf/tmp/230203a.png https://abelian.vvsindia.com/vlf/tmp/230203b.png https://groups.io/g/VLF/message/29733 https://groups.io/g/VLF/message/29734
2023-01-16	DL3JMM	N4VLF	8270.03	7033	5	New distance record for east-to-west. 300W into large ground loop antenna. Ebnaut 8K19A, 30 second symbols, Eb/N0 +0.7dB. https://groups.io/g/VLF/message/29667
2023-01-04	EA4GHB	DL0A0	8270.0075	1524	3	EbNaut 8K19A 30 second symbols, Eb/N0 0.0dB. First EbNaut from Spain. https://groups.io/g/VLF/message/29619
2022-12-18	EA4GHB	Todmorden UK	8270.0075	1432		Carrier detection, 13nV/m, -24.2dB in 1Hz. TX 60V putting 450mA into 350m ground loop antenna over dry sandy soil, oriented 355/175. First VLF and sub-9kHz out of Spain. First Spain to UK. https://groups.io/g/VLF/message/29511 https://groups.io/g/VLF/message/29536 https://abelian.vvsindia.com/vlf/tmp/EA4GHB-todmorden.png
2022-12-06	DL3JMM	ILDN/Tirunelveli	8270.03	7493	4	New world distance record for sub-9kHz. EbNaut 8K19A, 30 second symbols. Eb/N0 -0.6 dB via the Indian Lightning Detection Network receiver at Tirunelveli. DL3JMM with approx 300W into large ground loop antenna. Also decoded at ILDN/Prayagraj 6379 km with Eb/N0 +5.1 dB.

Why VLF Automated Reception Systems are Important:

LIGO Gravitational Wave Detection

LIGO gravitational wave detection

Paul

Referring to yesterday's announcement from LIGO

https://en.wikipedia.org/wiki/Gravitational_wave_observation

I'm pleased to report that our VLF receivers played a very small part in this.

On October 17th we got a request from Dr Robert Schofield looking for VLF data for the period 09:51 +/- 1 minute.
He didn't say what for but it was easy to put 2+2 together.

