Very Low Frequency Receiver

User Manual

www.ukraa.com

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Acknowledgements

Design Team

The UKRAA VLF Receiver design is a combination of public domain material and original improvements by John Cook and Peter King. The circuit board layout was undertaken by John Cook.

Testing Team

The VLF Receiver was tested by David Farn, Paul Hyde, Martyn Kinder and Andrew Lutley. Aerial Characterisation experiments were undertaken by Alan Melia and Whit Reeve.

Production Team

The initial batch of the VLF Receivers was produced by Andrew Lutley, Paul Hyde and Norman Pomfret.

Contributors

The following authors have contributed to the VLF Receiver User Manual: Tony Abbey, John Cook, David Farn, Prof Tudor Jones, Martyn Kinder, Andrew Lutley, Alan Melia, Dr Laurence Newell, Whit Reeve, Dr Chris Thomas.

Table of Contents

Introduction

UKRAA

The UK Radio Astronomy Association (UKRAA) is a non-profit-making Charitable Incorporated Organisation. It was established by the Radio Astronomy Group of the British Astronomical Association (BAA) to facilitate the production and sale of radio astronomy products.

Any suggestions or recommendations for improvement of this Manual would be appreciated. See the Contacts page for further details.

The UKRAA VLF Receiver

The UKRAA VLF Receiver Circuit Board

This Manual covers the 2015 version of the VLF Receiver, with the DB9 socket as shown above. If you have the earlier version of the VLF Receiver, with the DB25 socket, please refer to the previous edition of this Manual.

The UKRAA Very Low Frequency (VLF) Receiver is designed to record Sudden Ionospheric Disturbances (SIDs) induced by solar flares. It does this by monitoring transmissions from Earth-based beacons, which are affected by changes in the ionosphere, giving an indirect indication of events on the Sun. The main motivation for this work is to correlate these radio observations of solar activity with those from optical observers, and to follow the cycles of sunspots as they appear on the Sun.

The VLF Receiver output is a voltage varying with time, which may be fed to a data logger and the popular Radio-SkyPipe data logging software. This is described in more detail in later sections of this Manual.

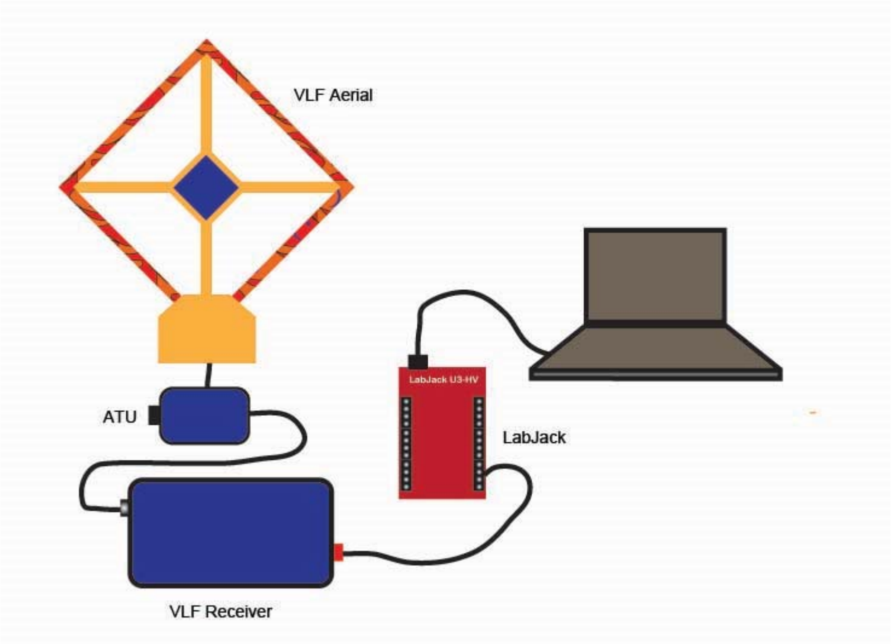
The UKRAA VLF Receiver has a tuning range of about 12kHz to 35kHz, requires a supply of 15v DC at 35mA, and provides an output signal at 0 – 2.5 Volts or 0 – 5 Volts. It is designed to work with the UKRAA VLF loop Aerial and the UKRAA VLF Aerial Tuning Unit.

The VLF Receiver, a VLF loop aerial and a VLF Aerial Tuning Unit are available from UKRAA in kit form, or built and tested. You may also find one of the range of VLF Signal Generators useful during tuning of the system.

VLF Receiver System Requirements

You will need various other elements in order to operate your VLF Receiver. The UKRAA VLF Receiver is part of a complete system and all these elements are available from UKRAA with the exception of a computer and software. The key system elements:

- A suitable tuned aerial such as the UKRAA VLF Aerial with the UKRAA Aerial Tuning Unit (see below);
- A power supply (see below);
- A length of coaxial cable with BNC connector(s) to connect the Receiver to the Aerial/ATU – this is supplied with the UKRAA Aerial Tuning Unit;
- A LabJack U3-HV data acquisition device (DAQ) to convert the Receiver output from an analogue signal to a digital format;
- A computer and software to display and record the VLF signals for analysis.



The UKRAA VLF Receiving System

Power Supply Considerations

This can either be a battery or a mains adapter, in each case capable of supplying 15V DC at 35mA. UKRAA supplies a suitable 15V regulated power supply unit (Part number: UKR026).

It is important to ensure that the **positive** output of the power supply is connected to the 2.5mm central **socket**.
All UKRAA modules are standardised to use this type of supply.

Make sure that the power supply is not covered in any way; it should run only slightly warm to the touch.

Support

All users of the VLF Receiver system are encouraged to make use of the support available from UKRAA for setting up and operation. Please see the Contacts section for details.

Flare Detection using VLF Radio signals

The detection of Solar Flares can be achieved by continuously recording the signals from some of the Military radio transmitters on VLF (Very Low Frequency) radio. In the radio field these events were given the name Sudden Ionospheric Disturbances (SID) early on, and Flare detection is sometimes referred to as SID detection. The effect depends upon the response of the ionosphere to the burst of solar radiation, and the mechanics of the radio propagation mechanism.

The Ionosphere

The ionosphere is a region of the Earth’s atmosphere where the gas density is low enough for atoms that become ionised to exist for a significant period of time before meeting and colliding with another atom and becoming neutralised again (collisional recombination). This region is at an altitude of between 50 km and about 600 km above sea level. The ionising energy arises mainly from the Sun in the form of particles and electromagnetic radiation from the visible spectrum right through to gamma rays.

Flare Detection Mechanism

The part of the Ionosphere that interests us from the point of view of Flare detection is referred to as the ‘D-layer’ (at about 75 km to 95 km altitude) and the ‘lower E-layer’ (about 95 km to 150 km altitude). In the radio field the D-layer is known mainly as an absorbing blanket that stops long distance propagation at lower “short wave” frequencies. At VLF and LF, which are defined as frequencies below 300 kHz, the D-layer provides the means by which these frequencies could reach world-wide before the short-wave bands were opened up in the 1930s. The D-layer is often explained as forming a (lossy) “waveguide” with the

Earth's surface that guides the waves round the curvature of the Earth. Squeezing of this waveguide by changes in the D-layer change the amplitude and phase of waves passing through the guide. Although the simpler analogy of a mirror "reflection" can be used to describe the propagation mechanism, the physical mechanism is actually 'refraction', the same mechanism that is responsible for the "bent pencil in the tumbler of water" effect. The term 'reflection' is used here in quotes when describing the ionosphere returning an upward radio signal back towards the Earth.

The Ionosphere is characterised by an increasing electron density from about 50 km altitude upwards. At low electron densities and the higher air pressures around 50 km, the incoming radio wave loses energy to the free electrons, which recombine before they have chance to return energy to the wave. However, at higher altitudes the electrons have a chance to interact with the wave for longer, in a way that apparently speeds up the wave, bending its direction back towards Earth again. These two mechanisms, absorption and "reflection" are vital to the understanding the SID detection mechanism.

Ionospheric Layers

- Topside

  From F2 layer to 500/1000km transition O^+ less than H^+ and He^+

- F Layer

  Above 150km, reflecting F2 layer, ions NO^+ (lower) to O^+ (upper)

- E Layer

  95 - 150km, ions are mainly O^{++}, also thick E2, thin sporadic E

- D Layer

  75 - 95km, weak ionisation, absorbs HF

Normal Quiet VLF Propagation

At relatively short distances, less than 1000 km, the radio signal from the VLF transmitter reaches the Receiver by two paths. One of these hugs the ground and is called, unsurprisingly, the "ground wave"; the other is via "reflection" from the ionosphere, called the Ionospheric-wave, often colloquially known as the "sky wave". These two paths are of different lengths, and lead to the formation of an 'interference pattern'. In this case the term 'interference' is used in the optical sense and not meaning unwanted noises and lightning static as in the radio sense. The different path lengths for the two signals means that the phases of these signals will differ *at the Receiver*. If the path difference is an even number of half wavelengths the signals on the two paths will reinforce and if the number of half-wavelengths is odd there will be some cancellation. The same kind of effect is obtained by listening to a steady sound from a loudspeaker in a sparsely furnished room and moving slowly around. You will find places whether the sound you hear is reduced and other where it is enhanced. The difference in distance between these points is one half wavelength of the sound-wave. If the amplitudes of the signals on the two paths are the same and they are out-of-phase there will be perfect cancellation. However, the reflected wave is usually attenuated so it arrives weaker than the direct wave so there is less than complete cancellation. If, as in the case of the ionosphere, the "reflector" moves up and down there is a continuous change in the received signal which is normally referred to as 'fading'.

In daytime the sky wave is attenuated by the absorbing part of the D-layer, but the amount of absorption is dependent on the amount of penetration. High angle waves penetrate deeply and are severely attenuated, but waves at low angles of incidence penetrate more shallowly and are less attenuated. The ground wave component of the signal progressively weakens as the Receiver becomes further from the transmitter. At about 700 km range the ground and sky waves are approximately the same strength.

After dark the D-layer, which is mainly ionised by Solar Ultra Violet rays, quickly disappears and with it all the absorbing ionisation. "Reflection" now occurs from the lower part of the E-layer at around 90 km to 100 km altitude. The result of this is that once the mid point of the path is in shadow at 100 km altitude, the signal strength will usually increase significantly, while the ground wave signal stays exactly the same strength. Thus night-time reception is marked by large and rapid swings in signal strength as the two, now more nearly equal strength, signals swing in and out of phase. This is of little interest to the SID observer as there can be no Solar Flares detected in the Earth shadow, but it may help to set up the Receiver levels correctly, so that you do not miss or corrupt a flare-induced signal.

The later section *Classification and Interpretation of Results* has many examples of the types of recording which may be made.

Changes due to Solar Flares

A Solar Flare is caused by the sudden collapse of the very highly strained magnetic field in the region of a Sun-spot. Electro-magnetic waves are generated by changing magnetic fields, and the size and strength of the field in a Sun-spot are enormous. When the twisted and strained field snaps into a lower energy condition, vast amounts of energy are released as high energy electro-magnetic radiation. This can be detected from microwaves right up to gamma-rays. This radiation travels in a straight line at the speed of light and takes about 8 minutes to reach Earth. If we had no atmosphere we would be fried!! Fortunately our atmosphere and the Earth's magnetic field protect us from the worst of the radiation blast. The UV penetrates to the D-layer and the higher energy waves create an avalanche of particles in the very outer regions of the atmosphere.   When the radiation reaches the D-layer it produces a very high level of ionisation, pushing the "reflection" level right down through the normally lightly ionised absorbing layer. In effect we have a "mirror" at 50 km and no attenuation of the sky wave signals. Hence the usually displayed "shark-fin" response on the signal strength plots. The height of the trace is related to the strength of the flare (see the NOAA web site for a tutorial) though a very strong flare may saturate. From experience it is unlikely that a flare of below Class-C1.0 will be reliably detected. In solar quiet conditions it may be possible in retrospect to relate deviation in signal strength to flares of B5.0 or higher. Detection sensitivity depends upon many factors including the distance from the VLF transmitter and the time of day. It may be useful to monitor several stations to determine which gives the best sensitivity.

Abnormal Results

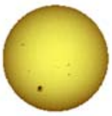
It is not unusual for an observer to get strange results that are difficult to understand at first. A common one is a negative going “shark-fin” at a flare. This has been written off by some as an equipment fault, but it is a function of the distance from the transmitter of the monitored signal. Remember the fading effect mentioned earlier; if the ground wave is much stronger than the normal quiet sky wave and they are out of phase, then an *increase* in sky wave strength will *reduce* the level of the composite signal. This can be complicated by some flares which cause the signal to go one way at first and then the other before the signal returns to the undisturbed level.

