Application of the UKRAA Very Low Frequency Receiver System

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Abstract: Members of the UK Radio Astronomy Association have been working on a VLF receiver system prototype design since 2006 and UKRAA now sells it in kit and built form. The system consists of three major components: VLF receiver, 0.4 m square loop antenna, and antenna tuning unit. A signal generator also is available for testing and tuning the receiver. This paper discusses: 1) Receiver system architecture and characteristics; and 2) Kit construction details.

Note: The original intent of this paper was to include a third part – 3) Performance in my observatory in Anchorage, Alaska USA – but local interference conditions prevented reception during SID events and there is nothing to report.

I. INTRODUCTION

The Very Low Frequency (VLF) receiver system is a useful sensor for monitoring Sudden Ionospheric Disturbances (SID) caused by solar flares. It does not receive solar radio emissions directly. Instead, it receives terrestrial transmissions that propagate in an Earth-ionosphere waveguide, which is affected by solar flares. Solar flares change the waveguide's propagation characteristics and, thus, are indirectly observable with the receiver.

A number of inexpensive VLF receiver designs have appeared over the years, many of them designed by radio amateurs and experimenters (for example, some of the popular ones are [1,2,3,4]). Few of these receiver designs were based on a systems approach and some suffered serious limitations. Many of the designs focused only on the receiver with little attention to the other parts of the receiving system. A few were available as kits or already built. Yet other receivers (for example, the SolarSID and SuperSID [5]) were specifically designed for educational purposes.

In contrast, the UK Radio Astronomy Association (UKRAA)[1] receiver is part of a modular system. The system also includes a loop antenna, antenna tuning unit (ATU) and signal generator for testing and alignment. It has provisions for a built-in analog-digital converter (ADC), addressable Inter-Integrated Circuit (I^2C)[2] bus connection to an optional external controller, and on-board temperature sensor. Of course, some method of logging the receiver output also is required. The UKRAA receiver has two analog outputs as well as an ADC output that is compatible with Radio-SkyPipe software but, unfortunately, requires the obsolete parallel printer port.[3]

The UKRAA VLF receiver system is available as a kit or already built, catering to both experimenters and others who would like to start using the receiver immediately. The kits can be assembled by inexperienced builders with relatively simple tools and test equipment. System modules can be purchased as needed (Table 1).

Table 1- VLF receiver prices (current as of Dec 2009)

Description	Price (GBP)	Price (US$)
VLF receiver kit, no enclosure	60.00	~96.00
VLF receiver assembled, no enclosure	90.00	~143.00
VLF receiver, assembled with enclosure	120.00	~191.00
Loop antenna kit, no wire	15.00	~24.00
Loop antenna kit, with wire	31.00	~49.00
Loop antenna, assembled	35.00	~56.00
Antenna tuning unit, assembled	25.00	~40.00
VLF signal generator, 23.4 kHz	15.00	~24.00

Prices do not including shipping from UK to destination
To order, send inquiry to info@ukraa.com

II. RECEIVER SYSTEM CHARACTERISTICS

A. System block diagram

An overall block diagram reveals the system components (Fig. 1). The major components are antenna, antenna tuning unit, receiver, and measurement device. Optional components (not required for operation) are controller and

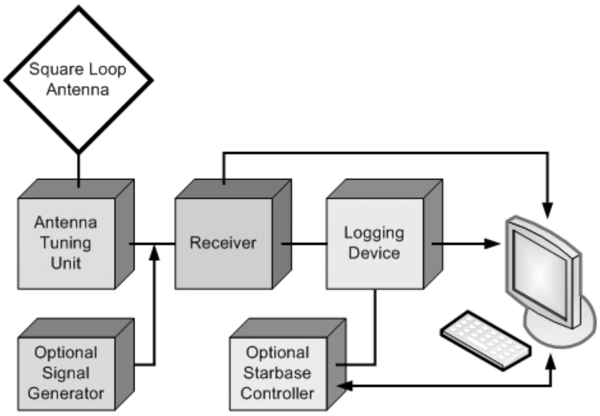
[1] The UKRAA (www.ukraa.com) is the commercial arm of the British Astronomy Association (BAA) Radio Astronomy Group (RAG). The BAA is the parent body of additional astronomy groups. For additional information: www.britastro.org.

[2] For additional information: http://www.i2c-bus.org/.

[3] The persistent use of the parallel port by many amateur radio astronomers is universally justified by their claim that "everyone has an old PC lying around with a parallel printer port."

signal generator. The controller is another UKRAA hardware development project as is the Starbase software system that can be used with a number of controllers and associated sensors, including VLF receivers and geomagnetometers.

Fig. 1 – Overall system block diagram



The receiver system can be connected to an external dc voltmeter for real-time display or, more commonly, to a datalogger for charting and data archiving. The overall system design is based on considerable experimentation by various UKRAA members and incorporates circuits from published and unpublished projects by others.