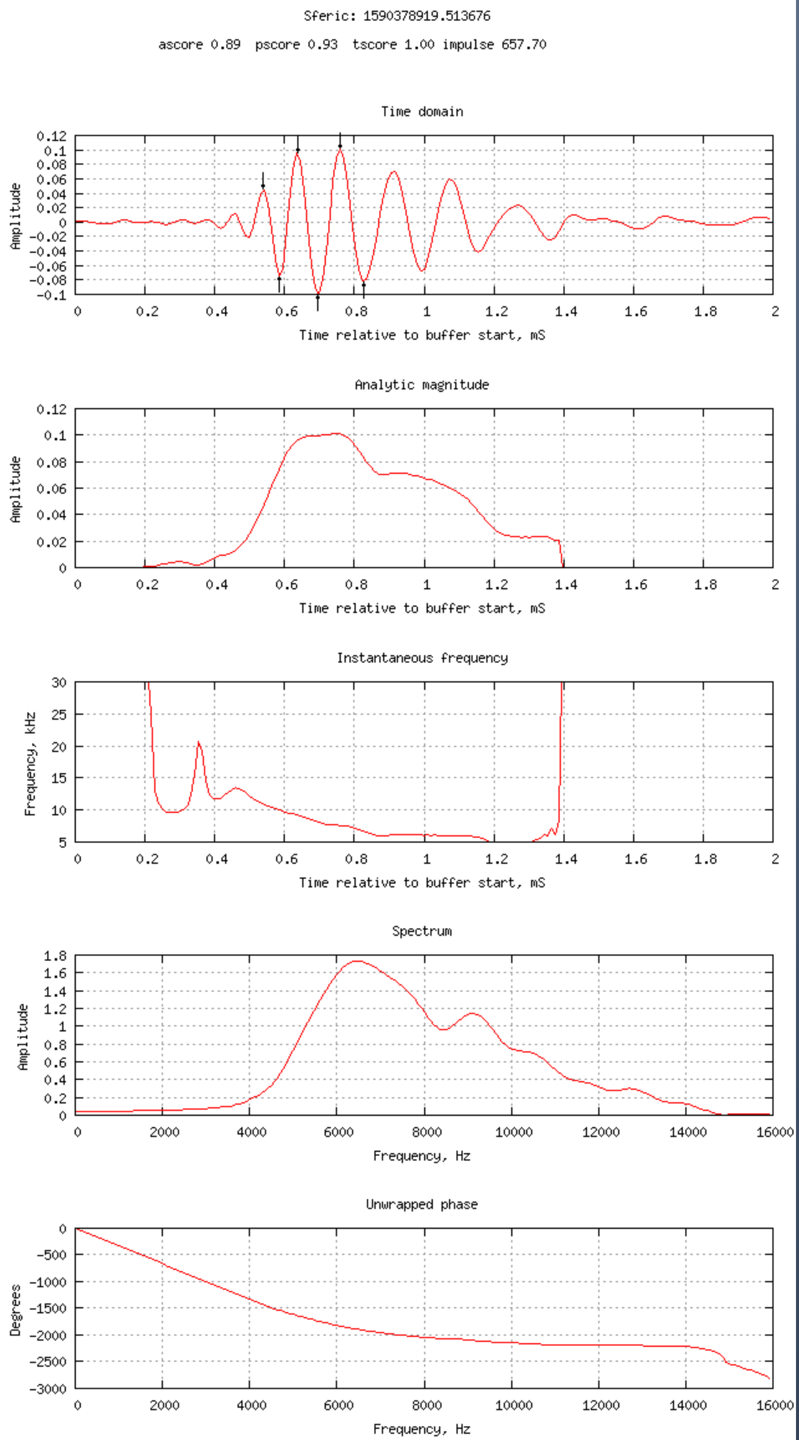
I guessed this was to check that there was no electromagnetic interference from the VLF spectrum that might cause a false detection.

Unfortunately our stream server only keeps 20 days of recent signal and by the time the request came in, the signal had expired from the server's cache. That meant we couldn't do a thorough check, but luckily Mike Smith at Forest keeps a long raw archive of vlf35 so we could at least supply something from North America.

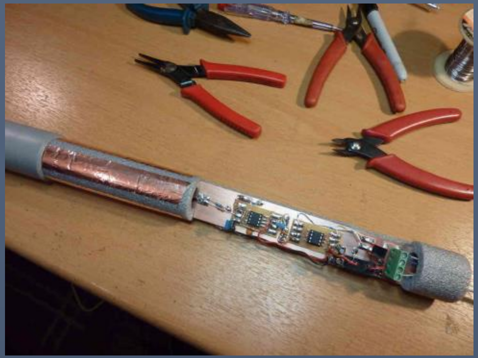
There's a lot to be said for keeping the raw signal stored locally. We never know when something interesting will turn up, perhaps months later and the local raw signal has wider bandwidth and fewer artifacts than the streamed version.