The shape of the recording will depend on:

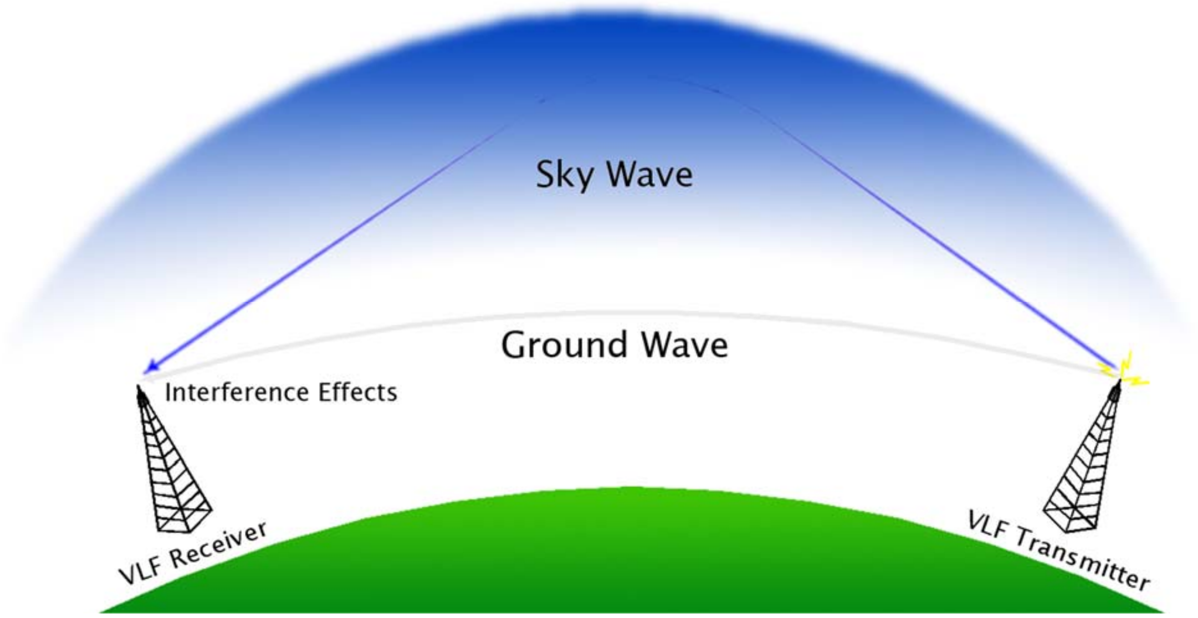
- The distance between the transmitter and the Receiver
- The effects of the signal level going both up and down before returning to normal

If you are a great distance from the station (when monitoring LF beacon stations at 2000 km the flare effect will always be upward because the ground wave is very weak at this range) then there are some special effects that take place at sunrise and sunset. These are often referred to and the morning and evening “dips”. These are caused by the daytime Sky-wave being wiped out by an unexpected effect. At sunrise and sunset the Ionospheric “reflection point” is actually illuminated from underneath, by weak rays that have grazed the ground at the edge of the darkness shadow. These produce weak ionisation levels that strongly absorb radio signals but are not enough to “reflect”. They totally cloak the E-layer that will soon take up the reflection of the night-time sky wave, thus virtually removing the daytime sky wave. The composite signal level at this time correlates well with calculations of ground wave only signal strength, which are based on transmitter power, range, and ground conductivity.

Detection Summary

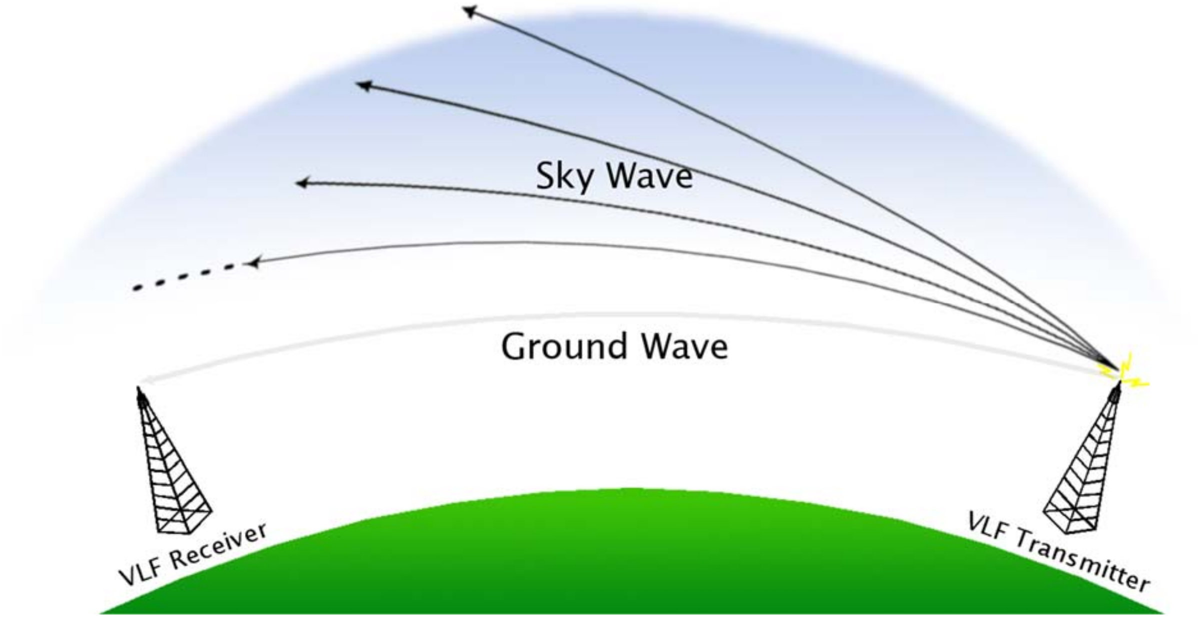


Quiet Sun

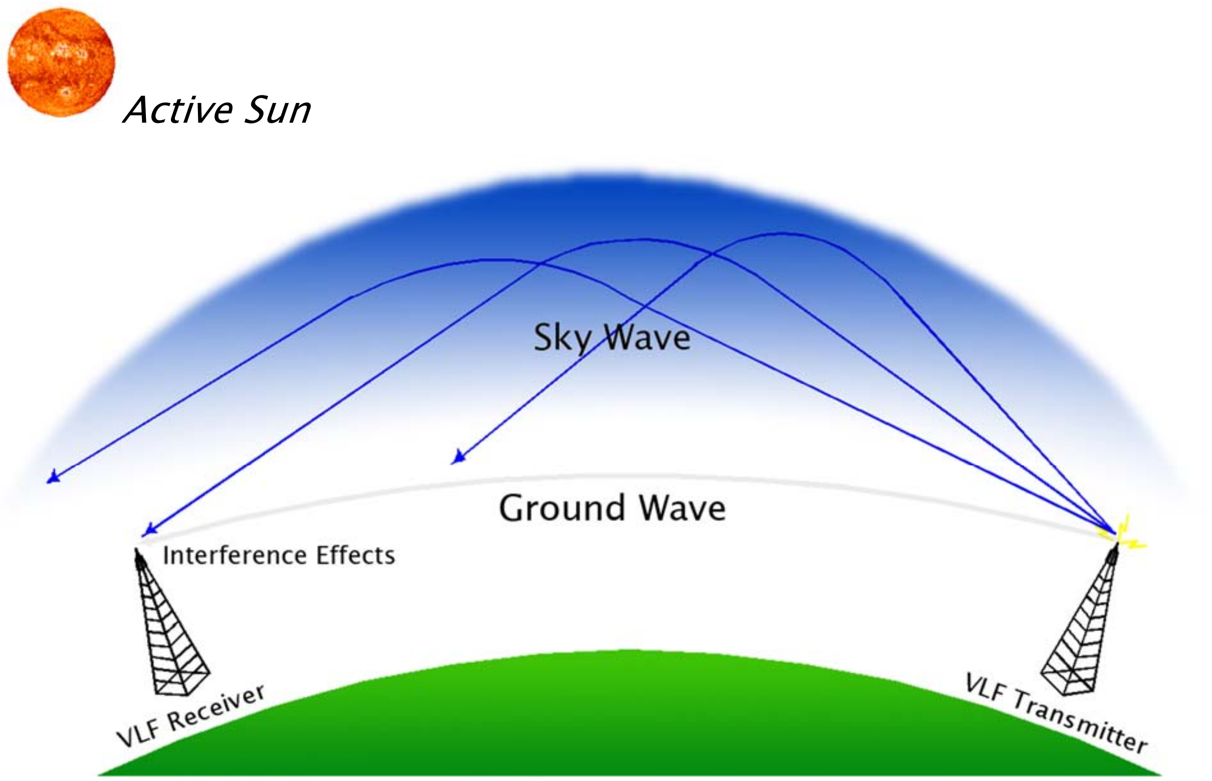


Low level of sky wave signal received vs. ground wave.

At Night



Erratic level of sky wave signal vs. constant ground wave.



High sky wave signal level received during a flare.

Selecting a Suitable VLF Transmitter

Background

There are a number of Military transmitting stations in VLF that normally transmit 24 hours a day every day (see the Transmitter frequency list in the Appendix). This makes them excellent beacons for probing the ionosphere for the changes produced by Solar Flares. VLF waves are used for time signals and radio navigation beacons such as the Russian hyperbolic radionavigation system RSDN-20. Since VLF can penetrate water to a depth of several metres, it is used by the military to communicate with submarines near the surface. Transmitters have a power of a few hundreds of kilowatts.

As described in the preceding section, a received VLF signal has two components: the ground wave, which follows the curvature of the earth, and a sky wave which is 'reflected' from the D layer of the ionosphere.

At about 700 km range the ITU Recommendations suggest that the sky wave (or ionospheric 'reflected' wave) is comparable in strength to the ground wave. Stations closer than this will be mainly received by ground wave, which is not affected by ionospheric conditions and is in fact very steady in strength. At distances greater than 700 km the sky wave predominates. This suggests that a station between 500 km and 1000 km is a good choice for detecting SIDs.

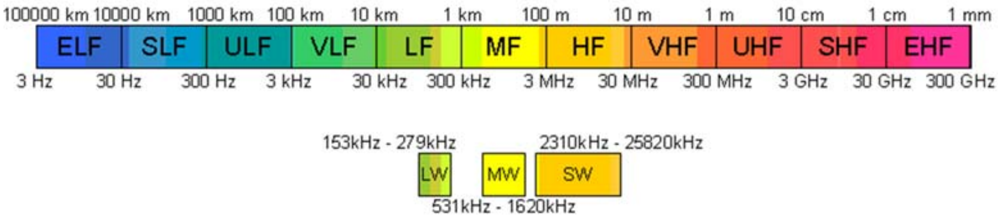
In practice observers have found that closer stations can give good responses to SIDs. For UK observers, 19.6kHz from Anthorn and 22.1kHz from Skelton are closer than 700km but can give a strong response to SIDs. Tavolare in Italy is at a suitable distance but may need a sensitive aerial as it transmits a relatively weak signal.

Experience has shown that Ramsloh in Germany, transmitting on 23.4kHz, is a favourite station. It has a strong signal and is easy to identify as it often has a characteristic shutdown for an hour around 07:30 UTC.

One very distant station which UK observers can monitor is 24kHz from Cutler in the USA. The upper limit for having a single hop is about 1,900 km during the day (assuming a D-layer at an altitude of 70 km) and 2,100 km during the night (assuming an E-layer at an altitude of 90 km). Transmitters at a greater distance will be received through two or more hops and will exhibit more than one sunrise and sunset pattern.

In recent years the level of radio interference in the VLF band has increased substantially as "switched-mode" power supplies are installed in everything from TV and PCs to mobile phone chargers, and everyone uses "dimmers" on their house lights. It is probably best to select a strong station at less than the optimum range initially, and progress later to more difficult targets when you understand the local radio environment. Radio Astronomy is dogged by radio-interference problems at all frequencies.

The radio frequency spectrum has been split into regions according to ITU radio regulations, as shown in the diagram below. The VLF region corresponds to frequencies between 3kHz and 30kHz (wavelengths between 100 and 10km). Those frequencies are much lower than those used for AM broadcast radio stations (LW, MW, SW).



The VLF frequency range is also home to natural electromagnetic emissions (called spherics, tweeks, whistlers...) emitted thousands of miles from the Receiver. They can be turned into sound that we can hear. This is called "natural radio". The book Radio Nature (see References) describes these phenomena in more detail.

Choosing a Transmitter for SID Monitoring

You can find in this website a list of VLF transmitters that can be used for SID monitoring. Appendix 2 lists various VLF transmitters.

The NATO transmitter at 23.4kHz, situated in Ramsloh, Germany, is often chosen by UK VLF observers due to its generally favourable location, signal strength and the distinctive 1 hour daily shut down.

The 23.4kHz NATO transmitter is located close to the site where the European DCF77 time signal is transmitted. The web site (see DCF77 range) mentions a predominant ground wave until 500km (300 miles) and a similar ground and sky wave field strengths from 600 to 1100km (400 to 700 miles).

UKRAA has chosen 23.4kHz as the default tuning for its Receiver.

UKRAA will supply Receivers tuned to other frequencies on request. Please contact UKRAA to discuss your requirements. Outside Europe there are numerous other stations, some of which are included in Appendix 2.

For any observing site the response of a particular channel will depend on the relative magnitude and phase of the ground and sky waves. Monitoring several different frequencies shows how the observed effect can vary depending on distance and the height of the ionosphere when a SID occurs.

VLF Receiver Technical Description

The previous sections have shown how the SID detection mechanism relies on monitoring VLF beacons over a long period of time. The UKRAA VLF Receiver is a high-gain, very narrow band amplifier that may be tuned to the specific frequency of a VLF beacon. The loop aerial normally used is also tunable, to further enhance the selectivity of the system. Some users may find adequate results with an untuned single-wire aerial, but this will require an electrically quiet location.

Please refer to the circuit diagram in the Appendix. A cascode input stage buffers the tuned aerial, providing a small gain. Its primary function is to isolate the aerial from the narrow-band filter. The filter circuit uses four operational amplifiers (opamps), and is based on a circuit used in analogue computing. While it is greedy on opamps, it provides nearly independent control of gain, frequency and Q (a measure of the bandwidth), a feature that greatly speeds up initial tuning. Just two close tolerance capacitors are required. To eliminate the build-up of offset voltages in such a circuit, the filter output is AC coupled into a selectable x1 or x10 gain stage. In conjunction with the filter gain control, this can be set to fit the diurnal change in signal strength within the range of the output.

