VLF Audio Module for the Tangerine SDR

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Automated VLF Reception Systems

- VLF Natural Radio emissions often occur randomly and can’t be predicted reliably.
- Impractical to constantly listen for and record VLF emissions, as they can occur at inconvenient times and may never happen again for months!
- Often times, a listener can listen with their portable receiver for months and not hear anything except sferics and tweeks.
- Power line interference is a still a huge problem, and it’s getting worse!

Automated VLF Reception Systems

- Automation of VLF reception is a solution to the limitations of live listening and recording.
- VLF receivers (E-Field and B-Field) (and their antennas) are permanently installed outside, either in a radio quiet location or where power line interference is not strong enough to overload the receiver.
- VLF receivers are powered using either batteries or isolated DC.
- The antenna (E-Field probe or B-Field loop) is connected directly to the receiver. Antenna feedlines are not used.
- Feedlines from the receiver audio output transport the audio to the DAQ system inside.

Anatomy of an automated VLF Reception System

- VLF receiver with preamp/filtering.
- Can be either E-Field or B-Field receiver depending on the front end.
- E-Field
  - High impedance front end consisting of a JFET or op amp with some added gain, used as an impedance converter.
  - JFET input stages use a gate resistor to set input impedance of the front end; antenna is connected directly to the gate, often with an inline choke.
  - E-Field antenna is just an E-Field probe, connected directly to the input stage.
  - Antenna length can be as small as one meter, often 2-3 meters in length.
  - Since the antenna is a tiny fraction of the wavelength, the high impedance of the input stage.

Anatomy of an automated VLF reception System: E-Field Receiver

Can be Op Amp input as well

Anatomy of an automated VLF Reception System

- B-Field
  - Frontend usually consists of an op amp circuit with added gain.
  - Loop is coupled to the input of the op amp via an audio transformer.
  - The audio transformer serves to match impedance; the low impedance of the loop to the high impedance of the op amp stage.
  - Filtering is done after the frontend like in the E-Field receiver, then is amplified for a headphone monitor or a feedline driver circuit.
  - Two loops (and two receivers) are required for East-West and North-South reception.
  - The receiver also requires a good ground or counterpoise and feedline isolation.

VLF Receivers: B-field Receivers

Loop Antenna (Can be two loops orthogonal to each other for N-S and E-W channels

Audio Transformer and Op Amp Input Stage (Impedance Converter and Gain Stage)

Filtering stage (Band Pass)

Output Stage (Headphone or Feedline Driver)