B. Loop antenna

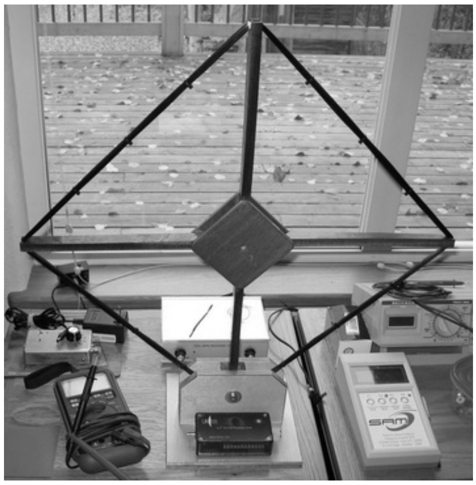
1. Configuration: The UKRAA antenna is a square loop with 0.4 m sides (Fig. 2). It has a hardwood cross-beam structure and consists of 125 turns of magnet wire (wire can be optionally purchased with the antenna kit or users can supply their own). The loop is supported by a plywood base.

2. Characteristics: The loop characteristics are:

Parameter	**Value**
Dimensions	0.4 m
Wire	24 AWG
Turns	125
Inductance	22.5 mH
Resistance (dc)	17.1 ohms at 21 °C
Q	50
Self-resonant frequency	52.2 kHz

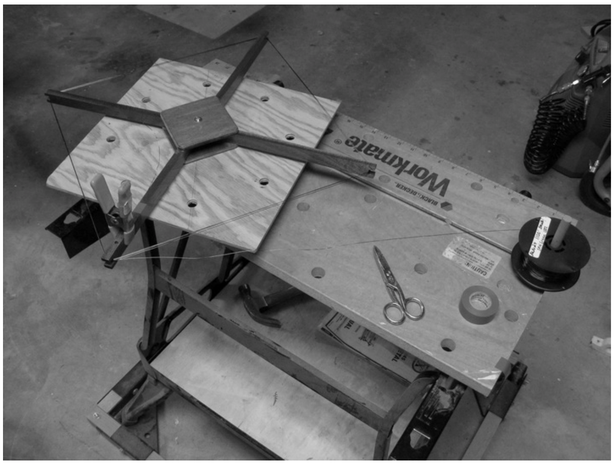
Note: Q and self-resonant frequency measured for a 137 turn loop antenna

Fig. 2 – UKRAA loop antenna posing with the antenna tuning unit (just below bottom corner of loop) and unrelated equipment



Loop frame and base construction was fast and simple, consisting of only a few pre-cut wood components that are glued together. After the glue cured overnight, a protective varnish was applied and allowed to cure. Then the windings were placed using the shop winding table (Fig. 3).

Fig. 3 – Loop antenna frame (left) on the shop winding table. The table is the square rotating platform with a mandrel directly under the frame and placed on a Workmate® bench. Winding 125 turns from the wire spool (right) required approximately 20 minutes



2. Inductance: For reference, the approximate inductance, in μH, of a polygon coil with rectangular cross-section is given by[4]

[4] Eq. 157, pg 257, Circular C74, Radio Instruments and Measurements, US Department of Commerce, National Bureau of Standards, 1937. The units specified in the original source are used in this analysis.

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

where

L inductance (μH)
a average of inscribed and circumscribed radii, $r \cdot \cos^2\left(\frac{\pi}{2 \cdot N} \right)$ (cm)
r radius of circumscribed circle (cm)
N number of polygon sides (4 for square)
b axial dimension of the coil cross-section (cm)
c radial dimension of the coil cross-section (cm)
d diagonal of the coil cross-section (cm)
n number of turns
y_1 value from Table 14, pg 285 of reference based on ratio b/c
y_2 value from Table 14, pg 285 of reference based on ratio c/b

The following values apply to the UKRAA loop:

a 24.5 cm
b 0.79 cm
c 0.79 cm
d 0.79 cm
r 28.7 cm
n 125 turns
b/c 1
c/b 1
y_1 0.8483
y_2 0.816

Substituting the above values, the calculated inductance

L = 22,456 μH = 22.5 mH

These calculations were verified by field measurements and found to differ by 2-3% (within the measurement tolerance of the test equipment).

3. Loop open circuit voltage: From Faraday's law of induction

$$V = -\frac{d\varphi(t)}{dt}$$

where

V open circuit rms voltage (V)
φ(t) magnetic flux (weber = V · s)
t time (s)

Therefore, an induced voltage appears across the terminals of a circuit immersed in a changing magnetic field. If the circuit consists of an electrically small air core loop antenna with n turns, the voltages in the turns are additive, or[5]

$$V = -n \cdot \frac{d\varphi(t)}{dt}$$

The magnetic flux is related to the time varying magnetic induction by

$$\varphi(t) = B(t) \cdot A_e \cdot \cos(\theta)$$

where

B(t) magnetic induction (tesla, T = V · s/m^2)
A_e area of equivalent circular loop with radius *a* (m)
θ angle between magnetic field lines and normal of loop frame (radians)

Note that $B(t) = B \cdot \cos(\omega \cdot t)$

where

B rms magnetic induction (T)
ω radian frequency ($2 \cdot \pi \cdot f$, radians/s)
f frequency (Hz)

Differentiating the expression for magnetic flux gives

$$\frac{d\varphi(t)}{dt} = \frac{dB(t) \cdot A_e \cdot \cos(\theta)}{dt} = -B \cdot A_e \cdot \omega \cdot \sin(\omega \cdot t)$$

Finally, by substitution, the open circuit rms voltage across the loop terminal is

$$V = 2 \cdot \pi \cdot n \cdot A_e \cdot f \cdot B \cdot \cos(\theta)$$

The above expression indicates the loop antenna responds to the magnetic field component (magnetic induction or flux density, *B*) of a signal and converts it to a voltage at the antenna terminals.