The amplified and filtered signal is rectified to provide a simple DC output with a fairly long time constant of about 10 seconds. This will remove all of the original modulation, and produce a smoothly changing voltage free of too much noise. A final x2 amplifier drives the output to the recording device. Outputs are provided at 0…2.5V and at 0…5V, depending on the measuring device to which the receiver is connected. Further filtering can be provided by the recording system, if required. No calibration of signal strength is required, as this is an indirect recording of the Sun. The important part of the observation is to record the *timing* of the events.

A small serial memory (EEPROM) is included in the Receiver to ensure backwards compatibility with the Starbase software and the associated Controller which is no longer available. This stores identification and configuration details for the module (as XML), allowing the Starbase Observatory to automatically identify which instruments are connected.

The Receiver module contains a temperature sensor, allowing calibration of the response with variations in ambient temperature.

Setting up the VLF Receiver System

Tools required

Multimeter

Small watchmaker's screwdriver

VLF Signal Generator

The UKRAA Multi Frequency VLF Signal Generator is shown below. The generator has one high-level output for driving an aerial, and a low-level output for direct connection to the Receiver input. Each Signal Generator includes 6 frequencies and various frequency sets are available. The standard (UK) frequency set includes 23.4kHz, which simulates the Ramsloh VLF transmitter, which is a common choice for UK residents.

The UKRAA Multi Frequency VLF Signal Generator

Tuning the Receiver

***** PLEASE READ THIS BEFORE ATTEMPTING TO TUNE THE VLF RECEIVER *****

UKRAA VLF Receivers are supplied already tuned to 23.4 kHz (Ramsloh). Do NOT attempt to re-tune your VLF Receiver unless you wish to receive a different frequency. If you are trying to receive 23.4 kHz (Ramsloh) but are not receiving the expected trace, please contact UKRAA (info@ukraa.com) before you try to re-tune the Receiver, unless you are confident that you know what you are doing!

Tuning the Receiver requires a digital multimeter, a signal generator operating at the frequency of your chosen VLF beacon, a screwdriver, and some patience! The characterisation section contains a receiver response curve to show what can be achieved by carefully following this procedure.

- VR1 is RF gain
- VR2 is Q factor of the filter
- VR3 is Coarse Frequency
- VR4 is Fine Frequency

Proceed as follows:

1. Unscrew the four end panel screws from the DC input end of the Receiver case, ease the end panel away from the enclosure and slide off the top panel to expose the printed circuit board. The four trimmer variable resistors, coloured blue and marked on the printed circuit board, are adjusted by means of a screw on the top of the casing.

2. Put a shorting link on the aerial socket.

3. Remove the shorting link from P11. This removes the time constant produced by C6 and allows the Receiver output signal to change more rapidly to follow the tuning adjustments. Remember to replace the link when tuning is completed.

4. Wind VR1(RF gain) fully clockwise and VR2 (Q), VR3 (Coarse Frequency) and VR4 (Fine Frequency) fully anti-clockwise - about 30 turns should do. Some trimmer pots produce a definite click when they reach the end as the guide jumps a thread, some don't. Then wind VR4 (fine Frequency) back clockwise about 15 full turns, to mid-position.

5. Connect a voltmeter to the output terminals on P10 or P7. Either an analogue or digital meter will do, although digital meters are a little slower to respond when looking for tuning peaks. Connect the 15 Volt supply. If you can also measure the current drawn from the supply it should be around 30mA. If it is less than 25mA or more than 40mA remove the power and examine the board for problems.

6. Assuming the current draw is correct, observe the output voltage level on the meter across P10 or P7. It should be approximately 0.25V (between 0.2V and 0.3V is acceptable) on P1 or approximately 0.5V on P7. Set the range on the output meter to a range which will display 2.5 Volts if using P10 or 5 Volts if using P7. Turn VR2 (Q) clockwise slowly, say a quarter turn at a time, watching the meter for any sign of an increase in the indicated output level. At some point before the fully clockwise position the output level will start to rise rapidly. Stop turning the trimmer adjust screw and await a stable reading. In all probability this will be 2.5V (or 5.0V). Now very slowly inch the adjuster screw back (count to five between each move of say 1/8th turn) anti-clockwise until you detect the level dropping then stop and allow the meter to settle, probably at 0.25V (0.5V) again. You should then be able to put a further quarter turn clockwise on the adjuster without the output level changing. You have adjusted the filter to its most selective just below the point where it bursts into self-oscillation.

7. Remove the power plug and the short across the aerial pins and connect a signal generator set to the desired frequency (such as one of the UKRAA Signal Generators). Re-connect the power to the receiver and the generator and apply a signal of a few millivolts amplitude to the receiver (use the low level output on the UKRAA Signal Generator). The output level should read around 0.25V (0.5V) at this stage (if not, repeat step 5 above).

8. It may be useful to select a more sensitive range on the meter measuring the output level, say the 2 Volt range.

9. Now turn the coarse frequency control VR3 clockwise about a quarter turn at a time and give a few seconds between each adjustment. After a few turns you will see the output level increase significantly (several tens of mV). Allow the meter to settle, then slowly continue adjusting the control to achieve the highest reading. If, however, the output level reading goes to over about 1.7V, reduce the RF gain by turning VR1 anticlockwise until a

reading of around 1.0V is obtained, then continue adjusting VR3 for the highest output level reading.

10. When you cannot achieve any better output, return to adjusting VR2 (Q) very slowly clockwise, watching as the output level rises. Reduce the RF gain VR1 again if the reading creeps over 1.7V. At some point the output level will rise rapidly to 2.5V. Back off the Q adjustment slowly 1/8th turn at a time until the output level just begins to drop. Stop there and wait for the output level to stabilise. You may be able to re-set another clockwise 1/8th turn or even quarter turn without the filter oscillating.

11. You now have a high selectivity and sensitivity at the required frequency, but there is some interaction between the controls and some hysteresis on the Q control. You now need to adjust the frequency to get right on the peak of the filter and you should use the Fine frequency control VR4 to give the highest output level reading. At this stage remove the signal generator connection and check that the output level drops to 0.2V again. If the level does not drop with the signal generator removed the Q setting is adjusted too high and the filter is oscillating. Turn the Q control VR2 about 1/8th turn anti-clockwise waiting several seconds between each adjustment.

12. You will soon become adept at slowly walking the receiver sensitivity and selectivity up to a maximum, by repeating the above adjustments in turn.

13. You must now check for the reliability of the setting, to ensure the receiver does not burst into oscillation with changes in room temperature or when you switch it on. We cannot do a temperature test very easily but when you start to use it you will become aware of traces that saturate your “recorder” at 2.5V. You can however set the RF gain for a reading of about 1.0V output level with the signal generator applied and then remove the power from the receiver and reconnect it. If the receiver is stable you should see it settle back each time to about the same output level.

14. Replace the shorting link on P11.

15. Tuning is now complete and you should be able to measure your selected signal now when you connect a tuned aerial or 10 metres or more of wire aerial. You may find you wish to carefully readjust the fine frequency control on the live signal to get best protection against other nearby signals, because the signal generator may not be quite on the same frequency as the transmitted signal. This adjustment is not essential and the receiver as set up by the above instructions will produce a good record.

16. There are some adjustments you may need to make when using the receiver which are dependent on your distance from the target transmitter. These are covered in a later section.

The RF gain (VR1) and DC gain (x1, x10 jumpers) and fine tuning (VR4) should be left until the aerial has been tuned and should be used to set a Solar-quiet level of about 1 Volt or possibly slightly less if using the 2.5 Volt output. The fine tune should be used to peak the signal from *(e.g.)* Ramsloh coming in on the aerial when it has been correctly identified (*e.g.* by the breakfast "maintenance break"). The maximum signal in event of a flare will be of similar strength to the peak signal received after dark – flares cannot be detected after dark of course.

Monitoring over a period of days should allow any final adjustments to be made. Beware that signals may go off for periods of time, and may indeed not be present when initial tuning is attempted! Try different times of day if the signal cannot be found first time. If subsequent attempts to find a signal fail, then try for an alternative signal.

Tuning the Aerial

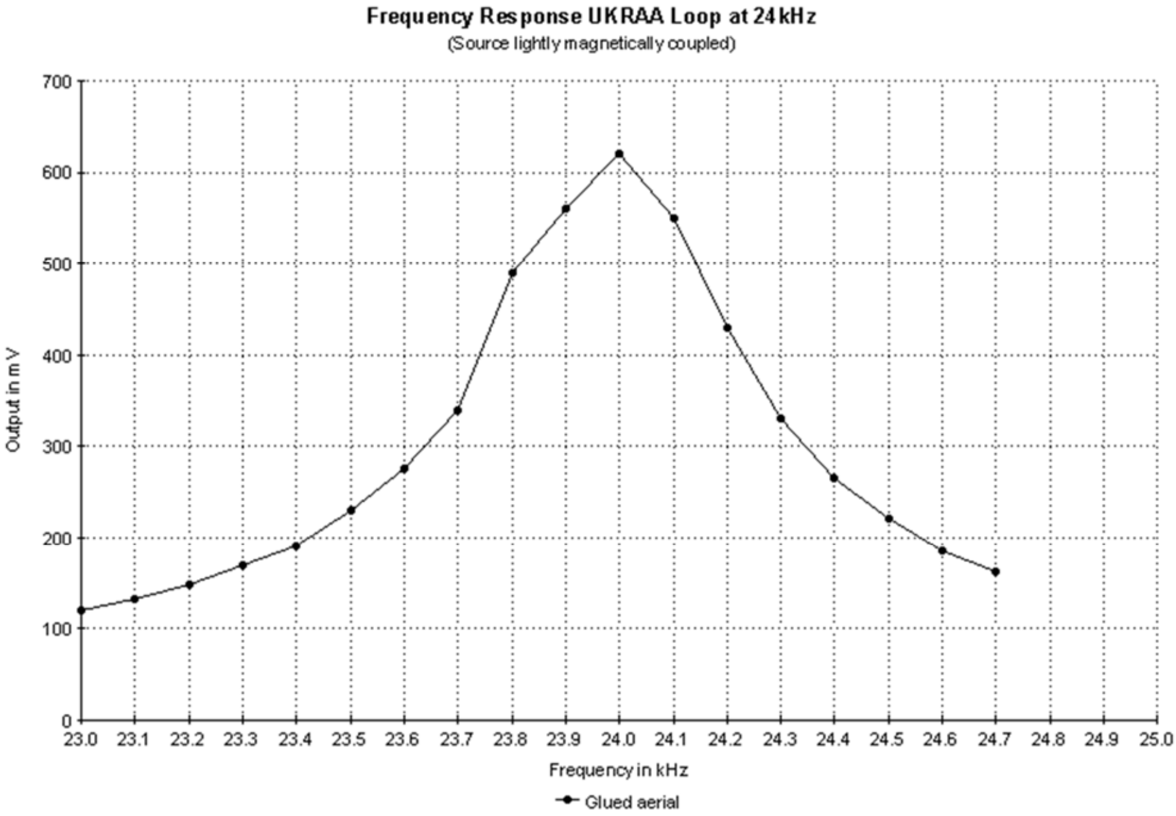
The aerial is tuned with an audio signal generator. Connect a signal generator (such as the UKRAA Signal Generator) through a 100k resistor to the aerial, and set it to the required frequency. Alternatively, if a tuned VLF Receiver is available, it will be found that sufficient signal level is present to tune the aerial by placing the signal generator on the base plate of the aerial. Monitor the voltage across the aerial with an oscilloscope or AC voltmeter (this will need to be quite sensitive), and adjust the tuning capacitor for maximum voltage. If a maximum cannot be found, then add or remove padding capacitance according to which way the tuning capacitor has stopped. Tuning is complete once the maximum is found within the range of the variable capacitor (ideally somewhere near mid-range).

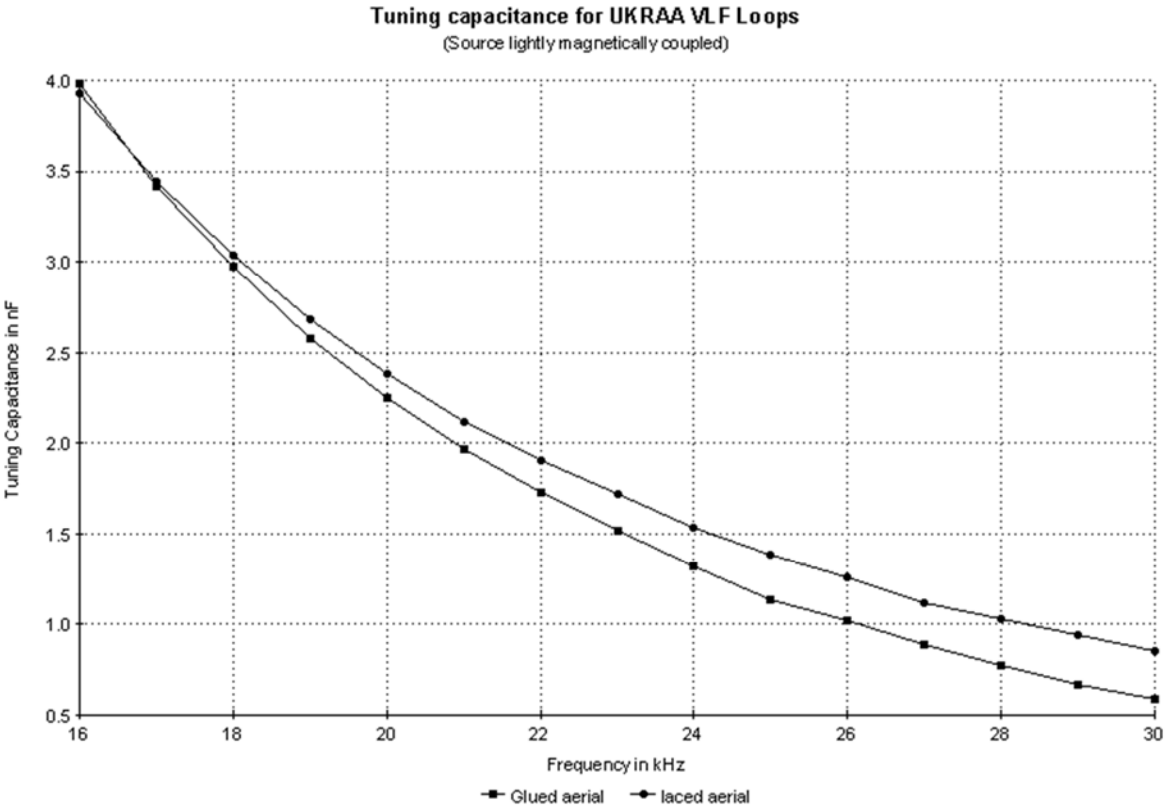
Aerial Characterisation Measurements

UKRAA have made some basic measurements on the UKRAA loop aerial, to give an indication of the frequency response. The source used was a Philips synthesised function generator, and the response was measured on a Tektronix 7603 oscilloscope. The generator was connected to one untuned loop to provide the stimulus signal; the "loop-under-test" was tuned with a JJ Lloyd Instrument Capacitance Substitution Box. The source and measured loops were separated by about half a metre.