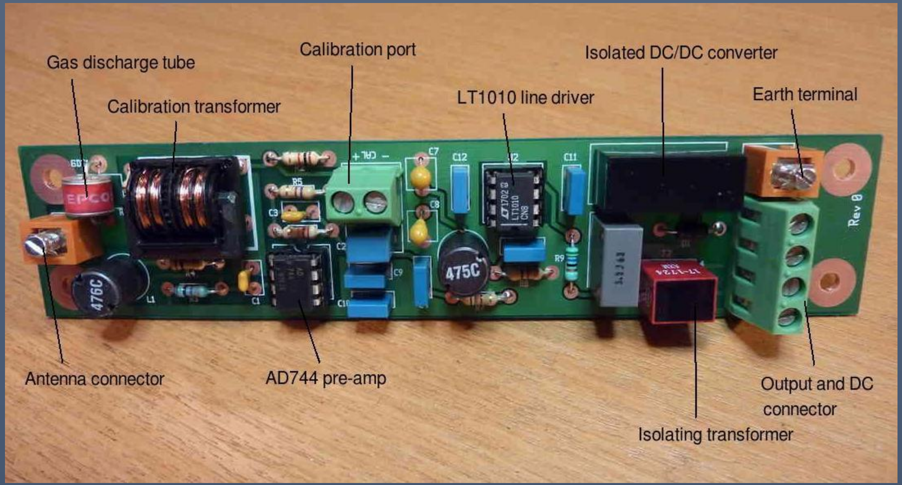
--
Paul Nicholson
--

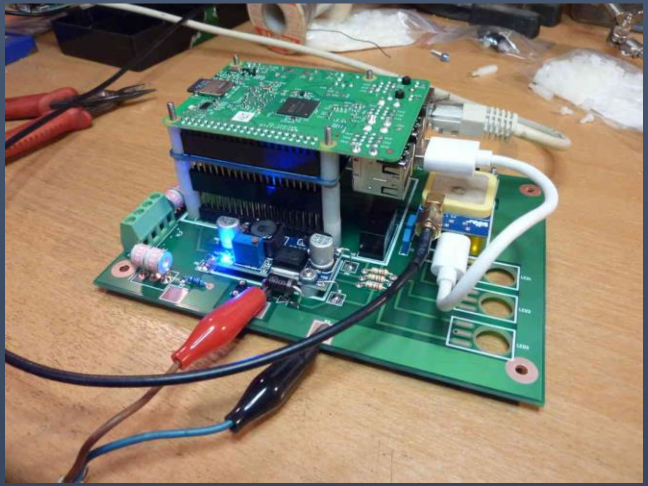
Sferic Analysis sferic-plot



ILDN Hardware Development







ILDN System Calibration

RPVLF Documentation

Timestamped signal capture and processing using a Raspberry Pi.