4. Effective height: The voltage at the terminals is related to the electric field strength, E, by

$$V = h_e \cdot E$$

where

h_e effective antenna height (m)

[5] An electrically small loop antenna has a circumference much less than a wavelength. Note that for any frequency < 300 kHz one wavelength in free space is > 1,000 m, and the circumference of any practical loop antenna is much smaller.

E rms electric field strength (V/m)

For small loop antennas, there is no relationship between the effective height and physical height of the antenna. The effective height is a measure of how much induced voltage there will be in the antenna for a given electric field strength. There is a relationship between effective height and physical height of vertical antennas whose physical length is comparable to the operating wavelength.

The relationship between the electric field strength and magnetic induction is

$$E = c \cdot B$$

where

c speed of light ($3 \cdot 10^8$ m/s), *note redefinition of c*

By substitution, the effective height of an air-core loop is

$$h_e = \frac{2 \cdot \pi \cdot f \cdot n \cdot A_e \cdot \cos(\theta)}{c} = \frac{2 \cdot \pi \cdot n \cdot A_e \cdot \cos(\theta)}{\lambda}$$

where

λ wavelength (m)

For the loop in question, the equivalent area

$A_e = \pi \cdot a^2 =$ 1,886 cm^2 = 0.19 m^2

where

a 24.5 cm = 0.245 m

It is seen that, for a given electric field strength, the rms voltage at the loop terminals is proportional to the effective height and, therefore, is proportional to the frequency, number of turns and loop area. Effective height can be viewed as a loop performance measure – the larger the effective height, the better is the loop's sensitivity to a given field strength.

For a given frequency the effective height can be increased by increasing the number of turns or loop area. Generally, it is better to increase the area than number of turns for better performance. Depending on loop winding configuration, increasing the number of turns also increases the loop's distributed capacitance and lowers its self-resonant frequency. If there is too much distributed capacitance it may not be possible to resonate the loop at the desired operating frequency.

For the case where the loop frame is parallel to the propagation direction and the magnetic field is normal to the propagation direction, in which case θ = 0 deg. = 0 radians, and if the frequency is 24 kHz

$$h_e = \frac{2 \cdot \pi \cdot n \cdot A_e \cdot f}{c} = \frac{2 \cdot \pi \cdot 125 \cdot 0.19 \cdot 24 \cdot 10^3}{3 \cdot 10^8}$$
$$= 0.0119 \text{ m}$$

For example, at the given frequency and for a field strength of 1,000 μV/m, the open circuit (unloaded) loop terminal voltage for the loop in question is

$$V = h_e \cdot E = 0.0119 \cdot 1000 = 12 \ \mu\text{V}$$

In air and free space, the magnetic field strength and magnetic induction are related by

$$H = \frac{B}{\mu_0}$$

where

H rms magnetic field strength (A/m)

μ_0 permeability of air or free space ($4\pi \times 10^{-7}$ H/m)

Therefore, when the loop frame is parallel to the line of signal propagation, the loop terminal voltage in terms of the magnetic field strength is

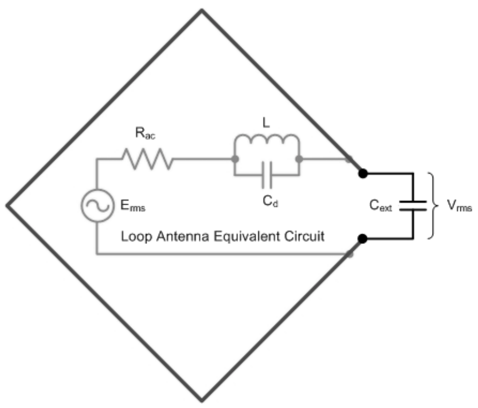
$$V = 2 \cdot \pi \cdot \mu_0 \cdot n \cdot A \cdot f \cdot H$$

C. *Antenna tuning unit (ATU)*

1. Quality (Q) factor: If an external capacitor is connected in parallel with the loop antenna (Fig. 4) and adjusted to resonate the antenna, the voltage across the terminals increases by the factor Q, or

$$V = h_e \cdot E \cdot Q$$

Fig. 4 – Loop antenna equivalent circuit and external resonating capacitor, C_{ext}. The received electric field strength is E_{rms} , C_d is the loop distributed capacitance and R_{ac} is the equivalent ac resistance