The loops were each resonated over a range of frequencies most like to be of interest for VLF SID detection, and the tuning capacitance required against frequency was plotted. One loop was laced and the other was wound with an adhesive coating on the wire that was activated by heating. (The heating was achieved by passing a current through the loop.) The loops are referred to on the plots as "glued" and "laced". The bandwidth response of the glued loop was then measured by tuning it to 24kHz and measuring the response at 100Hz intervals either side of the resonance.

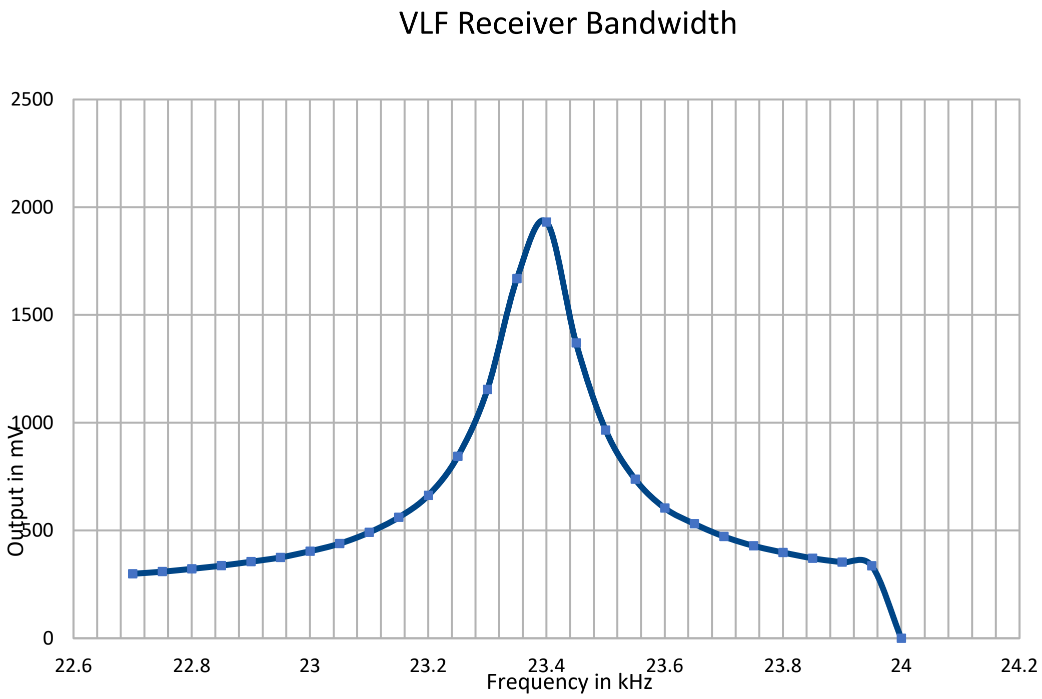
The “glued” coil had 125 turns, the “laced” coil had 128 turns. The results are shown below.



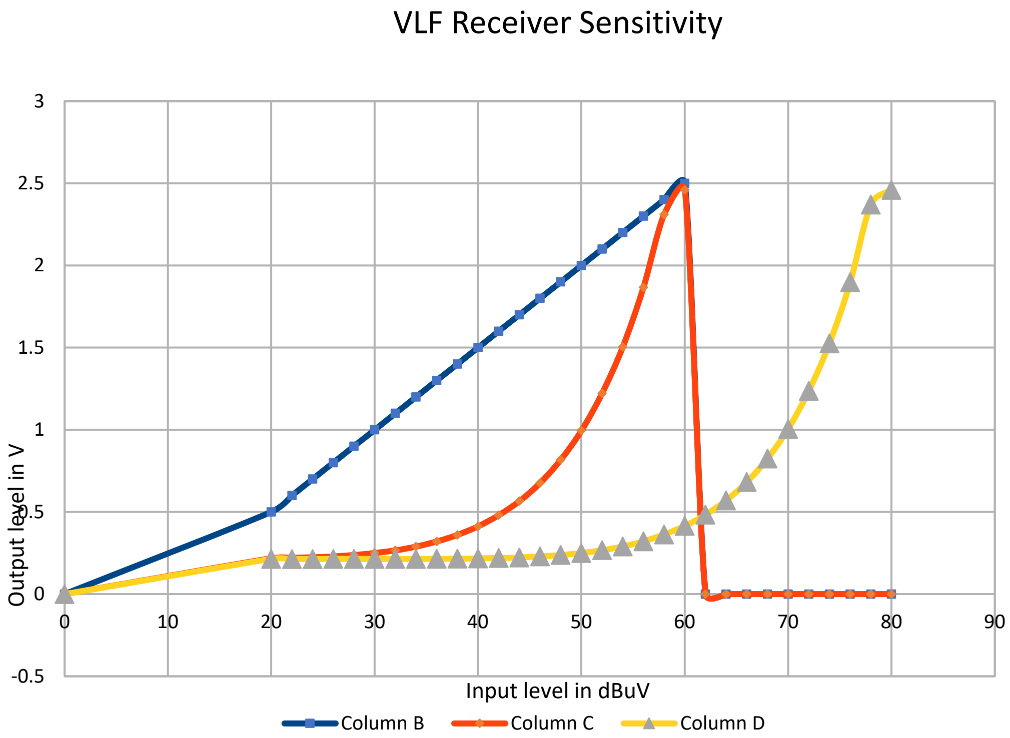


Tuning capacitance for UKRAA VLF Loops

(Source lightly magnetically coupled)



VLF Receiver Bandwidth



Column B – Log Scale, Column C – DC Gain x10, Column D – DC Gain x1

Dimensional and Electrical Considerations

These notes were contributed by Whit Reeve, Alaska.

This section gives three methods for calculating the loop inductance, as opposed to direct measurement of an assembled coil. All of the methods are estimates and none perfectly fit the actual aerial construction. Specifically, the coil cross-section on the actual aerial is more or less circular, but the methods assume either a flat, single-layer cross-section or rectangular, multi-layer cross-section. The dimensions are given in units convenient to the original equations.

Mechanical Dimensions

The UKRAA loop aerial has a square shape with a diagonal length of 0.575 m = 57.5 cm. The loop is made from hardwood and plywood and consists of 137 turns of 24 AWG coated magnet wire. The wire has a coated nominal diameter of approximately 0.0205 in. = 0.521 mm = 0.0521 cm and uncoated nominal diameter of 0.0201 in. = 0.511 mm = 0.0511 cm.

The width of a square in terms of its diagonal length is

$$W = \frac{\sqrt{2}}{2} \cdot l \qquad \textbf{Eq. (1)}$$

where

W = square width

l = diagonal length

The perimeter length of a square is

$$p = 4 \cdot W \qquad \textbf{Eq. (2)}$$

where

p = perimeter length

Therefore, for the loop in question

$$W = \frac{\sqrt{2}}{2} \cdot 0.575 = 0.4066 \text{ m} = 40.66 \text{ cm}$$

$$p = 4 \cdot 0.4066 = 1.626 \text{ m}$$

The enclosed area of a square is

$$A = W^2 = (0.4066)^2 = 0.165 \text{ m}^2 \qquad \textbf{Eq. (3)}$$

where

A = enclosed area of square

Inductance Method 1: Single-layer polygon coil

The approximate inductance in μH of a polygon is given by[1]

$$L \approx \frac{0.03948 \cdot a^2 \cdot n^2}{b} \cdot K$$

Eq. (4)

where

a = Average of inscribed and circumscribed radii,

$$r \cdot \cos^2\left(\frac{\pi}{2 \cdot N}\right) \text{ (cm)}$$

Eq. (5)

r = radius of circumscribed circle (cm)
N = number of sides (4 for a square)
n = number of turns
b = length of coil, or $n \cdot d$ (cm)
d = distance between turn centres = wire diameter for close spacing (cm)
K = function of $2 \cdot a / b$ from Table 10, page 283 of the reference NBS document

The radius of a circumscribed circle for a square is

$$r = \frac{W}{\sqrt{2}} = \frac{l}{2} = 0.2875 \text{ m} = 28.75 \text{ cm}$$

Eq. (6)

and the average of the inscribed and circumscribed radii is

$$a = 28.75 \cdot \cos^2\left(\frac{\pi}{2 \cdot 4}\right) = 24.54 \text{ cm}$$

The estimated coil length is b = 7.9 mm = 0.79 cm. K is based on $2 \cdot a / b = 2 \cdot 24.5 / 0.79 =$ 62 and is found in the reference by interpolation, or

K = 0.05158.

Substituting the above values, the calculated inductance is

$$L \approx \frac{0.03948 \cdot 24.5^2 \cdot 137^2}{0.79} \cdot 0.05158 = 29{,}135 \text{ μH} = 29.1 \text{ mH}$$

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[1] Eq. 153, p 252, Circular C74, Radio Instruments and Measurements, US Department of Commerce, National Bureau of Standards, 1937

Inductance Method 2: Multi-layer polygon coil with rectangular cross-section

The approximate inductance in µH of a square coil with rectangular cross-section is given by[2]

$$L = 0.01257 \cdot a \cdot n^2 \left[2.303 \cdot \left(1 + \frac{b^2}{32 \cdot a^2} + \frac{c^2}{96 \cdot a^2} \right) \log\left(\frac{8 \cdot a}{d} \right) - y_1 + \frac{b^2}{16 \cdot a^2} \cdot y_2 \right]$$

Eq. (7)

where

a = Average of inscribed and circumscribed radii,

$$r \cdot \cos^2\left(\frac{\pi}{2 \cdot N} \right)$$ (cm)

b = axial dimension of the coil cross-section (cm)
c = radial dimension of the coil cross-section (cm)
d = diagonal of the cross-section (cm)
n = number of turns
y_1 = value from Table 14, p 285 of reference based on b/c
y_2 = value from Table 14, p 285 of reference based on c/b

The following values apply:

a = 24.54 cm
b = 0.79 cm
c = 0.79 cm
d = 0.79 cm
n = 137
b/c = 1
c/b = 1
y_1 = 0.8483
y_2 = 0.816

Substituting the above values, the calculated inductance is

$$L = 0.01257 \cdot 24.54 \cdot 137^2 \left[2.303 \cdot \left(1 + \frac{0.79^2}{32 \cdot 24.54^2} + \frac{0.79^2}{96 \cdot 24.54^2} \right) \cdot \log\left(\frac{8 \cdot 24.54}{0.79} \right) - 0.8483 + \frac{0.79^2}{16 \cdot 24.54^2} \cdot 0.816 \right] =$$

27,029 µH = 27.0 mH

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[2] Eq. 157, pg 257, Circular C74, Radio Instruments and Measurements, US Department of Commerce, National Bureau of Standards, 1937

Inductance Method 3: Single-layer square coil

The approximate inductance in µH of a square coil with rectangular cross-section is given by[3]

$$L = 0.008 \cdot a \cdot n^2 \left[2.303 \cdot \log\left(\frac{a}{b}\right) + 0.2231 \cdot \frac{b}{a} + 0.726 \right] - 0.008 \cdot a \cdot n \cdot [A + B]$$

Eq. (8)

where

a = width of square measured between centres of the cross-section (cm)
b = length of coil (cm)
n = number of turns
A = 0.557 (Table 11, page 284 of reference)
B = 0.330 (Table 12, page 284 of reference)

The coil width is a = W = 40.66 cm, coil length is $b = 7.9$ mm = 0.79 cm and the number of turns n = 137.

Note: For calculation purposes, the estimated winding pitch, D = d (that is, wire diameter). Therefore, D/d = 1 and from Table 11, A = 0.557. Also, the correction factor, B, is based on the actual number of turns and from Table 11, B = 0.0330 by interpolation.

