Application of the UKRAA Very Low Frequency Receiver System

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Contents

- Introduction
- Receiver system characteristics
- Kit construction
- Performance
- Conclusions

INTRODUCTION

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Introduction

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

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VLF Receivers

- A number of inexpensive amateur-designed VLF receivers have appeared over the years, for example
  - A Modular Receiver for Exploring the LF/VLF Bands, Coyle, L., QST, Part 1: Nov 2008, Part 2: Dec 2008
  - A Gyrator Tuned VLF Receiver, Communications Quarterly, Stokes, A., Spring 1994
  - Gyrator II - An Improved Gyrator Tuned VLF Receiver, Stokes, A., American Association of Variable Star Observers - Solar Division, Vol. 10, No. 1, Jul 1999
  - AMRAD Low Frequency Upconverter, Gentges, F & Ratzlaff, S., QST, Apr 2002

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VLF Receivers

- At least two receivers were professionally designed for educational purposes, for example
  - SolarSID and SuperSID, Stanford Solar Center, SID Monitors at: http://solar-center.stanford.edu/SID/
  - SuperSID available from Society of Amateur Radio Astronomers (SARA): https://www.radio-astronomy.org/node/276
- Wideband (192 kHz & 96 kHz sample rate) soundcards also have been used
  - Not designed for connection to outdoor antenna without lightning protection

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VLF Receivers

- Many receiver designs did not use 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
- Software Defined Radio (SDR) Receivers now are a viable alternative
  - Notably: SDRPlay RSPxxx-series SDR Receivers
  - Other SDR Receivers with frequency range extending down to 10 kHz

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UK Radio Astronomy Association

- In contrast, the UK Radio Astronomy Association (UKRAA) receiver is part of a modular system
  - Receiver
  - Loop antenna
  - Antenna tuning unit (ATU)
  - Optional signal generator for test and alignment
- Available as kit or already built

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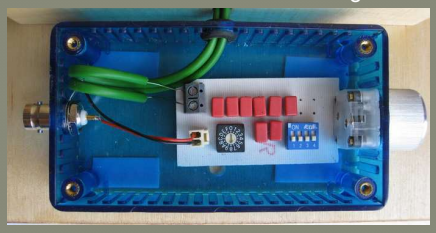
UK Radio Astronomy Association

Receiver

Antenna Tuning Unit



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UKRAA

- UK Radio Astronomy Association
  - www.ukraa.com
  - Commercial arm of the British Astronomy Association (BAA) Radio Astronomy Group (RAG)
- BAA is the parent body of additional astronomy groups
  - www.britastro.org

British Astronomical Association
Radio Astronomy Group

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Prices (shipping extra) → 2010 : 2026 !

Description	Price (GBP)	Price (US$)
VLF receiver kit, no enclosure	60.00 (67.00)	~96.00
VLF receiver assembled, no enclosure	90.00 (98.00)	~143.00
VLF receiver, assembled with enclosure	120.00 (130.00)	~191.00
Loop antenna kit, no wire	15.00 (26.00)	~24.00
Loop antenna kit, with wire	31.00 (50.00)	~49.00
Loop antenna, assembled	35.00 (N/A)	~56.00
Antenna tuning unit, assembled	25.00 (43.00)	~40.00
VLF signal generator	15.00 (25.00)	~24.00

Converson factor was ~1.59 and presently ~1.36

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RECEIVER SYSTEM CHARACTERISTICS

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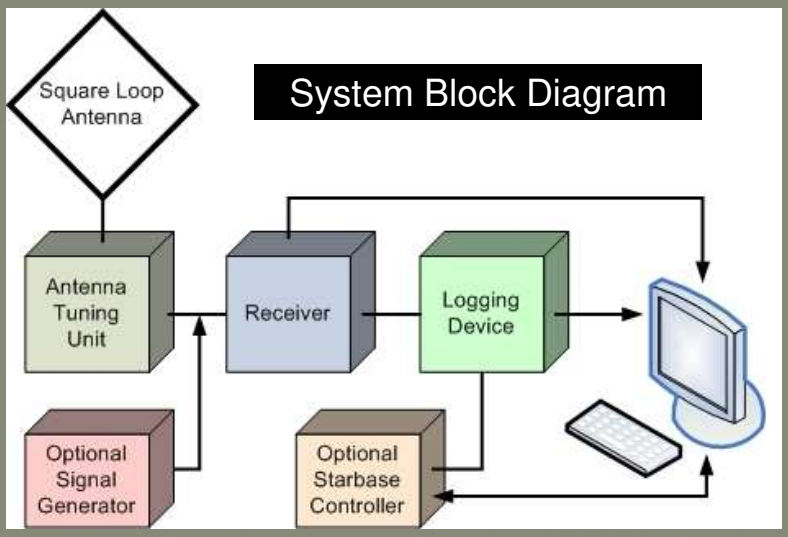
Receiver System Characteristics