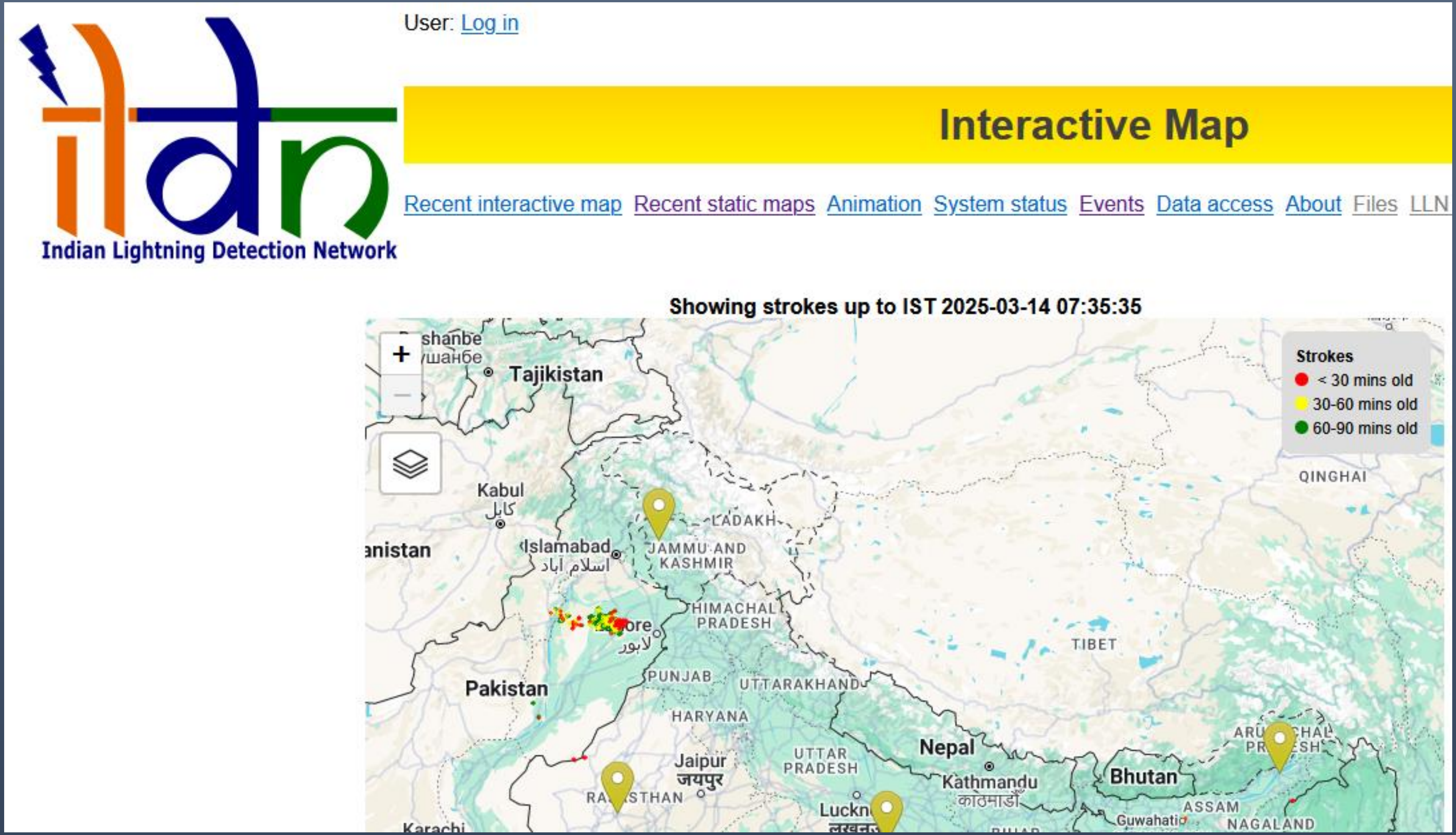
Using a Raspberry Pi and either a 2-channel or a 6-channel Audioinjector board, combined with a low-cost GPS module to provide the timing, you can build yourself a multi-channel VLF SDR for timestamped signal capture. This is a headless device which you connect to via ethernet from Spectrum Lab (from Windows) or vlfrx-tools (from Linux), to receive multi-channel signals timestamped to an accuracy of better than 50 nanoseconds. The device also functions as a streaming audio server and NTP time server for your LAN, and runs an automatic whistler/aurora detector, a SID monitor, continuous signal recording, and retrieval of historic signal.

GPS timing of signals to accuracy better than a microsecond is essential if you're doing amateur radio work at VLF, for serious SID monitoring, for combining signals from multiple receivers, or for any kind of professional work at VLF.

These notes describe the hardware and software setup.