Substituting the above values, the calculated inductance is

$$L = 0.008 \cdot 40.66 \cdot 137^2 \left[2.303 \cdot \log\left(\frac{40.66}{0.79}\right) + 0.2231 \cdot \frac{0.79}{40.66} + 0.726 \right]$$
$$- 0.008 \cdot 40.66 \cdot 137 \cdot [0.557 + 0.330] = 28.484 \text{ µH} = 28.5 \text{ mH}$$

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[3] Eq. 165, p 264, Circular C74, Radio Instruments and Measurements, US Department of Commerce, National Bureau of Standards, 1937

Measurements

Note: Number of turns, n = 137
Measured inductance: 27.0 mH (by two different instruments)
Measured self-resonance frequency: 52.21 kHz
Measured dc resistance: 19.17 ohms at 21 °C
Calculated distributed capacitance, C_d, based on self-resonance: 344 pF

Resonant frequency with external capacitance of 2.03 nF (C_1): 19,978 kHz (f_1)
Calculated total capacitance at f_1: 2.35 nF
Calculated distributed capacitance based on C_1 and f_1: 320 pF

Resonant frequency with external capacitance of 2.13 nF (C_2): 19,554 kHz (f_2)
Calculated total capacitance at f_2: 2.45 nF
Calculated distributed capacitance based on C_2 and f_2: 324 pF

Resonant frequency with external capacitance of 3.01 nF (C_3): 16,812 kHz (f_3)
Calculated total capacitance at f_3: 3.319 nF
Calculated distributed capacitance based on C_3 and f_3: 309 pF

Frequency range with Aerial Tuning Unit (assuming zero length transmission line and C_d = 320 pF):

At C_{min} = 30 pF (+C_d): 51.8 kHz

At C_{max} = 3,665 pF (+C_d): 15.9 kHz

Troubleshooting and Radio Interference

- It is important to make sure that your Receiver has a good quality, stable power supply of the correct voltage.
- Check that the power supply pin size is 2.5mm, since 2.1mm pins may appear to fit, but will not be reliable.
- Take care with the tuning process; it may require several iterations before the tuning is at the optimum setting.
- The most likely cause of problems after successful tuning is interference from domestic electrical equipment. Position the aerial and the receiver well away from electrical devices, particularly those with electric motors or switched-mode power supplies. Fluorescent lighting may also be a problem.

Interference

The military communications stations that are used for our SID detection are spaced in frequency at various intervals but generally around 500Hz to 1000Hz apart. There are few if any potentially interfering stations in located in any particular area because these stations are designed for a very wide service area. However, because of the relatively narrow spacing it is essential that the receiver be tuned with the highest possible stable "Q". (Technically this is the ratio of the centre frequency to the bandwidth.) If the receiver is tuned properly there should in theory be no reason why the signal from Ramsloh (or other stations) should not be received. In practice the radio spectrum has become extremely polluted in the last 10 years by badly-designed consumer electronic equipment and inadequate regulation and policing. It is possible if your plots do not follow the smooth lines of the example plots in daytime that you may be dogged by local domestic radio interference.

Sources of interference

Despite some beliefs to the contrary radio interference cannot be "filtered out" and the best solution is to tackle it at its source. Of course to do this we need to understand the cause and location of the interference. Almost any modern electrical consumer appliance may be responsible and even some older ones. Any unit that is powered by a mains-plug power supply can be a problem. The majority of these used what is referred to as a "switching regulator", which transforms the 50Hz mains frequency to a much higher frequency where it may be efficiently reduced and regulated. The switching operation is often done at 20 to 40khz, yes right in the area we wish to receive radio signals! A unit like this in your house will provide a much bigger signal at your aerial than a transmitter 700 km away, and so will swamp the wanted signal. Some people may already have noticed the effect of some low energy light bulbs (CFLs) on Long-wave BBC Radio 4 reception.

Possible sources of domestic interference are

- Computers, desktops, or laptops...these may create special problem if part of the logging system.
- Mobile-phone battery chargers, or any other battery appliance charger.
- Television
- Baby alarms
- Mains computer networking systems.... e.g. *Homeplug*
- ADSL, your broadband system should not be a problem but can be if the splitter and modem are not placed close to the entry point of your telephone cable.
- Low-energy lightbulbs (CFL), some are better than others, try a different brand or keep a tungsten filament lamp for testing.

How to clean up

Start with possible sources that are close to the aerial, for instance a PC. Use a multimeter, (preferably digital) to monitor the VLF receiver output and switch the PC off. You can then move away from the aerial, and make you self a complete nuisance to the family by switching off every piece of domestic equipment and check to see if the signal changes. This of course assumes that the interference is at a much higher level than the wanted signal. You can check that you have the right item by using the loop aerial as a radio direction finder. The signal received by a loop will always be a maximum when it is located along the plane of the loop and a minimum when located on the axis of the loop. You may need to move the location of loop to get a "triangulation" on the source and locate it more definitely.

The initial intention is to remove major sources of interference from the vicinity of the aerial. If the culprit is, say, a phone charger, you could try plugging it in to a socket in a different room. Sometimes quite small changes in position will have a significant effect.

Another approach to tracking interference sources is to use an old-fashioned AM Medium and Long Wave pocket radio. Tune it to a position between stations on the long wave and then move round the house holding it close to anything that be generating interference. You are listening for a significant increase in the noise level. At a pinch a Medium Wave only radio can be used tuned to the very low end of the medium wave band (about 550kHz or 500 metres) Note that an appliance that causes an increase in noise may NOT be affecting your SID receiver if the frequency generated is above the VLF band.

When you have found possible sources of problems try to move them as far away from the aerial as possible. You may be able to get a better idea of what could be possible by moving your aerial and receiver down to the bottom of the garden as far away from any houses or power lines as possible. Running your laptop on batteries will help to check out the laptop charger.

Since every household has different problems it is impossible to define a way of defeating interference in all cases, but if you have an idea where the culprits are it is easier to control. If you have access to a local Radio Amateur, they may be able to provide useful advice on grounding (or earthing) though their expertise is generally at higher frequencies than we are using. Do try to contact us through the UKRAA Instrument Group on Yahoo and we will try to suggest ways to attack the problem.

Computer problems

These can be the most frustrating because the PC is often a vital part of the logging equipment. Generally, desktop machines are fairly docile because they have metal cases which must be grounded to the mains safety "Earth" on the power plug. Laptops can be a problem because they mostly have no safety earth connected through to the laptop itself. The result of this is that all the interconnecting wiring acts like a big wire aerial conducting not only the computer's radiations but also those from any other source in the area right into the receiver. In this case it may be necessary to make an "RF ground" to the Aerial Tuner unit. The effectiveness of this can often be quickly tested by connecting the outer of the BNC socket to a nearby central heating radiator. Alternatively, a yellow ESD protection plug can be modified to provide a safe grounding point.

Classification and Interpretation of Results

Flare Classification

Flares are classified on a rather curious scale, running A, B, C, M and X. The scale is logarithmic, and is calibrated as follows:

Class	Energy
X	$10^{-4}..10^{-3}$W/m^2 (measured at 0.1..0.8nm wavelength)
M	$10^{-5}..10^{-4}$W/m^2
C	$10^{-6}..10^{-5}$W/m^2
B	$10^{-7}..10^{-6}$W/m^2
A	$10^{-8}..10^{-7}$W/m^2

As it is a logarithmic scale, each category can be subdivided into 10, with a resolution of 0.1, leading to a flare being quoted as C5.6 or M1.2. The background level from a ‘quiet’ sun is often within A or B-class, with most flares being of B or C-class. More energetic active regions produce M or X-class flares. At the extreme, a flare can exceed X9.9, and produce X17 or X20 flares. Flares of X-class pose a threat to orbiting satellites, as well as human space travellers. C-class flares are easily detected as sudden ionospheric disturbances, while some larger B-class events can also be recorded. X-class events produce spectacular SIDs, as the ionosphere slowly recovers from the radiation impact.

Event Recording

When recording SIDs, start, peak and end times are required. ‘Start’ is the time at which the event is first recorded by the Receiver. ‘Peak’ is the time at which the maximum or minimum signal strength is recorded, and ‘End’ is the time at which the signal strength returns to its previous diurnal trend. Start and peak times are easily read in most cases, while the end time often requires a little guesswork to identify.

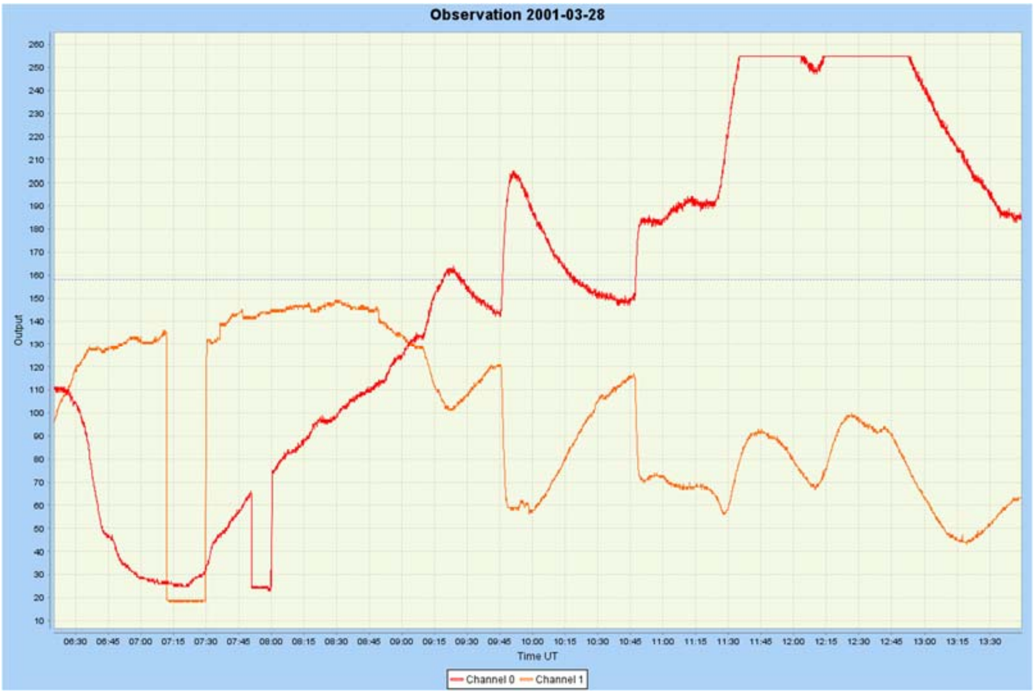
The amplitude of the disturbance usually correlates with the flare class, but will depend on the state of the ionosphere at the time. Since it is an indirect observation of solar activity, the amplitude is not recorded in VLF reports. The length (duration) of the SID recorded does not always correlate with flare class, but can be recorded as the ‘importance’ of the event on the Earth. This has traditionally been recorded as follows:

Duration	Importance
<18min	1-
19...25min	1
26...32min	1+
33...45min	2
46...85min	2+
86...125min	3
>126min	3+

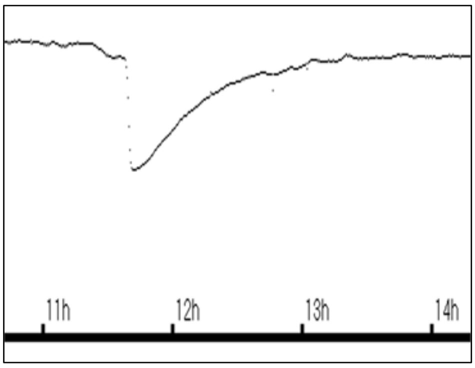
Interpretation of Recordings

The shape of recorded flares will vary from one observer to another, but a little experience while the Sun is active will allow most events to be isolated from other interference. The textbook SID has a sharp rise to a definite peak, followed by a longer recovery period. In practise, many SIDs do not look that simple, and may have multiple peaks. SIDs may also appear inverted, with the peak at a lower signal strength followed by a rising recovery period. This variation in shape is due to a combination of the path from Transmitter to Receiver, and the varying state of the ionosphere. The sun often produces multiple flares over a short period, leading to superimposed SIDs that can create confusion.

The following illustrations show some typical events:

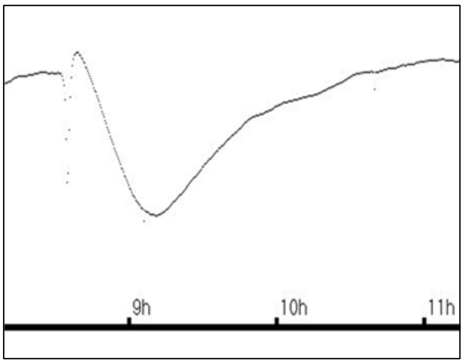


This plot shows the effect of a flare event on the signals from two different transmitters at two different ranges. the red trace follows the standard "textbook" shape, whilst the yellow trace shows the effect of the same flare when the ground- wave and sky wave are out of phase. the increased strength of the sky wave during the flare depresses the received signal level.



This is typical of an ordinary SID. Measurement is fairly easy. It is inverted relative to 'normal', but it is clearly the correct shape. It would be recorded thus:

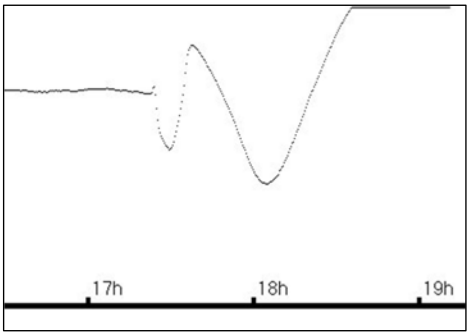
2005 March 10th. Start 11:39 Peak 11:42 End 12:42 Importance 2+



This is typical of a much more energetic solar flare, producing a SID that has a double peaked structure. The start and end times can be measured as usual; the peak time should be measured at the maximum point, in this case at 08:37UT.