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Receiver System Characteristics

- Overall system design based on considerable experimentation by various UKRAA members
- Incorporates published and unpublished circuits by others

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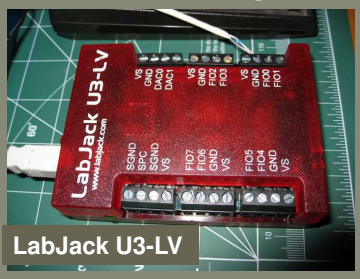
Receiver System Characteristics

- Data output
  - Internal or external dc voltmeter for real-time display
  - External datalogger for charting and data archiving



LabJack U3-LV

Shop Built Datalogger

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Optional Components

- Starbase controller (No Longer Available ?)
  - UKRAA hardware development project
  - Works with the Starbase software system
  - Can be used with a number of controllers and associated sensors, including VLF receivers and geomagnetometers

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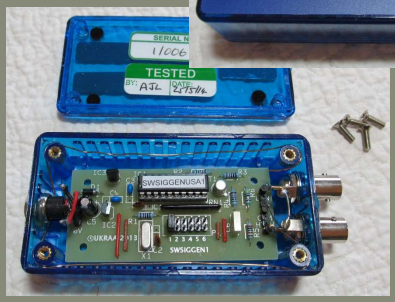
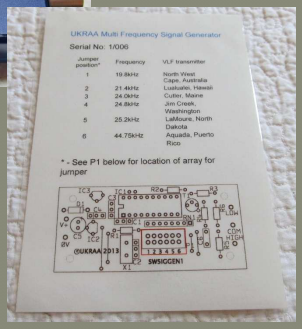
Optional Components

- Signal generator
  - Single fixed frequency
  - Crystal controlled
- Signal generator
  - Multifrequency
  - Processor controlled





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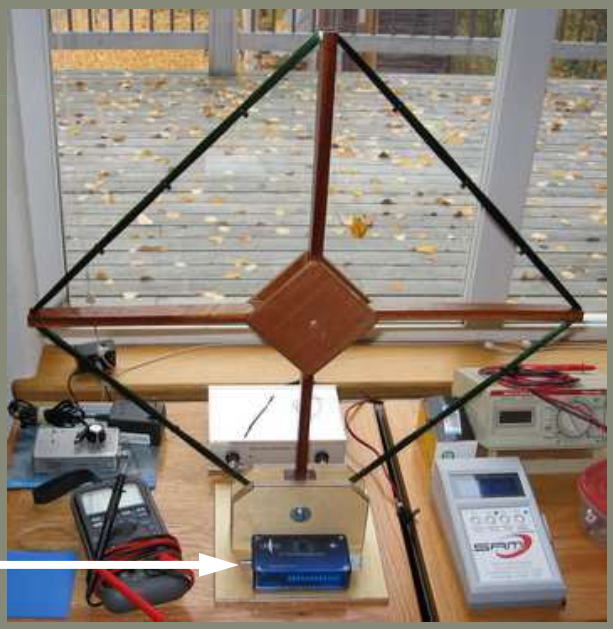
Loop Antenna

- Square configuration
- Hardwood frame
- Plywood base
- With proper finishing and without base can be used outdoors

Antenna Tuning Unit



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Loop Characteristics

- Dimensions: 0.4 m sides
- Wire: 24 AWG
- Turns: 125
- Wire length: ~ 203 m
- Inductance: 22.5 mH
- Resistance (dc): 17.1 ohms at 21 °C
- Q: ~ 50 (note)
- Self-resonant frequency: 52.2 kHz (note)