Q is determined from

$$Q = \frac{f_r}{\Delta f}$$

or, equivalently

$$Q = \frac{2 \cdot \pi \cdot f_r \cdot L}{R_{ac}}$$

where

f_r resonant frequency (Hz)

Δf 3 dB (power) bandwidth (Hz)

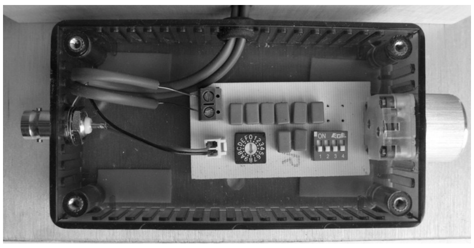
R_{ac} equivalent ac resistance of loop winding (ohm)

Field measurements of the UKRAA loop show the loaded (1 Mohm) Q is close to 50. In other words, the induced voltage is magnified by a factor of 50 simply by tuning the antenna to resonance. A loading of 1 Mohm was used because the input impedance of the receiver is 1 Mohm, as will be shown in Sect. D.

2. ATU configuration: The ATU consists of a small (112 mm x 60 mm x 30 mm) plastic enclosure and PCB that has been preassembled by UKRAA before shipment. It arrives ready to use and no construction is required.

The resonating capacitance in the antenna tuning unit actually consists of several fixed capacitors connected in parallel through switches and a variable capacitor for fine tuning (Fig. 5). Thus, the ATU provides a means to tune the antenna for different operating frequencies.

Fig. 5 – Antenna tuning unit. The two leads from the loop antenna enter the enclosure at top of picture. Capacitance is adjusted by a small rotary switch (lower-left on circuit board), a dip-switch (lower-right) and a variable capacitor (right side of enclosure)

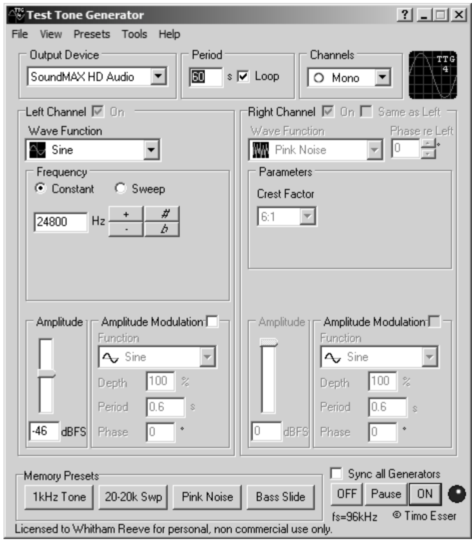


The antenna is tuned by adjusting the capacitor switches for maximum receiver output while injecting a signal into the receiver antenna input. The signal can be generated by a hardware-based low-frequency signal generator (Fig. 6a) or by a PC soundcard with test tone generator software (Fig. 6b). A signal generator output voltage in the range of 5 to 50 mv rms is required and it must be isolated from the antenna by a large value resistor (> 100 kohm).

Fig. 6 – Tone generators for test and alignment

a) Hardware based single-frequency tone generator available as an option from UKRAA

b) Screenshot of Test Tone Generator software by Esser Audio used with a PC soundcard (www.esseraudio.com)



The ATU is located adjacent and connected directly to the antenna windings. The antenna is balanced but it connects to the receiver through the ATU, which has an unbalanced output. The ATU output is equipped with a BNC connector for connection to a coaxial cable to the receiver. The capacitance of the coaxial cable is around 50 – 100 pF/m depending on the cable type and is high enough to affect tuning. Therefore, it is necessary to tune the antenna with the actual cable to be used with the receiver.

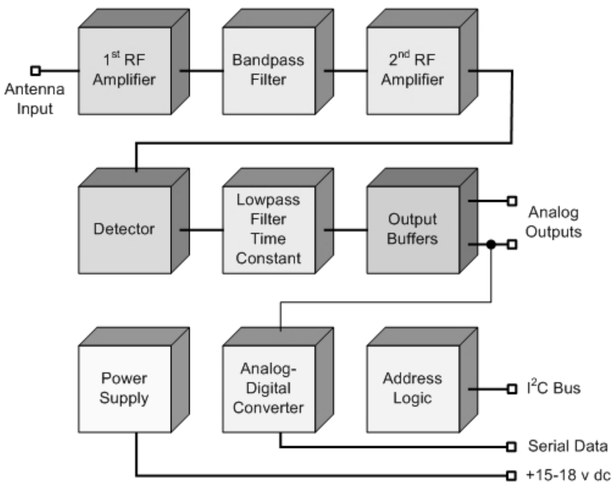
D. Receiver

1. Receiver configuration: The receiver specifications are:

Parameter	Value
Frequency range	10 – 35 kHz
RF input impedance	Approximately 1 Mohm, unbalanced
Minimum discernible signal voltage	Approximately 30 µV (determined by measurement)
Analog output voltage	No. 1: 0 to 5 V dc No. 2: 0 to 2.5 V dc
Optional input	Auxiliary input to channel 1 of MAX186 ADC
Power	15 – 18 V dc, approximately 35 ma

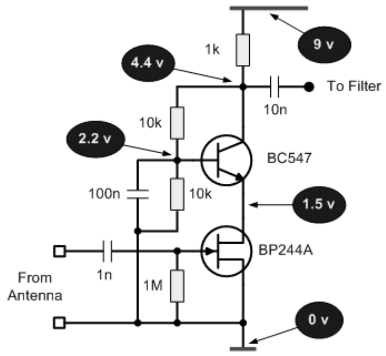
The receiver basically is a tunable audio frequency amplifier with an envelope detector. It consists of a number of functional blocks (Fig. 7), of which the main ones are 1st radio frequency (RF) amplifier, bandpass filter, 2nd RF amplifier, detector and associated lowpass filter, and output buffers.