It would be recorded thus:

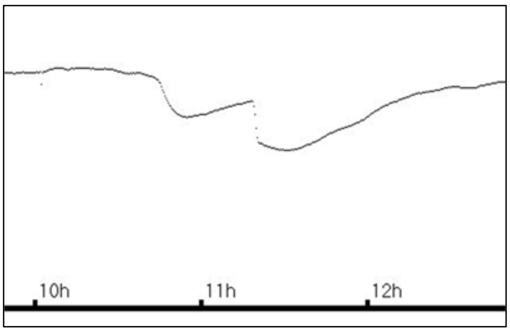
2005 September 15th. Start 08:33 Peak 08:37 End 10:33 Importance 3



This is much more difficult, as the flare occurred during the sunset dip in signal strength. The result is a combination of the two effects. The start is easily measured, and the peak is also clear (as above). The end time cannot be measured, and would be left blank.

It would be recorded thus:

2005 September 7th. Start 17:23 Peak 17:38 End ? Importance –

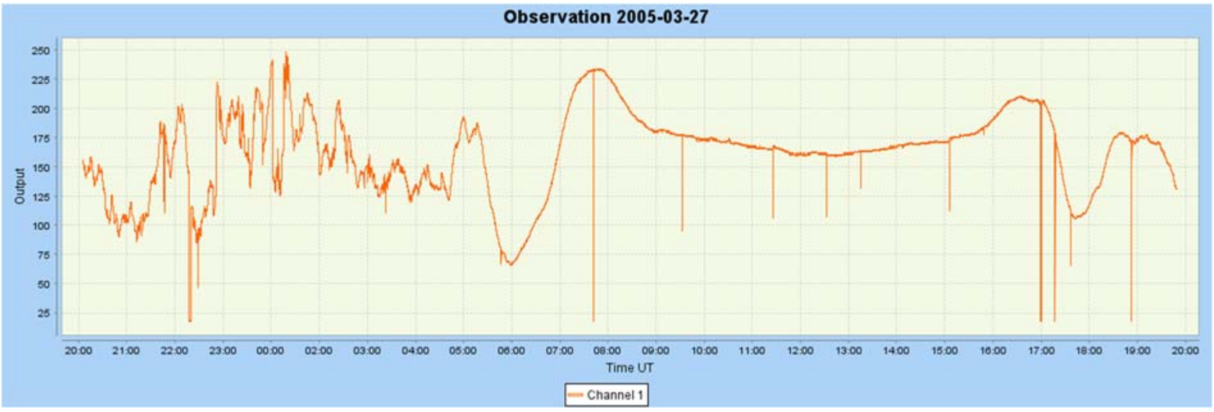


This recording shows 2 flares in rapid succession, such that the SIDs overlap. An end time for the first event cannot be measured.

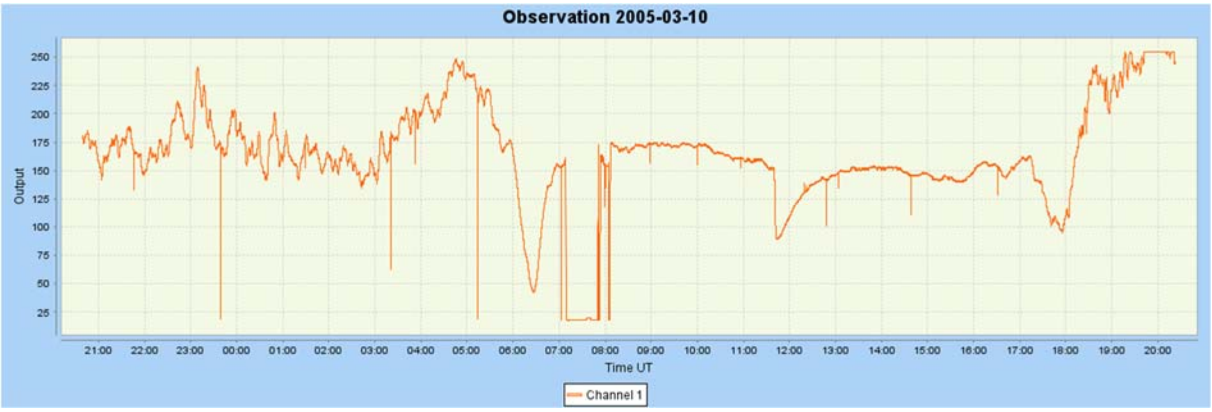
They would be recorded thus:

2005 September 13th. Start 10:45 Peak 10:55 End ? Importance –

2005 September 13th. Start 11:18 Peak 11:32 End 12:05 Importance 2+



Recorded at 23.4kHz, from the Ramsloh transmitter in North Germany, this graph shows signal strength against time over a 24 hour period. It shows random variation in signal strength at night, followed by a change as the rising sun recreates the D-layer. During the day, signal strength varies with the altitude of the Sun. At sunset, the D-layer recombines and is lost, producing another change in signal strength.



A C-class flare at 11:39UT disturbs the D-layer sufficiently to produce a distinctive change in signal strength, recorded as a SID. Note the sudden drop followed by a much slower recovery. SIDs can also show as a sudden increase in signal strength followed by the slow recovery. The transmitter was off-air between 07:10 and 07:50UT (the 'breakfast break').

This X-class flare recorded at 10:04UT had a more dramatic effect on the D-layer, as well as causing havoc to satellites and short-wave communications. The signal received from any transmitter is a combination of waves that have travelled slightly different paths and thus interfere with each other. Large D-layer disturbances can show this multiple-dip pattern as the interference pattern moves over the receiver. The slow recovery phase lasts for several hours.

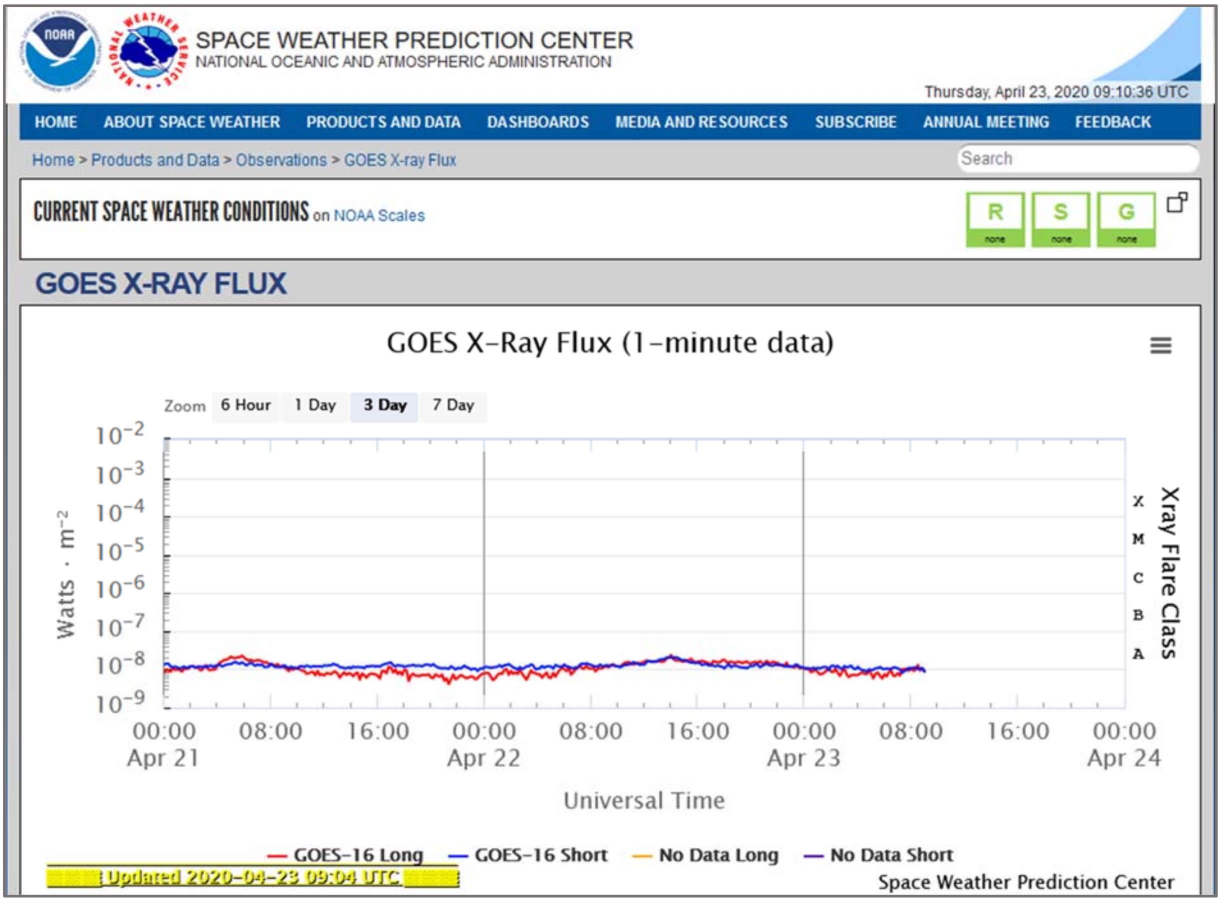
Note that all times are always recorded in Universal Time (UT = GMT+0), to the nearest minute where possible.

The GOES X Ray Satellites

When making observations of solar activity, it is sometimes useful to be able to compare your results with a reference set of observations which are known to be accurate. One very convenient set of data may be found at the NOAA Space Weather Prediction Centre (SWPC). This resource holds observations in many energy (wavelength) bands, and is also a good source of images of the Sun.

X-ray data from the GOES satellites is displayed graphically on the GOES X-ray Flux page (https://www.swpc.noaa.gov/products/goes-x-ray-flux). The raw data can also be downloaded from the NOAA website, which describes the location and format of the data.

An interesting set of solar images may be found at http://umbra.nascom.nasa.gov/images.



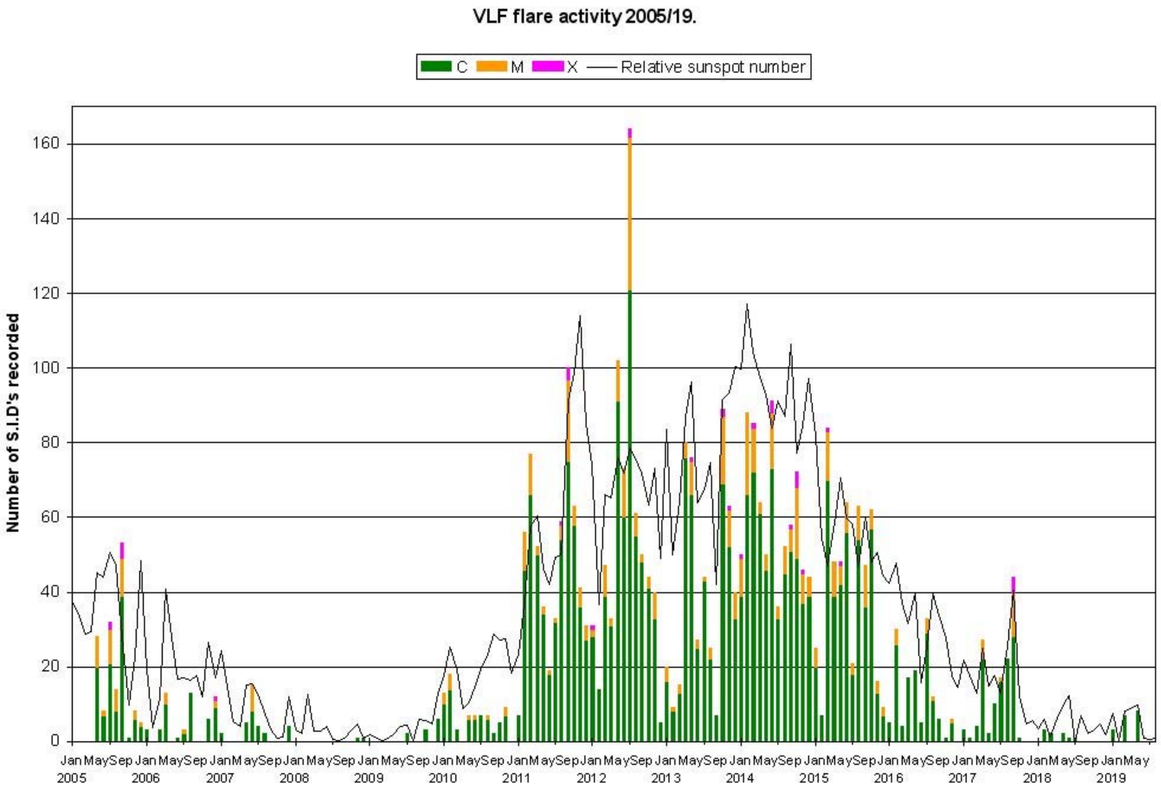
X-Ray data from the NOAA website

The Use of Multiple Receivers

Many experienced observers recommend the use of multiple receivers, tuned to different frequencies. This is because it is often possible to miss a SID event with a single receiver, since there are so many variables surrounding the location of receiver and transmitter, time of day, interference, weather and so on. Collaboration with other observers and sharing your results will also improve your chances of seeing an event, even if vicariously.

British Astronomical Association

The Radio Astronomy Section of the BAA collates SIDs observations from participating observers and issues a monthly report and an annual summary in the BAA Journal. New observers are welcome to make contact and submit their observations. This is also a good source of advice and encouragement. The record of SIDs starts in 2005 and covers the last solar cycle. The graph below shows that the frequency of SIDs follows the solar cycle.



Orientation of the Loop Aerial

The loop aerial responds to the magnetic component of the radio wave, not the electrical component as for example in a Yagi aerial. This means that the optimum orientation of the aerial relative to the transmitter is for the *plane* of the aerial to be pointing *towards* the transmitter. In other words, the axis of the loop should be at right-angles to the transmitter direction.

The magnetic response of the aerial should of course mean that it is much less sensitive to electrical interference.