Note: Q and F_{sr} measured on 137 turn loop

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Important Loop Parameters

- Inductance (see reference)

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

where

L	inductance (μH)
a	average of inscribed and circumscribed radii (cm)
b	axial dimension of coil cross-section (cm)
c	radial dimension of coil cross-section (cm)
d	diagonal of 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 c/b

Reference: Eq. 153, pg 252, Circular C74, Radio Instruments and Measurements, US Department of Commerce, National Bureau of Standards, 1937

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Important Loop Parameters

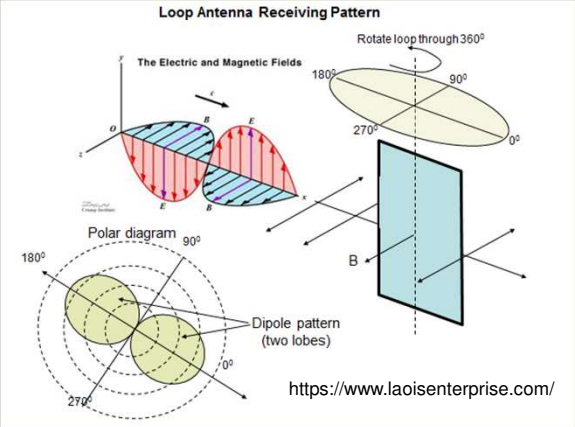
- Open circuit rms voltage

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

where

V open circuit rms voltage (V)
n number of turns
A_e Area of equivalent circular loop of radius a (m^2)
f frequency (Hz)
B rms magnetic induction (T)
θ angle between magnetic field lines and normal of loop frame (radians)

To increase terminal voltage:
- Increase antenna area, A_e
- Increase number of turns, n
- Increase frequency, f
- Increase magnetic induction, B



Important Loop Parameters

- Effective Height

$$h_e = \frac{V}{E}$$

Effective height is a measure of how well the field strength is converted to antenna terminal voltage

where

h_e effective height (m)
E rms electric field strength (V/m)
V open circuit rms voltage (V)

- Magnetic induction

$$B = \frac{E}{c}$$

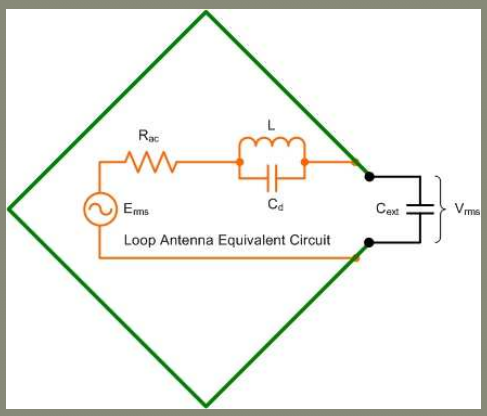
where

c speed of light (3×10^8 m/s)

Antenna Q

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

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



Loop antenna equivalent circuit

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Antenna Q

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

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

Q measurement made with 1 Mohm loading was 50

where

f_r	resonant frequency (Hz)
Δf	3 dB (power) bandwidth (Hz)
R_{ac}	equivalent ac resistance of loop winding (ohm)

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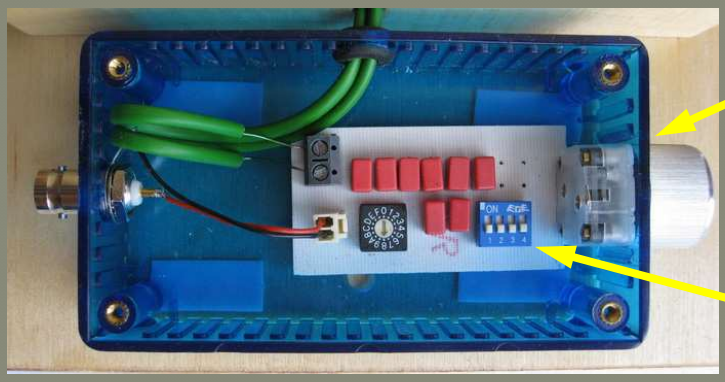
Antenna Tuning Unit

- ATU improves antenna voltage capture (resonating capacitor)
- Also compensates for interconnecting cable capacitance