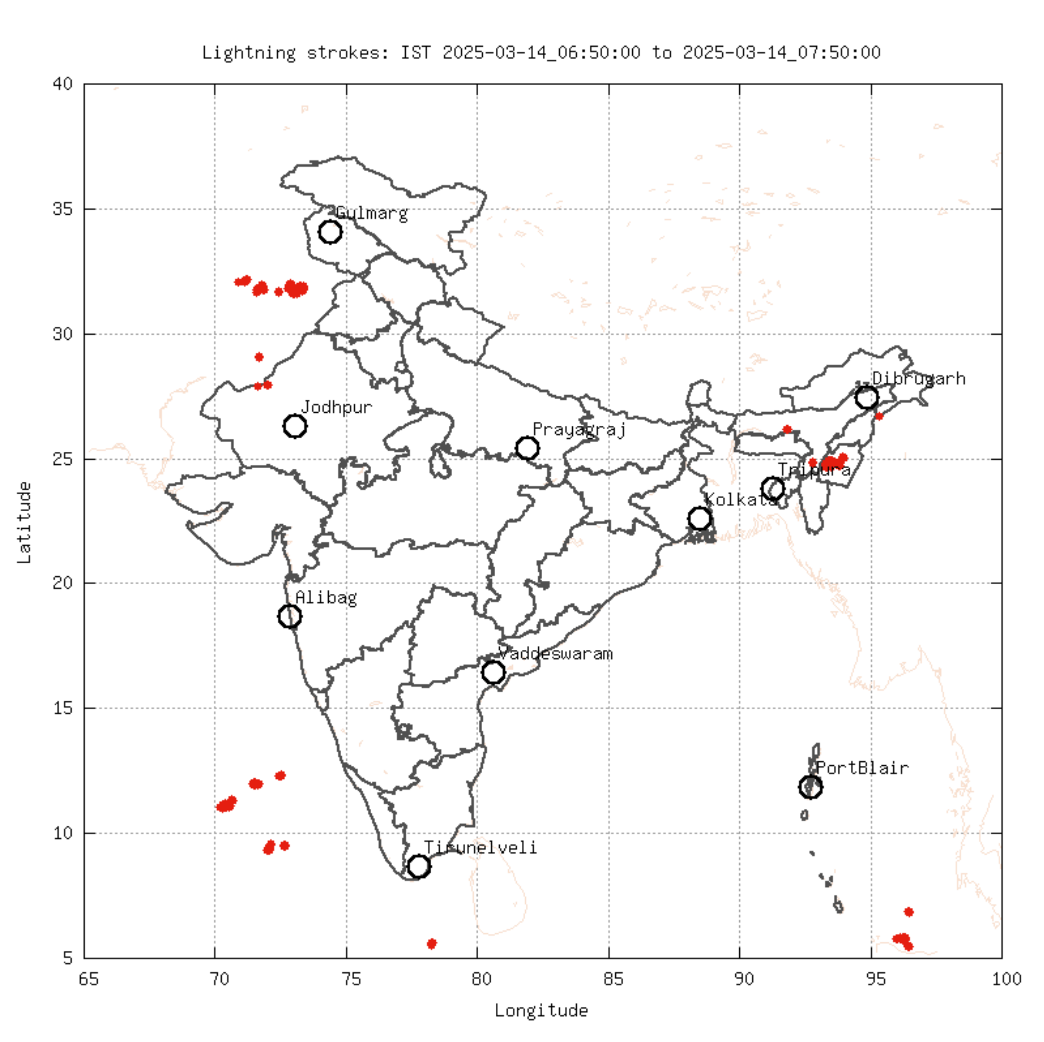
Contents

Indian Lightning Detection Network (ILDN)