Using the VLF Receiver

This section describes the background to data logging and one of the various options available for logging the output of the VLF Receiver:

- The UKRAA VLF Receiver produces a DC output voltage which can be converted to digital format using a LabJack digital-to-analog converter for recording and display using Radio-SkyPipe software.

The free version of Radio-SkyPipe II only allows one channel to be plotted but the Pro Edition supports up to 8 channels, allowing two channels (stereo left and right) to be plotted. Beware: some laptop PCs only have a mono microphone facility.

Configuring Output Voltage Options

The VLF Receiver offers a choice of output voltage ranges, 0-2.5V or 0-5V. The output voltage range is selected by connection to P7 (5V) or P10 (2.5V) as required. The LabJack U3 HV has four 0-10V and four 0-2.44V inputs. In order to obtain the highest resolution signal, the Receiver should be set to 2.5V output and the LabJack to 0-2.44V input.

Data Loggers

The output from the VLF Receiver is a varying voltage that is proportional to the strength of the signals received from the target transmitter. A continuous record of this voltage is required to indicate the presence of a Sudden Ionospheric Disturbance (SID) and thus a Solar Flare. In the days before readily available computers the output would have been recorded using a chart recorder ('strip chart') that would trace the signal level on a long strip of graduated paper using a pen. These were fun to use but refilling the ink reservoirs could be messy. These instruments can still be found on the vintage test equipment market and are still capable of doing the job. Their disadvantage is that one cannot re-analyse the data without carefully and laboriously reading it off, and it is not easily possible to compare two events or two days recordings in detail.

The development of digital measuring instruments in the 1960s laid the foundation for what became known as data-loggers. These are instruments that autonomously take measurements and record the values digitally, often against some form of time-stamp. The data can then be input to a digital computer for analysis, scaling, smoothing or filtering, display, publication, and finally archive storage.

There are several ways of recording the results from the VLF Receiver using data-loggers. UKRAA recommends using the Labjack U3-HV device, which is compatible with the VLF Receiver output and with Radio-Sky-Pipe.

Radio-SkyPipe

Radio-SkyPipe is a widely-used successor to the old 'stripchart' recorders. Full details of this free software application can be found at:

http://www.radiosky.com/skypipeishere.html

Radio-SkyPipe is available as free version and a paid for Pro version. The Pro version accepts up to 8 input channels and provides more functions than the free version. Full details are on the Radio-SkyPipe website. Radio-SkyPipe is a Windows operating software application.

Connecting to Radio-SkyPipe with a Labjack U3

As described above, the UKRAA VLF Receiver produces a DC voltage output. This needs to be converted into a form which can be read and processed by a computer. The LabJack U3 converts from analogue to digital signals. Full details of the device can be found at:

https://labjack.com/products/u3

The website has detailed instructions for installing the LabJack and its associated software. The LabJack U3 connects to a computer USB port and does not require an external power supply. LabJack provide software and drivers for Windows and a cross platform support library for Python software.

The output of the VLF Receiver can now be connected to the LabJack. We suggest that you connect to the first input channel, as follows:

VLF Receiver	LabJack
Positive (red terminal)	AIN0 terminal
Negative (black terminal)	GND terminal

Installing and Configuring Radio-SkyPipe

Use the instructions on the Radio-SkyPipe website to install the latest version on your computer. Please see the Radio-SkyPipe Support desk at

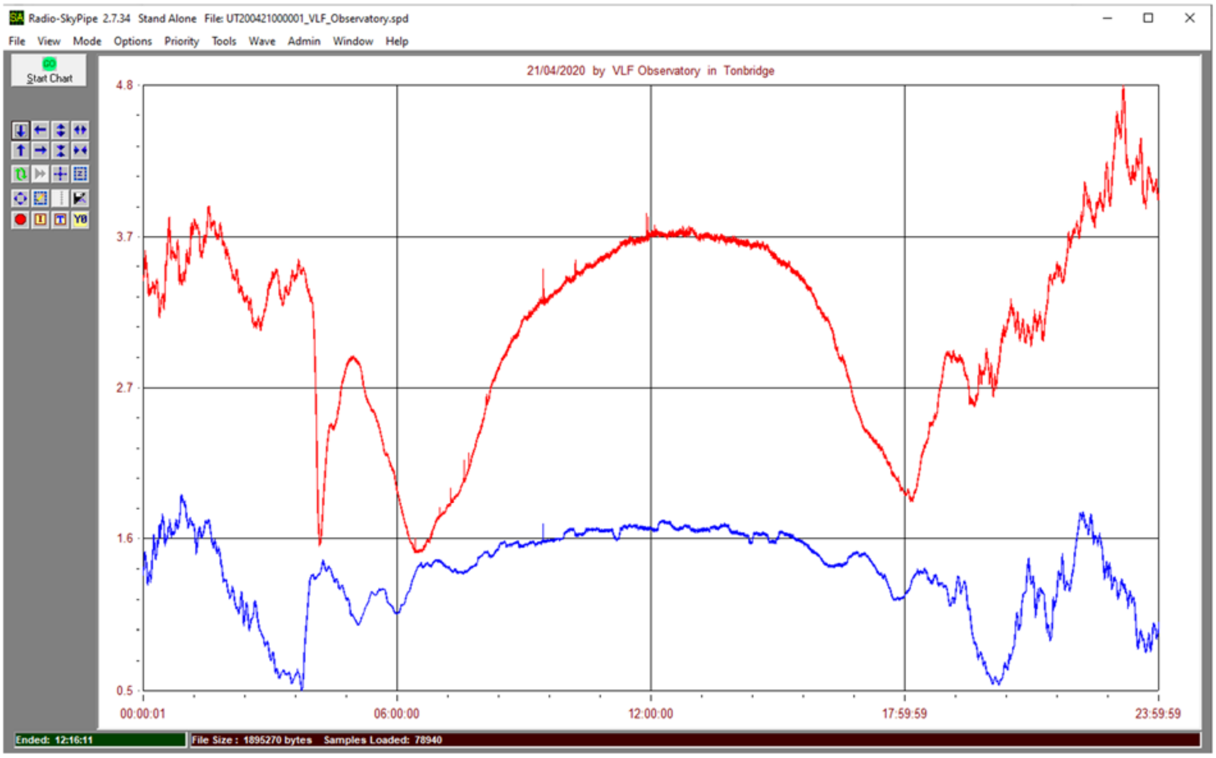
http://www.radiosky.com/support.html

for all queries related to the installation and operation of this application.

You will need to configure the Radio-SkyPipe application to work with the VLF Receiver. The most important step is to select the OPTIONS tab at the top of the main screen and set Data Source CH1 to LJ U3 ADC, assuming that you are using a LabJack U3 as your Analogue to Digital Converter. The Strip Chart settings can then be set to average ten readings taken every 0.2 seconds (giving a time constant of 2 seconds), to help average out any noise. A default Chart Width of 86,400 seconds will plot a full day's data on the screen. If you then use the Logging tab to restart charting at midnight, Radio-SkyPipe will create daily files that you can archive and review at leisure.

The LabJack U3 has 8 dedicated analogue inputs so it is ideally suited to monitoring additional VLF channels using UKRAA Receivers. For a more advanced set up, to increase the range of observations made, a UKRAA Magnetometer can also be connected.

The trace below is taken from a VLF system monitoring 23.4kHz from Ramsloh and 22.1kHz from Skelton in the UK.



Ended: 12:16:11

File Size : 1895270 bytes Samples Loaded: 78940

Radio Sky-Pipe Record of 2Channels of VLF data
Red trace 23.4kHz Ramsloh
Blue trace 22.1kHz Skelton

- Sound Card

It is now possible to use the UKRAA VLF Receiver without needing an analogue to digital converter. Radio-SkyPipe can work with the PC's sound card. The current version of the VLF Receiver has a facility to connect the 'raw' RF signal to the terminals. Connecting the 'raw' signal output requires the jumper lead from the PCB to the terminals to be moved from connector P7 or P10 to connector P8. This connects the output of the tuned circuit to the 4mm banana connections. The tuning of the Receiver means that the wanted frequency is the largest signal.

A 4mm to 3.5mm stereo jack-plug lead is required to feed this signal into the PC soundcard via the “mic” socket.

The range of signal that can be plotted is determined by the sample rate available on the sound card. Many internal soundcards operate at a sample rate of 48kHz, which limits the upper frequency that can be plotted to around 22kHz. However, USB soundcards are available relatively cheaply that sample at 96kHz and these will allow plotting of signals to just above 40kHz.

This output can be connected to a PC sound card and examined using software such as SpectrumLab. It is also possible to record the signal using Radio-SkyPipe. This connection provides a useful way to check that the Receiver is operating correctly and the aerial is correctly tuned. The signal can be displayed using software such as SpectrumLab (available free from https://www.qsl.net/dl4yhf/spectra1.html).

However this output is not recommended for long term logging. If the Receiver is not used in a UKRAA enclosure there is a risk of feedback into the Receiver if the connection is not carefully routed or screened.

Glossary

ADC	Analogue to Digital Converter
ATU	Aerial Tuning Unit
BAA	British Astronomical Association
BNC	Bayonet Neill-Concelman (connector)
CDROM	Compact Disc Read Only Memory
EEPROM	Electrically Erasable Read Only Memory
GMT	Greenwich Mean Time
GOES	Geostationary Operational Environmental Satellite
I2C	Inter IC Control Bus (also IIC bus)
ITU	International Telecommunications Union
LW	Long Wave
MW	Medium Wave
NATO	North Atlantic Treaty Organisation
NOAA	National Oceanic and Atmospheric Administration
RAG	Radio Astronomy Group
RF	Radio Frequency
RoHS	Restriction of Hazardous Substances
RS232	Electronics Industry Association Communications Protocol Standard
RS485	Electronics Industry Association Communications Protocol Standard, differential transmission
RSGB	Radio Society of Great Britain
RSP	Radio-SkyPipe
SID	Sudden Ionospheric Disturbance
SW	Short Wave
UKRAA	The UK Radio Astronomy Association
URL	Uniform Resource Locator
USB	Universal Serial Bus
UTC	Coordinated Universal Time
UV	Ultra Violet
VLF	Very Low Frequency
W/m^2	Watts per square metre
WEEE	Waste Electrical and Electronic Equipment
XML	Extensible Markup Language

References

Internet URLs

www.ukraa.com	UKRAA
www.britastro.org/radio	BAA Radio Astronomy Group
www.noaa.gov/	GOES satellite data & space weather
www.iaragroup.org/index.php/it/	Italian VLF group
www.vlf.it/	Renato Romero ELF/VLF website
https://sidstation.loudet.org/	SID Monitoring Station A118
https://www.ptb.de/cms/en/ptb/fachabteilungen/abt4/fb-44/ag-442/dissemination-of-legal-time/dcf77.html	DCF77 Transmitter
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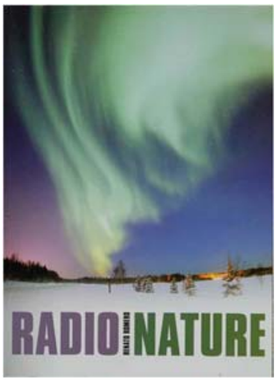
www.radiosky.com	Radio Sky Publishing

Books

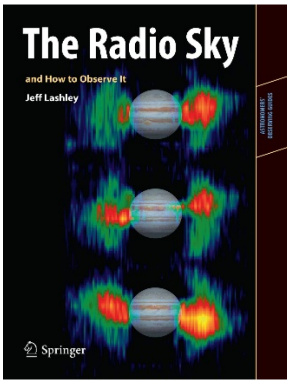


Radio Nature by Renato Romero

ISBN 9781-9050-8638-2

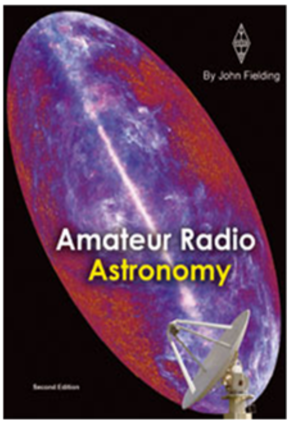
Published 2008

220 pages 240 x 175 mm



The Radio Sky and How to Observe It by Jeff Lashley
ISBN 978-1-4419-0882-7

First edition Published 2010

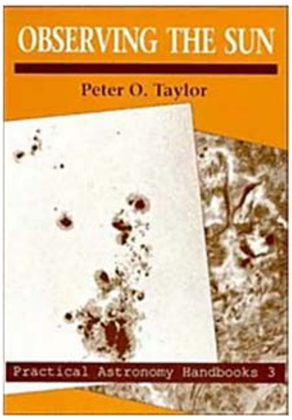


Amateur Radio Astronomy by John Fielding

ISBN 9781-9050-8662-7

Second edition Published 2011

384 pages 240 x 175 mm



Observing the Sun by Peter Taylor

ISBN-10: 0521401100

or ISBN-13: 9780521401104

Published November 1991

173 pages 279 x 215 mm

UKRAA Very Low Frequency Receiver

User Manual
Download from www.ukraa.com

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Website: www.britastro.org/radio

Appendix 1 – VLF Receiver Specifications

Tuning Range	12kHz...35kHz
Output Voltage Options	0...5V *or* 0...2.5V
Time Constant (hardware)	1 second
Gain Settings	x1 and x10
Control Interface	I^2C Bus
Temperature Sensor Range	-40C *to* +150C
Temperature Sensor Resolution	11 to 14 bit
Power Supply	15v DC at 35mA

Appendix 2 – VLF Transmitting Stations

Below is a list of frequencies currently being used by SID observers. It is not a complete list of available signals, but may prove useful in initial tuning of the Receiver and testing of a complete VLF system.

Refer to https://sidstation.loudet.org/stations-list-en.xhtml.