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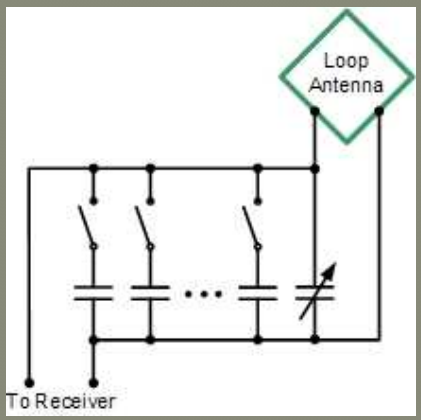
Antenna Tuning Unit

- Configuration



ATU enclosure is not weather resistant

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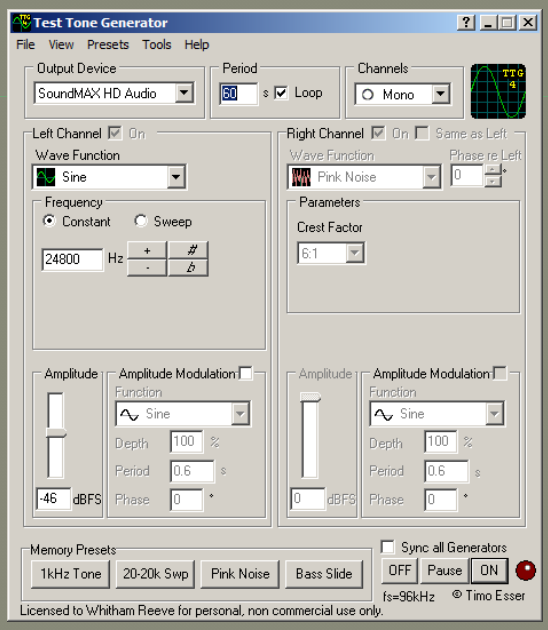
Tuning

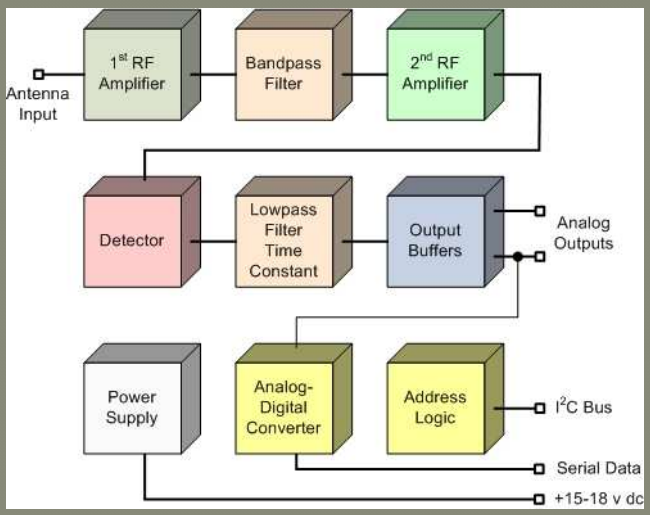
- Signal Generator
  - Hardware based

  - Hardware and software based
    - PC soundcard
    - Test tone generator software



VLF Receiver Module

- Receiver is a tunable audio frequency amplifier with an envelope detector



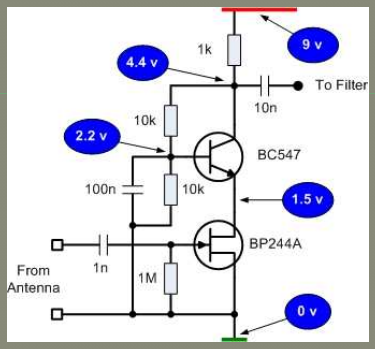
Receiver Specifications

Parameter	Value
Frequency range	10 to 35 kHz
RF input impedance	~ 1 Mohm unbalanced
Minimum discernible signal voltage	~ 30 μV
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 onboard ADC
Power	15 to 18 V dc, ~ 35 mA

