ELF/VLF Receiver Hardware
It’s AWESOME!

Morris Cohen
Stanford University
What’s a VLF Antenna?
What is a VLF receiver?

- Frequency range: 100Hz – 50kHz
The AWESOME Receiver

- Designed by Morris Cohen, Justin Tan
- Ultra sensitive
- Medium cost (~$3000)
- Narrowband amplitude/phase
- Broadband 100kHz data
- Deployed worldwide
- Auto-calibration
AWESOME receiver overview

- B-Field Antenna
- Preamp
- Long Cable
- Line Receiver
- GPS Antenna
- Computer
- Analog to Digital

Atmospheric Weather Electromagnetic System for Observation, Modeling, and Education
Atmospheric Weather Electromagnetic System for Observation, Modeling, and Education

Long Cable

AWESOME receiver overview
AWESOME receiver overview

Atmospheric Weather Electromagnetic System for Observation, Modeling, and Education
Antenna Design

- B-Field, magnetic loop
- Orthogonal pair
- 1.0 Ω, 1.0 mH (high pass cutoff at ~159Hz)
- Various sizes (larger ➞ more sensitive)
Maxwell’s Equations show that magnetic field (B) perpendicular to loop of wire produces a voltage, and current (I).

\[ \frac{d}{dt} \int B \cdot dA = \int E \cdot dl \]
Antenna Sizes

24.01 m²  17.58 m²

How big an antenna do we really need?

1.69 m²
AWESOME receiver overview

Atmospheric Weather Electromagnetic System for Observation, Modeling, and Education
Preamplifier

- Impedence matched
- Paschal amplifier
- 3 cutoff modes
- Gain selectable
- Calibration circuit
- Weatherproof
Pre-Amplifier Box

CABLE FROM ANTENNA

N/S CHANNEL

E/W CHANNEL

PRE-AMPLIFIER CARDS
Pre-Amplifier Card

CUSTOM-BUILT TRANSFORMER
Matches impedance of antenna to impedance of circuitry
Voltage induced in antenna loop: \( V = (\omega)(N)(A)(B) = (\omega)(12)(1.69m^2)(pT) / j\omega \)

Voltage is amplified and noise is attenuated: \( V_2 = \alpha V_1 + \text{noise} \)
Pre-Amplifier Card

RFI SUPPRESSION
Capacitors and inductors attenuate radio stations
Pre-Amplifier Card

CALIBRATION TONE GENERATOR
Generates special calibration tone that is used to convert digitally recorded values to magnetic field values
Pre-Amplifier Card

Optional Filtering

Allows filtering of signals to obtain data at desired frequencies

- Ex: Remove noise from power lines (collect only $f > 7\text{kHz}$)
- Ex: Extend data range for quiet sites (collect as low as $f > 80\text{Hz}$)
Pre-Amplifier Box

TRANSFORMERS
Match the impedance of output driver of pre-amplifier to impedance of cable
AWESOME receiver overview

Atmospheric Weather Electromagnetic System for Observation, Modeling, and Education
Preamp to line receiver

- Long cabling
  - Belden 1217B
  - Four twisted pairs, shielded
  - Provides +/- 15V
  - Calibration enable

- Line Transformer
  - Custom built
  - Better low frequency response
  - Matches to 75-Ohm transmission line
BELDEN 1217B CABLE
- Takes signal from pre-amplifier to line receiver
- Four twisted pairs, shielded
- Provides +/- 15V
- Calibration enable
- Impedance $Z = 75\Omega$
- Max 3500 ft length from pre-amplifier to line receiver
AWESOME receiver overview

Atmospheric Weather Electromagnetic System for Observation, Modeling, and Education

Long Cable
Line receiver

- Power supply
  - PowerOne Had15
- Anti-aliasing filter
- GPS synchronization
Line Receiver Box

Serial Cable to

CABLE FROM PRE-AMPLIFIER

Anti-Aliasing Filter Cards
Anti-Aliasing Filter

- LTC1562
- 12\textsuperscript{th} order lowpass
- Elliptical filter
- 47 kHz cutoff
- 90dB attenuation by 55 kHz
- <50us group delay
AAF Response
AWESOME receiver overview

Atmospheric Weather Electromagnetic System for Observation, Modeling, and Education
Line Receiver GPS

- Motorola M12+ OnCore
- Provides 1 PPS signal
  - 200 ns accuracy
- FPGA generates 100 kPPS
  - Divides down 10 MHz
  - Feedback trims block
  - Time synched to 1 PPS
  - 100 ns maximum draft
- Phase error < 2.7° at 25 kHz
- More accurate TrueTime also available
Timing feedback

- Motorola GPS unit supplies 1 PPS signal
- Need PRECISE 100 kHz signal for sampling
  - Phase coherence
  - Interferometry

Diagram:

- 1 PPS Signal
- Counter
- 10 MHz Oscillator
- 16-bit DAC
- 100x Divider
- 100 kPPS Output
- FPGA
AWESOME receiver overview

Atmospheric Weather Electromagnetic System for Observation, Modeling, and Education

Long Cable
Ni-DAQ Card

- Inserted into computer
- Data enters at 200 samples/s, N/S and E/W interleaved → 100kHz per channel
- 16 bit resolution
- +/- 5V
Receiver Response

Amplitude Response (mV/pF)

Phase Response (radians)

RMS Noise (nT/$\sqrt{Hz}$)

Noise response

- Measured
- Antenna Only

0 dB: Clip Level = 9600 pT
10 dB: Clip Level = 3270 pT
20 dB: Clip Level = 1030 pT
30 dB: Clip Level = 320 pT
System Response

NS Channel Frequency Response

NS Channel Noise Response
AWESOME receiver overview

Atmospheric Weather Electromagnetic System for Observation, Modeling, and Education
Software

- VLF_DAQ designed by Robb Moore, Eddie Kim
- Flexible recording schedule
- Broadband and narrowband
- Live spectrograms
- Data sent over ftp
Data management

- Data sent over FTP daily
- “Synoptic” data
  - Capture small amounts of data periodically
- Online spectrograms
- Automatic transfer to external hard drive
  - 500 GB hard drive → ~350 hours of data
- “Pac-man mode”
  - Archive most recent few days continuous data
  - Useful for major events know shortly afterward
AWESOME sample data
Narrowband and broadband

Stanford ELF/VLF, sec after 10:00 UT, 01–Jun–2008

NWC (Australia) dB–pT

Frequency (kHz), ΔF = 100 Hz

Lightning-generated sferic

Picoteslas

Zoomed-in time series plot, sec after 10:00 UT

NLK, NWC, received at Stanford

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Daily transmitter patterns

Source: Robb Moore
“That's all Folks!”