Fig. 7 – Receiver block diagram



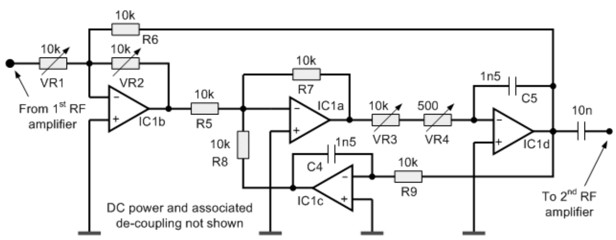
2. <u>1st RF amplifier</u>: The 1st RF amplifier consists of an untuned cascode amplifier (tuning is done at the antenna as previously described) with a junction field effect transistor (J-FET) at the antenna input interface and a bipolar junction transistor (BJT) at the output (Fig. 8). The cascode amplifier in this application has low voltage gain (approximately 1.5) but gain is not its only purpose. The configuration 1) prevents antenna loading by the bandpass filter and 2) reduces capacitance multiplication effects (Miller Effect) that would detune the antenna. The input impedance is determined by a 1 Mohm biasing resistor on the J-FET gate.

Fig. 8 - 1st RF amplifier with dc operating points shown



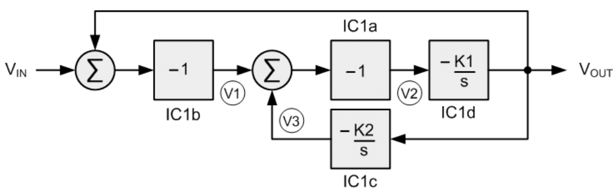
3. <u>Bandpass filter</u>: The bandpass filter immediately follows the input amplifier. The filter is a 4-amplifier bi-quadratic design that has the advantage of almost independent gain, frequency and Q controls (Fig. 9). In practice, there is some interaction between the various controls and it can be somewhat tricky to tune until the user attains some proficiency. The configuration was originally designed for analog computer applications but has proven to work well in the UKRAA receiver.

Fig. 9 - Bi-quadratic bandpass filter



The filter can be analyzed to a first approximation by breaking it into gain blocks (Fig. 10). This approximation does not account for the op-amps' limited gain-bandwidth products and the tolerances of real devices.

Fig. 10 – Filter functional block diagram



The transfer function of a bi-quadratic (biquad, also called state-variable) filter takes the form of

$$H(s) = K\,\frac{ms^2 + cs + d}{ns^2 + as + b}$$

where m and n are 1 or 0, depending on whether the filter is low-pass, high-pass, bandpass or band-reject. *Note redefinition of variables a, b, c and d.* For a bandpass filter, m = 0 and n = 1, and

$$H(s) = K\,\frac{cs + d}{s^2 + as + b}$$

For the filter in question

$$H(s) = \frac{V_{OUT}}{V_{IN}} = \frac{\left(-\dfrac{VR2 \cdot K1}{VR1}\right) \cdot s}{s^2 + \left(\dfrac{VR2 \cdot K1}{R6}\right) \cdot s + (K2 \cdot K1)}$$

where

VR1 RF Gain control (10 kohm variable)
VR2 Q control (10 kohm variable)
VR3 Coarse tuning control (10 kohm variable)
VR4 Fine tuning control (500 ohm variable)

$$K1 = \frac{1}{(VR3 + VR4) \cdot C5}$$

$$K2 = \frac{1}{R9 \cdot C4}$$

R9 = 10 kohm
$C4 = 1.5$ nF
$C5 = 1.5$ nF

Substituting variables yields

$$a = \left(\frac{VR2}{R6 \cdot (VR3 + VR4) \cdot C5}\right)$$

$$b = \left(\frac{1}{(VR3 + VR4) \cdot C5 \cdot R9 \cdot C4}\right)$$

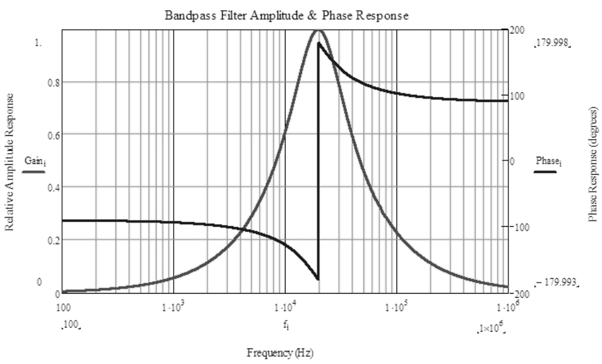
$$c = \left(\frac{VR2}{VR1 \cdot (VR3 + VR4) \cdot C5}\right)$$

$$d = 0$$

$$K = -1$$

The theoretical filter response is shown in Fig. 11 with the tuning controls set to 20 kHz and the Q control set to 6 kohm (which was found by measurement to be an actual operating value). There is some interaction between the filter gain and Q (that is, the filter gain can be increased or decreased by the Q control). The filter can be made to oscillate quite easily by adjusting the Q to an excessively high value. It turns out the best performance is obtained by increasing the Q control until the filter oscillates and then reducing it a fraction of a turn. This setting provides the highest possible gain.