Receiver Stages

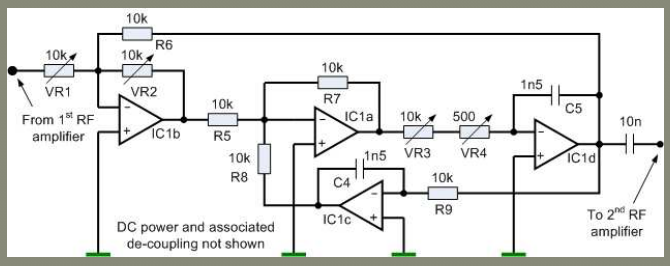
- 1st RF Amplifier

Cascode configuration ,~ 1.5X Voltage Gain
Externally tuned



- Bandpass filter

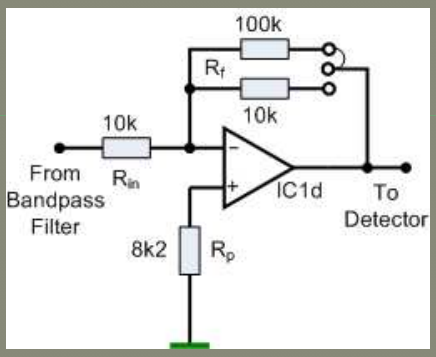
Almost independent tuning, gain and Q
Bi-Quadratic Filter (State Variable Filter)
1X Voltage Gain



Receiver Stages

- 2nd RF Amplifier

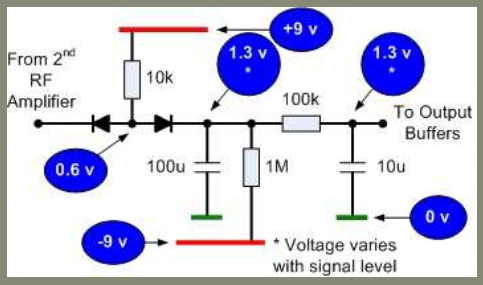
Inverting amplifier X1 or X10 Voltage Gain
Untuned



- Detector & Lowpass Filter

Time constants:
1 second (100 kohm : 10 uF)
100 seconds (1 Mohm : 100 uF)

~ 1 second rise time
~ 40 second fall time



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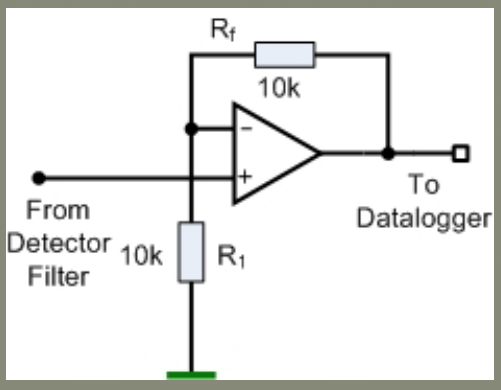
Receiver Stages

- Output Buffers

Dual Non-Inverting Amplifiers
1X (0 to 2.5 V output) Voltage Gain
2X (0 to 5.0 V output) Voltage Gain



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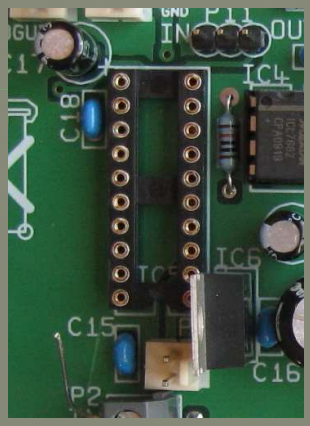
Receiver Options

- Printed Circuit Board On-Board Options
  - Provisions for a MAX186 analog-digital converter (ADC) IC
    - Compatible with PC parallel printer port and Radio-SkyPipe software

      Modern PCs do not have a built-in Parallel Print Port (LPT)

    - Auxiliary input port for unused channel on ADC
  - Option jumpers for selecting the PCB input/output connectors



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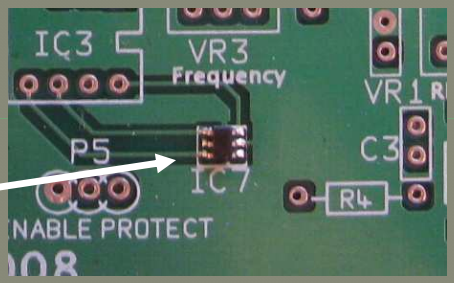
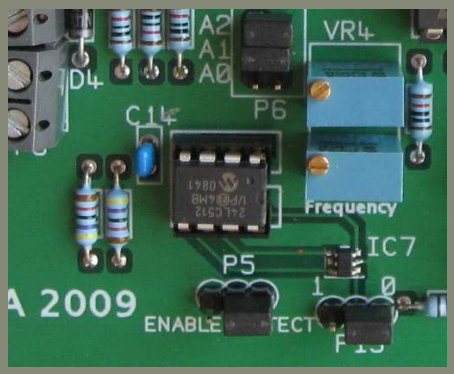
Receiver Options