Permanent VLF Observation

Image taken from VLF Experimentation Facebook Group and vlf.it

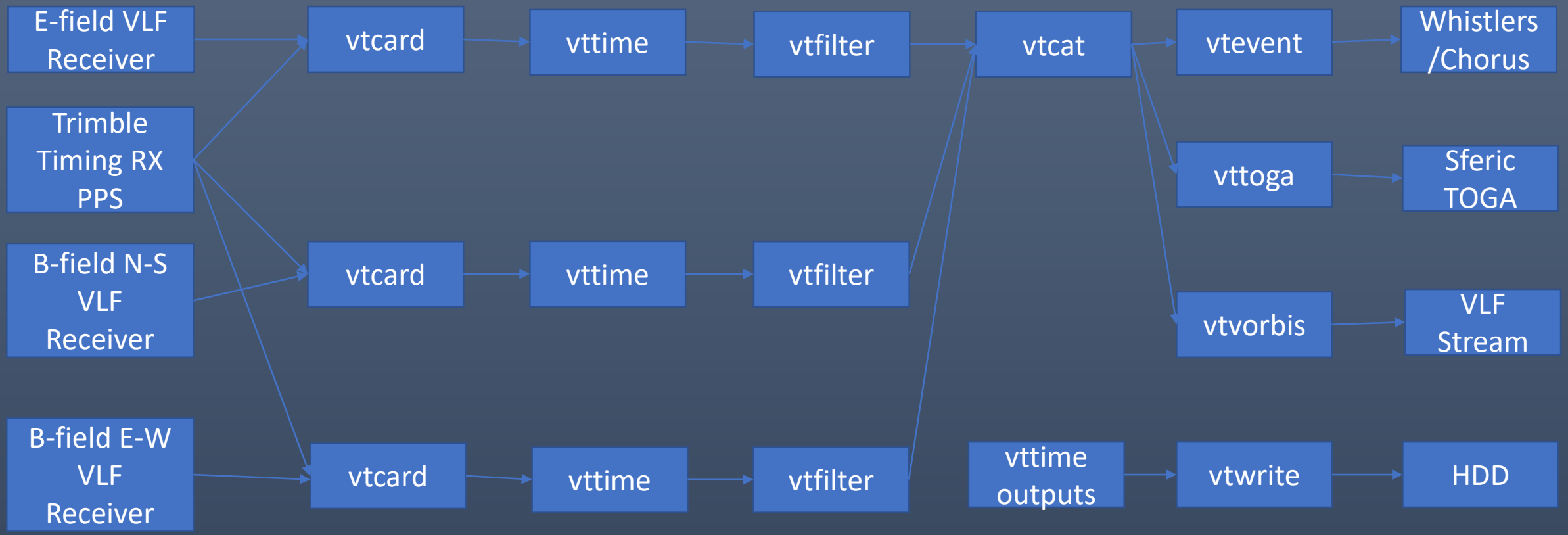
DAQ System

- The simplest DAQ system is an audio recorder. These days, digital audio recorders are used.
- For the serious enthusiast, a computer with a soundcard and appropriate software is often used. Appropriate software includes Spectrum Lab or vlfrx-tools.
- For the professional researcher, a professional DAQ from National Instruments or other DAQ manufacturer.
- Sometimes, a complete custom DAQ solution can be utilized by the professional researcher to fit their needs.

vlfrx-tools

- Open source VLF radio toolkit for capture, analysis, and storage.
- VLF audio and GPS PPS fed into soundcard. (Cannot feed GPS PPS into parallel or serial port)
- Automatically filters power line hum with tracking filter.
- Detects whistler and chorus events automatically and lightning location through TOGA method.
- Can support triple axis reception. (E-field, N-S B-field, E-W B-field)
- Can detect Sudden Ionospheric Disturbances.
- Can determine bearing and distance of VLF signals. (triple axis required)
- Can be compiled on Linux, FreeBSD, and OpenBSD. (BSD preferred)
- Audio streaming via icecast server of VLF audio for live listening.

vlfrx-tools System Diagram



VLF Audio Module: Inspiration

- A post on the VLF Natural Radio groups.io group talking about the performance of the Behringer UMC404HD professional USB audio interface as a DAQ instead of a high quality PC soundcard.
- Paul Nicholson liked it so much that he employed it in his automated VLF reception system replacing the M-Audio 192 PCI he was currently using. It performed as well or better in his testing.
- The UMC404HD utilizes Cirrus Logic CS4272 24-Bit, 192 kHz Stereo Audio CODEC for analog to digital conversion with 114dB dynamic range.
- The UMC404HD also utilizes the AD8694, NJM2122, and RC4850 op amps for analog filtering and gain stages.

VLF Audio Module: Inspiration

- For the VLF audio module, the Cirrus Logic CS4272 was not a good choice.
- Only two analog input channels are available. At least three are required for the VLF Audio Module.
- The Cirrus Logic CS4272 is a CODEC, which means both analog inputs and outputs. Only analog inputs are required.
- An alternative with at least 3 analog input channels, and input channels only is required for the VLF Audio module.
- A single IC simplified design and can offer the same performance.

VLF Audio Module: Design

- The VLF audio module will use the Cirrus Logic CS5364 114 dB, 192 kHz, 4-Channel A/D Converter.
- Master clock will be obtained from one of the programmable clock channels from the GPSDO.
- Audio samples transported via I2S or TDM port to the Data Engine FPGA.
- FPGA will set active A/D channels, sampling rate, sample length, and master clock frequency based on user settings.
- Interfaces to the Data Engine as a LEAF board; I2S/TDM port connects via M.2 connector and I2C control via the RPi I/O header.
- Possibly EEPROM for board ID.

VLF Audio Module: Operation

- VLF audio feeds will connect to screw terminals via audio isolation transformers.
- FPGA configures the active channels (1-4), sampling rate, sample length, and master clock via I2C.
- The FPGA configures the GPSDO DDS channel to generate the master clock frequency required for the configuration.
- Samples are transported via I2S or TDM (1-2/1-4 channels) to the FPGA.
- FPGA timestamps the sample referenced to GPS time the same way vtcard timestamps the sample.
- FPGA streams the samples to a TCP socket via the Ethernet port compatible with vlfrx-tools.
- FPGA combines channels into a single multichannel stream in the same way as vtcat.

VLF Audio Module: Clocking

LJ/I²S MASTER OR SLAVE	QSM Fs = 192 kHz				
MCLK Divider	÷4	÷3	÷2	÷1.5	÷1
MCLK (MHz)	49.152	36.864	24	18.384	12.288
SCLK (MHz)	12.288	12.288	12.288	12.288	12.288
MCLK/LRCK Ratio	256	192	128	96	64
SCLK/LRCK Ratio	64	64	64	64	64

Table 6. Frequencies for 192 kHz Sample Rate using LJ/I²S

TDM MASTER	QSM Fs = 192 kHz				
MCLK Divider	÷4	-	-	-	-
MCLK (MHz)	49.152	-	-	-	-
SCLK (MHz)	49.152	-	-	-	-
MCLK/FS Ratio	256	-	-	-	-
SCLK/FS Ratio	256	-	-	-	-

Table 11. Frequencies for 192 kHz Sample Rate using TDM

LIGO gravitational wave detection

Paul

Referring to yesterday's announcement from LIGO

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

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

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

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

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

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

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Paul Nicholson
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VLF Audio Module: Why VLF Automated Reception Systems are Important

VLF Audio Module: Thank you!

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