Fig. 11 – Theoretical bandpass filter amplitude and phase response

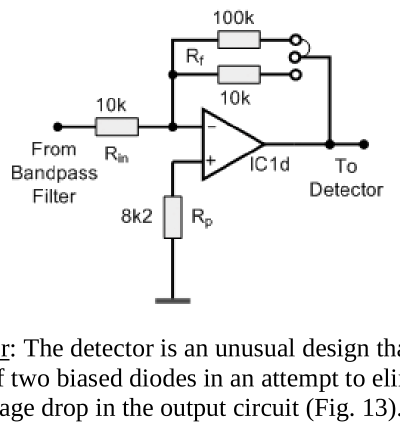


4. <u>2nd RF amplifier</u>: The 2nd RF amplifier (Fig. 12) is an op-amp configured as an inverting amplifier. It can be adjusted for a voltage gain of 1 or 10 depending on the position of a jumper block. The gain of an inverting amplifier is

$$G_v = -\frac{R_f}{R_{in}}$$

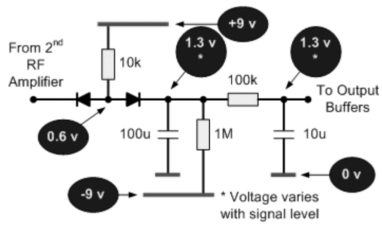
where R_f is the feedback resistance and R_{in} is the input resistance. The resistor R_p in the schematic is used to cancel the input bias current and reduce clipping of the output signal. Ideally, a different value resistance would be used for each gain setting, but a single compromise value is used in the UKRAA receiver. The input impedance of this configuration equals the input resistance value (10k) and the output impedance is very low.

Fig. 12 – 2nd RF amplifier circuit



5. <u>Detector</u>: The detector is an unusual design that consists of two biased diodes in an attempt to eliminate diode voltage drop in the output circuit (Fig. 13). This was only partially successful but the lack of complete success has no apparent effect on overall receiver operation.

Fig. 13 – Detector and lowpass filter circuit



The detector output is filtered by two resistance-capacitance (RC) circuits, with time constants of 100 seconds and 1 second, respectively. The detector filter provides a fast rise-time (1 -2 seconds) and very slow fall time (30-40 seconds). This helps to smooth the output when there are noise and quickly changing propagation conditions but provides good response to SID events. A voltage limiter circuit (not shown in the schematic above) is connected across the detector output to keep from overdriving the output buffers with strong noise or signal levels.

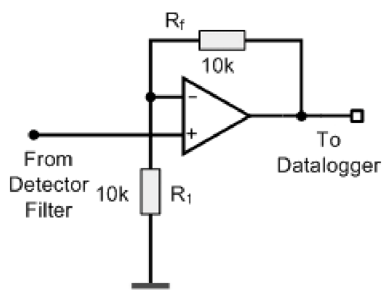
6. Output buffers: The receiver has two output buffers, one with a fixed voltage gain of 2 for 0 to 5 V analog output. The other buffer can be set by resistor placement for a voltage gain of 1 or 2 for 0 to 2.5 V or 0 to 5 V output. These two ranges accommodate almost all dataloggers.

The output buffers are configured as non-inverting amplifiers (Fig. 14). The gain of a non-inverting amplifier is

$$G_v = 1 + \frac{R_f}{R_1}$$

where R_f is the feedback resistance and R_1 is the resistance from the inverting input to ground. The input impedance of this configuration is very high and the output impedance is very low.

Fig. 14 – Output buffer (typical of two)



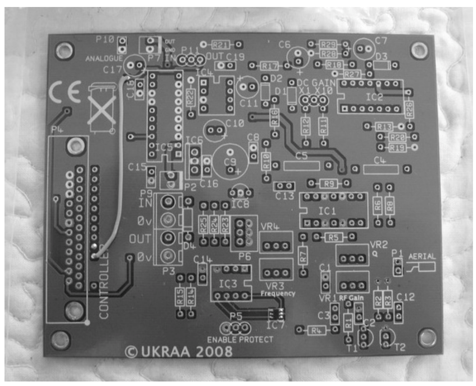
7. On-board options: The printed circuit board (PCB) has provisions for a MAX186 analog-digital converter IC that can be connected to a PC parallel printer port and used with Radio-SkyPipe software. The setup includes option jumpers for selecting the PCB output connector and also for connecting an auxiliary input port to an unused channel on the ADC.