- On-Board Options – Cont'd
  - Temperature sensor
    - Uses I²C bus for connection to Starbase controller
  - Electrically erasable programmable read-only memory (EEPROM) IC
    - Uses I²C bus for connection to Starbase controller
    - Sets receiver address
    - Stores configuration attributes





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KIT CONSTRUCTION

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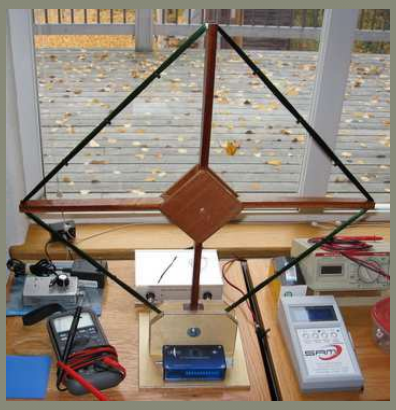
Construction

- Antenna



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Construction

- Receiver Kit
  - Individually bagged and marked parts

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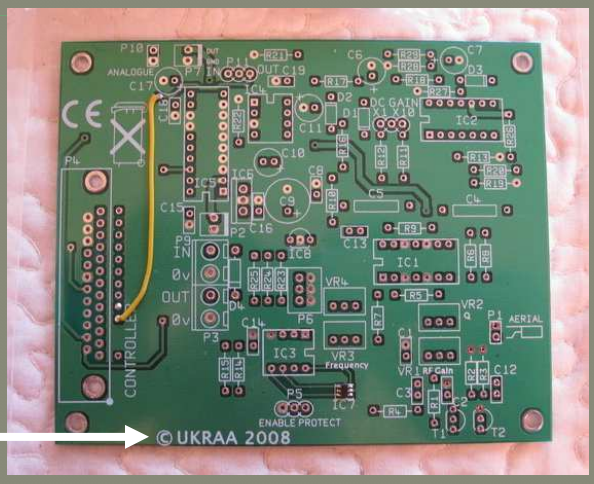
Construction

- Receiver Assembly
  - Simple enough that few problems will be encountered except
    - Poor soldering
    - Incorrect component placement



Date Stamp 2008

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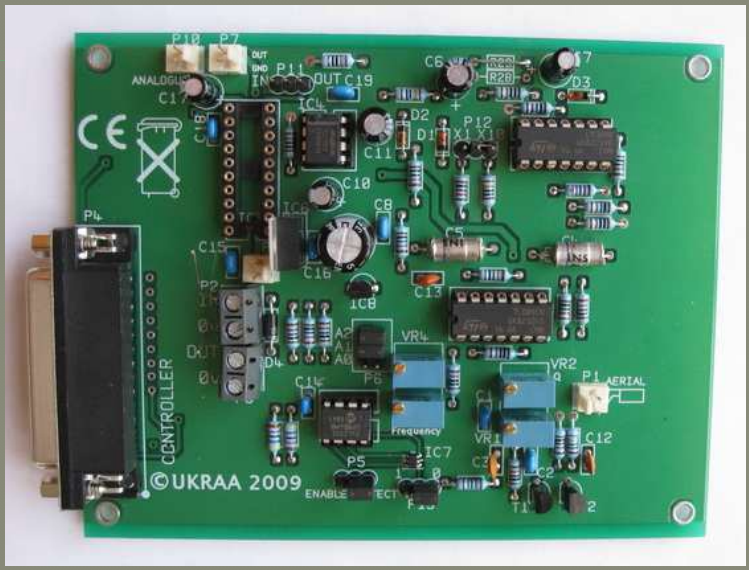
Construction

- Receiver
  - Completed board is not crowded and solder landings are properly sized for a fine-tip soldering iron

Date Stamp 2009 →



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Construction

- Receiver No. 1

For reference, analog meter is ~ 40 mm square

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Construction

- Receiver No. 2

For reference, analog meter is ~ 40 mm square

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Construction

- Receivers

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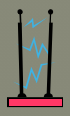
PERFORMANCE