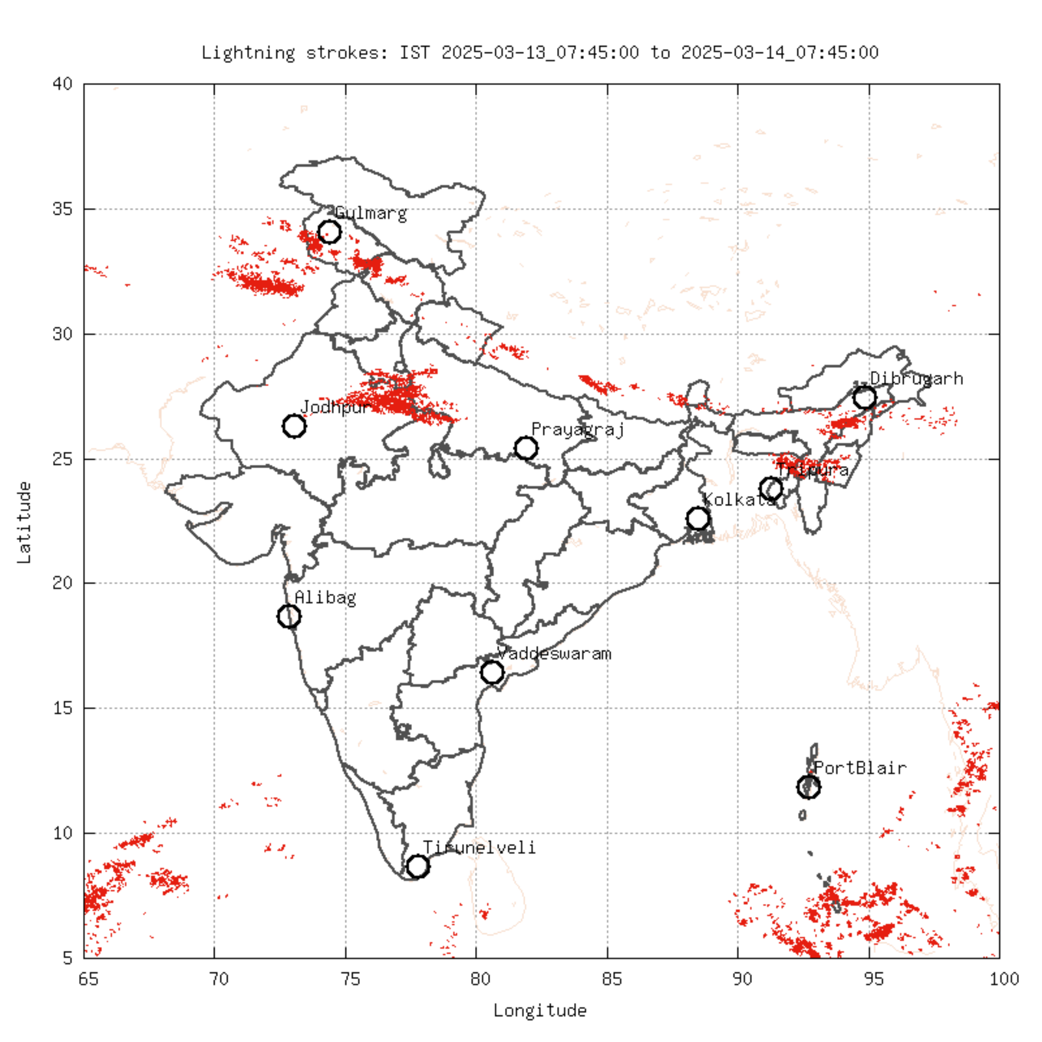


ILDN Maps

Past 60 minutes



Past 24 hours



ILDN System Hardware

VLF Accomplishments and Reflection

Thanks for all the kind words. I think it was about Autumn 2002 when I first set up a VLF receiver here and began experimenting with software to do hum filtering, whistler detection, timing, and recording. All of which eventually turned into vlfrx-tools.

By January 2003 I was regularly picking up whistlers and auroral signals from the home receiver, something I was never able to do with a portable receiver on outdoor expeditions.
Never in the right place at the right time!

The full history of developments can be traced in the VLF group archives, it's all there, the discussions, questions, experiments, very much a group effort. It took a few years for us to master the art of natural radio reception from home, calibration and timestamping, continuous recording, and automatic monitoring for interesting signals.

Job done! Home reception is surely as good as it can be.

And then in 2010 along came Stefan Shaefer with a huge loading coil and a kite big enough to need a car to hold it down and a NOTAM to warn air traffic.

That upped the game considerably. Timing had to be improved from mS to nS, locking to MSF - fine for timing whistlers, was suddenly nowhere near good enough and it had to be GPS from then on.

And we had to invent a really effective sferic blanker, eventually gaining 20dB on the S/N of very weak narrow band artificial signals from pioneering amateur stations.

It took four more years of refinements to receive amateur signals from North America, thoroughly vindicating those adventurous radio amateurs dreaming of getting a VLF signal beyond the garden fence.

And all that fed back into the natural radio side of things
- having now a timing system able to locate lightning strokes and to search for meteor signatures.

Job done now?

Of course not. We can't just settle for carrier detections, we want to send messages at VLF! Markus experimented with MFSK from 2011, OPDS from 2013 and then we played with BPSK from 2014. We kept being surprised by how good the results could be when we got everything right. Exciting times for all involved!