The PCB includes a temperature sensor that uses the I^2C bus for connection to a compatible controller. The PCB also has an electrically erasable programmable read-only memory (EEPROM) IC for setting the receiver address and storing configuration attributes when the receiver is used with a controller and Starbase software. These functions allow the receiver and other planned and existing UKRAA projects to work as a remotely or locally controlled unified observatory.

III. RECEIVER KIT CONSTRUCTION

1. Kit contents: The kit includes a silkscreened 2-sided PCB and all on-board components (Fig. 15). There are approximately 80 components and all are through-hole types except one (the LM73 temperature sensor is a surface-mounted device, SMD, and it is pre-soldered to the PCB).

Fig. 15 – Printed circuit board ready for assembly. Dimensions are 114 mm x 100 mm



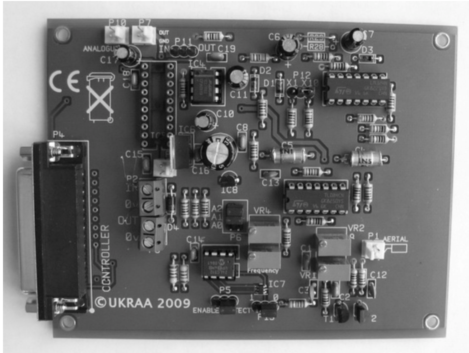
The kit includes only the PCB-mounted parts. External parts such as enclosure, antenna connector, dc power jack and output connectors are not provided. This allows builders to put the PCB in an enclosure of choice and use interface parts that are on-hand or meet their particular requirements.

2. Construction: There were no surprises during assembly and testing. The receiver assembly manual has enough detail for anyone with technical aptitude and minimum soldering skills. UKRAA provides a separate user manual

that includes tuning and application information. Manuals may be downloaded from www.ukraa.com/vlfkit.

The receiver design is simple enough that few problems will be encountered beyond poor soldering or incorrect component placement. The completed board is not crowded and solder landings are properly sized for a fine-tip soldering iron (Fig. 16).

Fig. 16 – Completed receiver PCB ready for testing

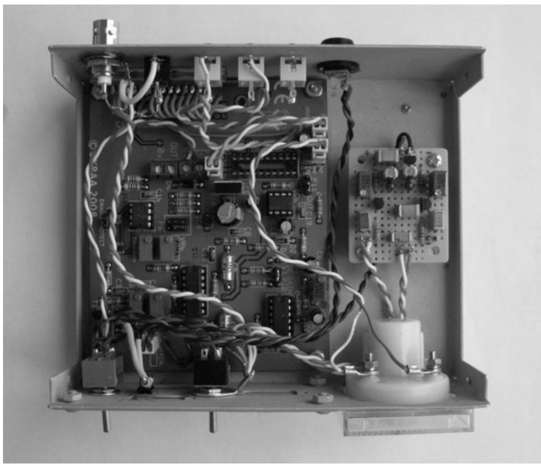


Two receivers were assembled. One was placed in a recycled computer/printer I/O switch box and the other in a new aluminum enclosure (Fig. 17). The receiver should be installed in a metal (and not plastic) enclosure to minimize electromagnetic interference (EMI). The receiver PCB dimensions are compatible with the Hammond Mfg. p/n 1455N1601 extruded aluminum enclosure.

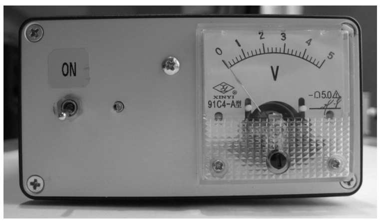
Both receiver enclosures were equipped with 3.5 mm phone jacks for input tuning and analog outputs and a small analog voltmeter for monitoring and tuning. Also, both receivers were converted to 12 V dc operation (rather than 15 V) by replacing the voltage regulator IC. One receiver was equipped with a 2-stage J-FET preamplifier and associated bypass switch for experimental purposes.

Fig. 17 – Completed receivers. Dimensions (a) upper three pictures: 150 mm x 135 mm x 60 mm, (b) lower three pictures: 115 mm x 180 mm x 55 mm. Receiver (a) has an experimental 2-stage preamplifier (seen on the right of the middle photograph)

(a)