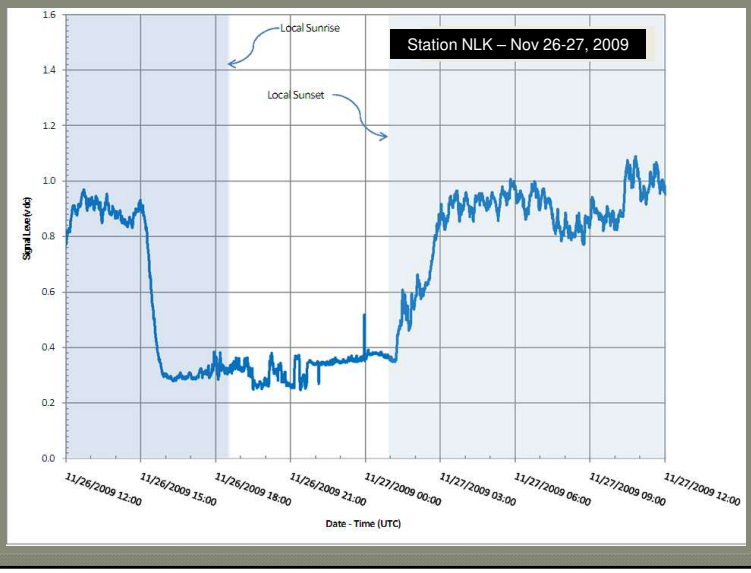
Performance ~ Live

- Considerable difficulty encountered with reliably receiving VLF transmissions in Anchorage, Alaska
  - Persistent local interference
  - Distance from transmitter stations
  - Northern latitude propagation



- Testing performed indoors during the winter
  - No opportunity to move antenna outdoors and away from potential interference sources

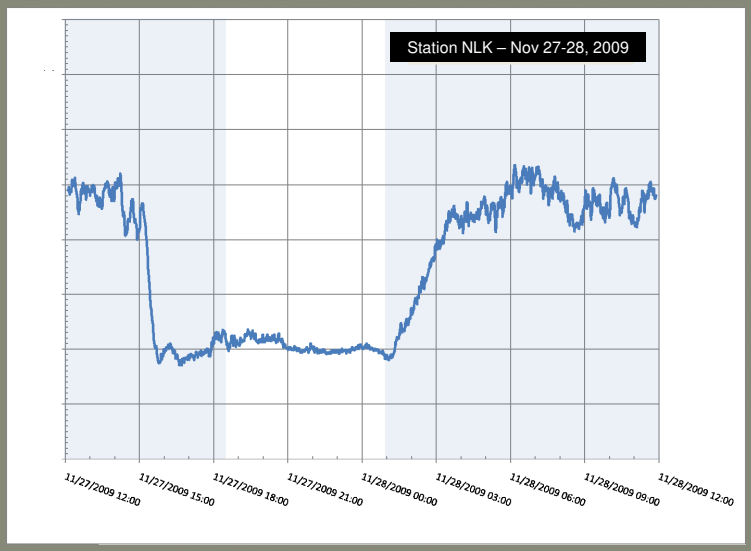
Performance ~ Live



Jim Creek, Washington
24.0 kHz: Day 1

Characteristic Trace:
- ✓ Noisy at night but higher signal level
- ✓ Signal level dip at sunrise and sunset
- ✓ Lower but relatively steady signal level during daytime
- ✓ Nighttime and daytime depend on path