Job surely done now? Well it probably is for Todmorden. Reception is now firmly limited by electrical interference of all kinds and it gets a little worse each year.

I want to move rebuilt and improved receivers to a more remote location further north.

May as well move myself too.

And get some darker skies and some new and wilder hills to roam.

I treat myself to a 6 month sabbatical from commercial work before I look for the next programming contract (although interesting offers are welcome!).

Am still very busy with improving the lightning tracking in India. Each year the monsoon lightning take a terrible toll and the system will save lives through a new free app delivering warnings. So beyond being interesting and great fun for 20 years, there's some real practical benefits from all this, from being able to deploy precision receivers made from low cost commodity parts and open source software in places that are mostly, like Todmorden, far from ideal for VLF reception.

--
Paul Nicholson
--

A Request from God

Paul
From: paul@abelian.org
To: Jonathan
Cc: Anirban Guha

Hi Jonathan,

I wonder if you'd like to get involved with ILDN?

I've got some major health problems and it would be handy to have some backup support for ILDN.

You're well up to speed with Linux, vlfrx-tools, and also the receiver electronics, so obviously you were my first thought!

The project is run by professor Anirban Guha in the physics dept of Tripura University, I cc Anirban.

A goal is to make the system fully supported and also develop the next generation of receivers, entirely within India. Between the two of us, we can refine the system and help to get people trained up on the technology.

I know you're busy getting your own lightning location network running, but I hope you'll have time to join the small core of the ILDN team.

--
Paul Nicholson
--

Paul
From: paul@abelian.org
To: Jonathan
Cc: Anirban Guha

Thanks Jonathan! Your enthusiasm is enormous and just what the project needs. We are so lucky! I know that Anirban will be delighted, he has seen some of your presentations on youtube and is most impressed.

ILDN has policy of open data and voluntary collaboration with various institutes and individuals, clearly your approach aligns well.

The guys in India are mostly scientists, professors and students, in the field of lightning and meteorology, and we can contribute where needed to make the technology do whatever is called for. Anirban is getting quite good with Linux but often has questions of the how-to-do kind.

It is also significant that you also have interest in the science and not just the tech.

I must warn you that Anirban, like all good professors, has the uncanny ability to ask difficult questions, questions which home in on any subtle weakness or defect in theories or suggestions or technology. This is a great pleasure and a challenge! Often a quick question leads me to a day or days of thinking and typing and detailed replies!

Do you have google-meet?

All I can type for now.

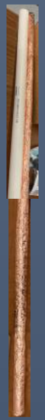
--
Paul Nicholson
--

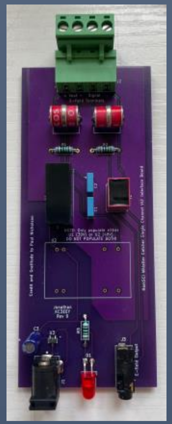
Paul Nicholson G8LMD [SK]
Eternal Memory

What Paul Means to Me

ILDN/HamSCI Collaboration

Continuing Paul’s Legacy – The Whistler Catcher




- The HamSCI Whistler Catcher VLF Reception System is solely and completely dedicated to the honor and memory of Paul Nicholson.
- VLF Active Antenna containing an E-field antenna element and preamp.
- VLF Interface Box to power the preamp and interface the signal.
- GNSS Interface Box to produce a PPS output and RS232/PPS port.
- Behringer UMC202HD and Thin Client PC with serial port.

In Gratitude

- Paul Nicholson – For everything you've done to make my life better and so fulfilling. Eternal memory!
- Deborah Nicholson – Paul's wife and partner.
- Anirban Guha – For allowing me to continue Paul's legacy and being a good friend.
- VLF Community Members Jean-Marie, Markus, Bernd, Renato, Stefan, Wolfgang, Peter Newton, Mike Smith, and many others.
- Steven McGreevy For introducing me to natural radio emissions.
- Dr. Nathaniel Frissell W2NAF for his endless support and friendship.