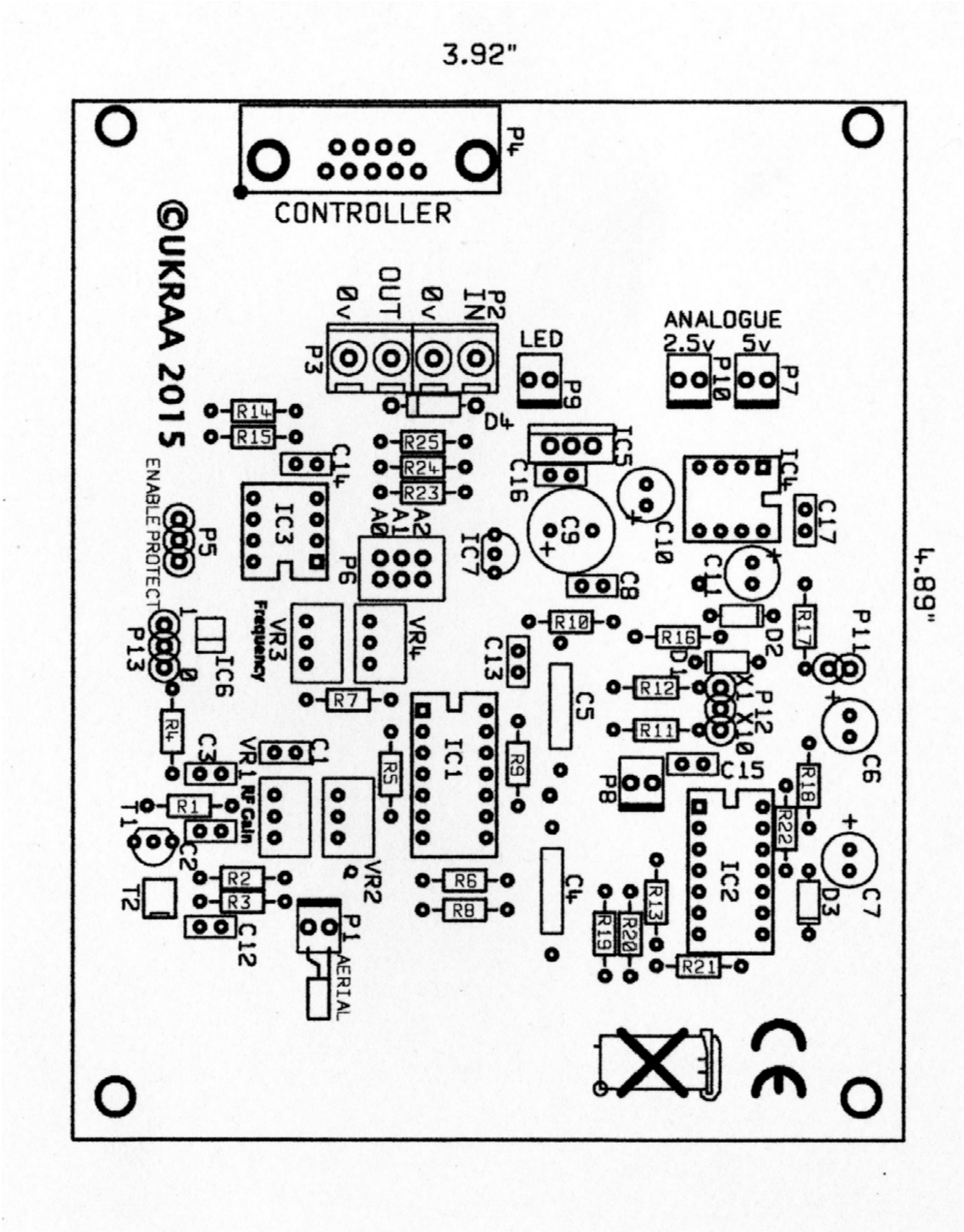
18.3kHz	French Navy Rosnay, France	001° 14' 42.89" E	46° 42' 47.26" N
19.6kHz	Royal Navy, Anthorn UK	003° 16' 42.44" W	54° 54' 41.91" N
20.27kHz	NATO / Italian Navy, Isola di Tavolara, Italy	009° 43' 51.64" E	40° 55' 23.26" N

20.9kHz	French Navy St. Assise, France	002° 34' 45.94" E	48° 32' 40.68" N
22.1kHz	Royal Navy Skelton, UK	002° 52' 58.92" W	54° 43' 54.48" N
22.6kHz	Rosnay, French Navy, France	001° 14' 42.89" E	46° 42' 47.26" N
23.4kHz	NATO / Bundesmarine Burlage Germany (Ramsloh)	007° 36' 54.00" E	53° 04' 41.77" N
Outside Europe			
18.2kHz	South Vijayanarayanam, India	N 08° 23' 13.25"	077° 45' 9.94"
19.8kHz	Harold E. Holt, North West Cape, Exmouth, Australia	S 21° 48' 58.78"	114° 09' 56.11

There are numerous other stations not included on this partial list.

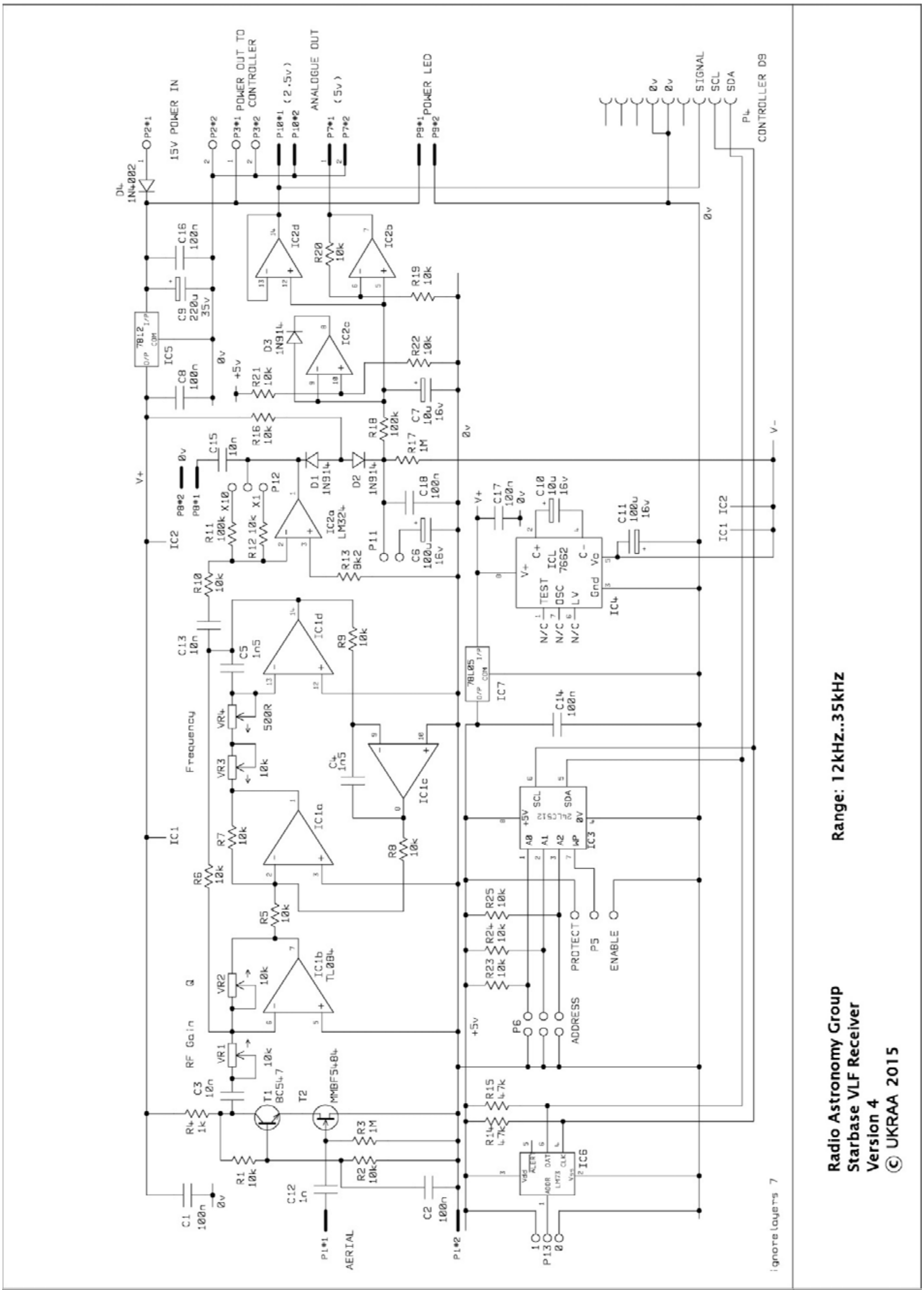
Note that not all transmitters are active all of the time. Some take breaks during the day, while others may be off for periods of weeks or months at a time. If one signal cannot be found, then try for another, or try again at a different time. Also remember that the strength of the signal will depend on the time of day as well as ionospheric conditions. Other frequencies may also be in use from time to time.

Appendix 3 – VLF Receiver PCB Layout



VLF Receiver Component Overlay

Appendix 4 – VLF Receiver Circuit Diagram



Appendix 5 – I²C Address Map

The VLF Receiver stores its configuration data in a serial EEPROM accessed via the I²C bus. The temperature of the circuit board is monitored with a temperature sensor device, also connected via I²C. All types of I²C device have restricted bus address ranges, depending on their specific function, which are allocated during manufacture. The temperature sensor and memory devices on the VLF Receiver can respond only to the I²C bus addresses shown in the table below. Developers of custom software may use any of these addresses, which are selectable by the two jumper fields **P6** and **P13**.

Address *(binary)*	Address *(Hex)*	Function
1001 1000	98	Write to LM73 Temperature Sensor Pointer Register
1001 1001	99	Read from LM73 Temperature Sensor Pointer Register
1001 1010	9A	Write to LM73 Temperature Sensor Pointer Register
1001 1011	9B	Read from LM73 Temperature Sensor Pointer Register
1001 1100	9C	Write to LM73 Temperature Sensor Pointer Register
1001 1101	9D	Read from LM73 Temperature Sensor Pointer Register
1010 0000	A0	Write to EEPROM
1010 0001	A1	Read from EEPROM
1010 0010	A2	Write to EEPROM
1010 0011	A3	Read from EEPROM
1010 0100	A4	Write to EEPROM
1010 0101	A5	Read from EEPROM
1010 0110	A6	Write to EEPROM
1010 0111	A7	Read from EEPROM
1010 1000	A8	Write to EEPROM
1010 1001	A9	Read from EEPROM
1010 1010	AA	Write to EEPROM
1010 1011	AB	Read from EEPROM
1010 1100	AC	Write to EEPROM
1010 1101	AD	Read from EEPROM
1010 1110	AE	Write to EEPROM
1010 1111	AF	Read from EEPROM

Appendix 6 – Jumper Settings and Pinouts

Jumpers

Component	Labelled	Function
P5	ENABLE PROTECT	Set to ENABLE when programming the EEPROM, otherwise set to PROTECT
P6	–	Sets Receiver EEPROM (IC3) base address (000 to 111 binary).
P11	–	Remove jumper for fast time constant, to aid alignment, replace jumper for normal use
P12	X1 X10	Selects RF Gain
P13	0 1	Selects the I²C bus address for the LM73 Temperature Sensor (default is no connection, for addresses 98, 98 Hex).

Headers

Component	Labelled	Function
P1	Aerial	Connects to aerial input socket on enclosure.
P7	Out Gnd	0 to 5V analogue output – connects to terminal 'banana' posts on the enclosure.
P8	–	Extracts the RF signal before detector.
P9	LED	Connects to LED
P10	Analogue	0 to 2.5V analogue output – connects to terminal 'banana' posts on the enclosure.

DB9 Socket

Pin	Function
1	Not used
2	Not used
3	Not used
4	Ground
5	Ground
6	Not used
7	0–2.5V analogue signal
8	SCL
9	SDA

Appendix 7 – Regulatory Compliance

RoHS

The Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment 2002/95/EC, (commonly referred to as the Restriction of Hazardous Substances Directive or RoHS) was adopted in February 2003 by the European Union. The RoHS directive took effect on 2006 July 1, and is required to be enforced and become law in each member state. This directive restricts the use of six hazardous materials in the manufacture of various types of electronic and electrical equipment. In speech, RoHS is often spelled out, or pronounced “rosh”.

The above paragraph was taken from the Wikipedia essay on RoHS.

The RoHS Directive restricts the use of the following six hazardous substances in electronic and electrical equipment products falling within the Directive:

- Lead
- Mercury
- Cadmium
- Hexavalent chromium
- Polybrominated biphenyls
- Polybrominated diphenyl ethers

UKRAA confirms that the suppliers of the components and materials used in the UKRAA VLF Receiver have stated that such components and materials are RoHS compliant and that reasonable steps have been taken to confirm these statements.

WEEE

RoHS is closely linked with the Waste Electrical and Electronic Equipment Directive (WEEE) 2002/96/EC that sets collection, recycling and recovery targets for electrical goods and is part of a legislative initiative to solve the problem of huge amounts of toxic e-waste.

The Waste Electrical and Electronic Equipment (WEEE) Directive is designed to ensure the efficient collection and recycling of electrical and electronic equipment at end-of-life. If a customer purchases a new product from UKRAA which falls within the WEEE Directive to replace an existing one (of similar function to the one that has been sold) and intends to dispose of the existing one, then the customer can request that we take back the existing product and deal with the costs and logistics of recycling it. Any customer wishing to take advantage of this facility should contact us. Provided that the existing product comes within the scope of the WEEE Directive, we will make arrangements for its return or collection and will deal with its disposal.

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