Performance ~ Live



Jim Creek, Washington
24.0 kHz: Day 2

Performance ~ Live

Jim Creek, Washington
24.0 kHz: Day 3

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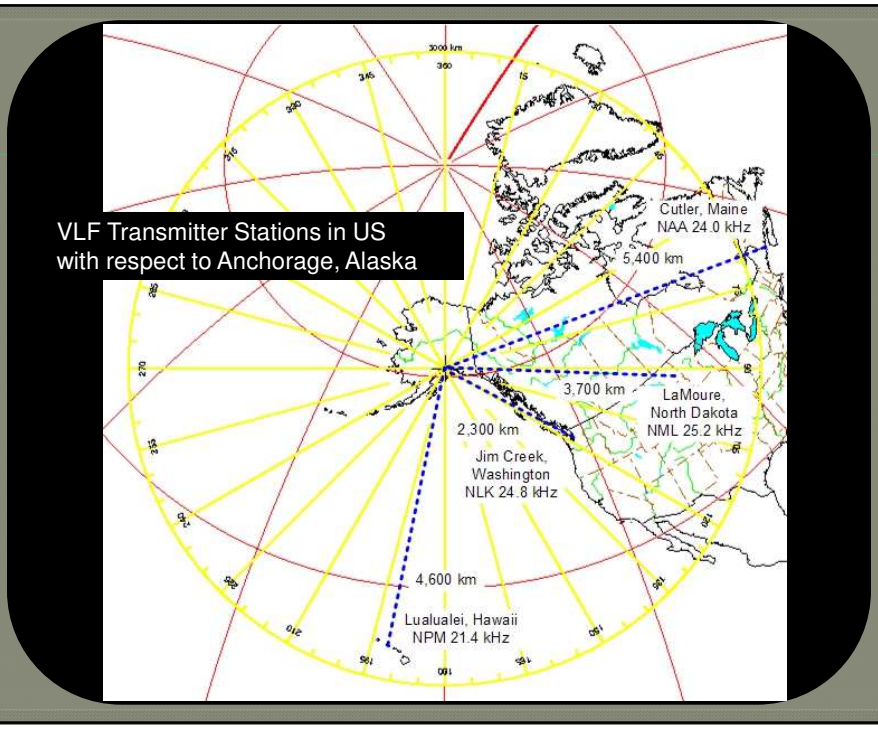

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Improving Performance

- Where the distance between the transmitter and receiver exceeds around 1,000 km, a larger antenna may be advisable
- Existing square loop design can be scaled up to any practical dimension
- Attention will need to be paid to the self-resonant frequency due to distributed capacitance of the windings
  - Self-resonant frequency > operating frequency

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Improving Performance

- Slight redesign of the 1st RF input amplifier to increase its gain
- Add a preamplifier with balanced low impedance input and unbalanced high impedance output to better match antenna to 1st RF amplifier
- Replace inexpensive TL084 IC used for bandpass filter with a higher performance quad op-amp
- Tweak bandpass filter circuit to reduce the chance of oscillation at high Q settings
- Shield stages to reduce undesired feedback

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CONCLUSIONS

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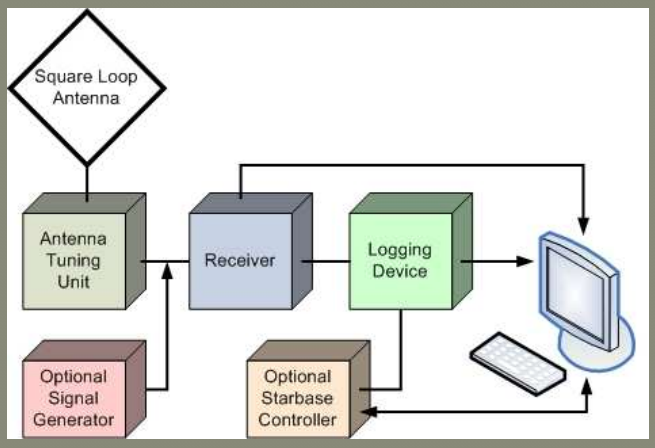
Conclusions

- The UKRAA VLF Receiver System consists of
  - Loop antenna
  - Antenna tuning unit
  - Tunable Receiver
  - Accessories
- Available in kit form or already built



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Conclusions

- Receiver design is unique among units used by amateur radio astronomers
  - Used with considerable success in the UK and Europe
  - Antenna and receiver input circuits are designed for receiving conditions in that region, where suitable VLF transmitters are less than 1,000 km away

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Conclusions

- Receiver should work well in much of the US
  - Considerable difficulty has been encountered in Anchorage, Alaska reliably receiving stations because of local interference and distance to stations
  - Larger antenna may be necessary in some locations

Reference: Application of the UKRAA Very Low Frequency Receiver System, https://www.reeve.com/Documents/LF-VLF/Reeve_SARA%20WestConf%20VLF%20Paper_Upd.pdf

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END OF PRESENTATION !

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