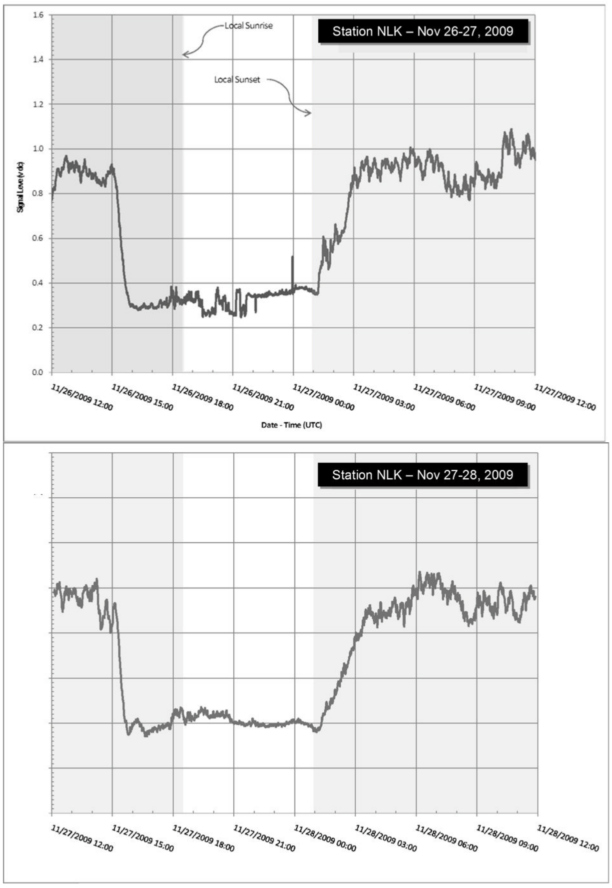
(b)



IV. PERFORMANCE

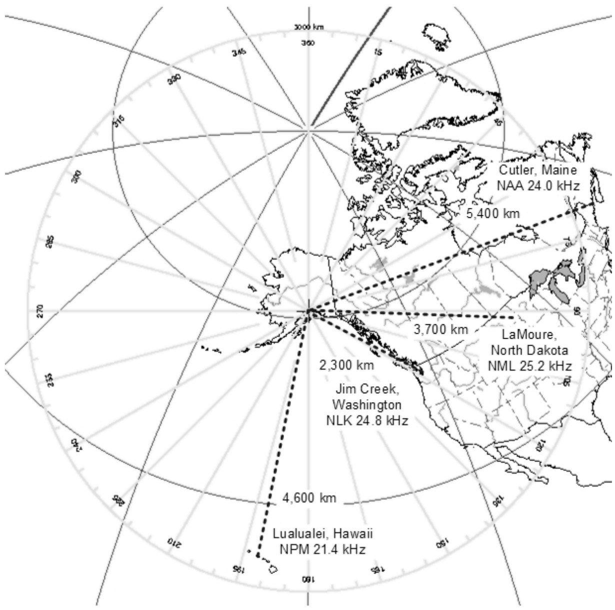
1. Receiving conditions in Alaska: Considerable difficulty has been encountered in Anchorage, Alaska with reliably receiving VLF transmissions, apparently due to persistent local interference, distance from transmitter stations and possible propagation conditions at northern latitudes. All tests were performed indoors during the winter of 2009/2010 with no opportunity to move the antenna outdoors and away from potential interference sources. The same problem was encountered with other receiver designs including the SolarSID and SuperSID as well as a particularly interesting setup using a frequency selective level meter as a receiver (Rycom model 6020). A limited amount of data was obtained with the UKRAA VLF receiver but there were no solar flares during this period (Fig. 18).

Fig. 18 – UKRAA VLF receiver outputs during late November 2009



There are four known VLF transmitter stations in the US that operate in the UKRAA receiver's frequency range (Fig. 19). The closest transmitter to Anchorage, Alaska is NLK (24.8 kHz) in Washington, a distance of about 2,300 km. The distances are large enough that groundwave reception probably is out of the question, and spacewaves via the Earth-ionosphere waveguide mode may be considerably attenuated while traveling multiple hops. The 4,600 km path from Lualualei, Hawaii (NPM at 21.4 kHz) to Anchorage is entirely over water and may provide a good multi-path opportunity because of the lower attenuation on this type of path. The other paths are overland.

Fig. 19 – VLF transmitting stations with respect to Anchorage, Alaska (Underlying map source: www.wm7d.net/az_proj/az_html)



2. Improving performance: Where the distance between the transmitter and UKRAA receiver exceeds around 1,000 km, a larger antenna may be advisable. The existing square loop design can be scaled up to any practical dimension or other shapes can be used. Attention will need to be paid to the self-resonant frequency due to distributed capacitance of the windings.

There is plenty of room for experimentation with the receiver design to improve its performance. Some examples are 1) slight redesign of the 1st RF input amplifier to increase its gain, 2) addition of a preamplifier with balanced low impedance input and unbalanced high impedance output to better match antenna to 1st RF amplifier, 3) replacement of the inexpensive TL084 IC used in IC1 (bandpass filter) with a higher performance quad op-amp, 4) tweaking of the bandpass filter circuit to reduce the chance of oscillation at high Q settings, and 5) shielding between stages to reduce undesired feedback.

V. CONCLUSIONS

The UKRAA VLF Receiver System consists of a loop antenna, antenna tuning unit and receiver. The receiver design is unique among units used by amateur radio astronomers and has been used with considerable success in the UK and Europe. The antenna and receiver input circuits are designed for receiving conditions in that region, where suitable VLF transmitters are less than 1,000 km away. The receiver should work well in much of the US, as well, although considerable difficulty has been encountered in Alaska reliably receiving stations, the closest of which is 2,300 km away. It may be necessary to use a larger antenna in some locations.

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Author Information

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