VLF Module for the Tangerine SDR HamSCI Workshop 2021 Progress Update

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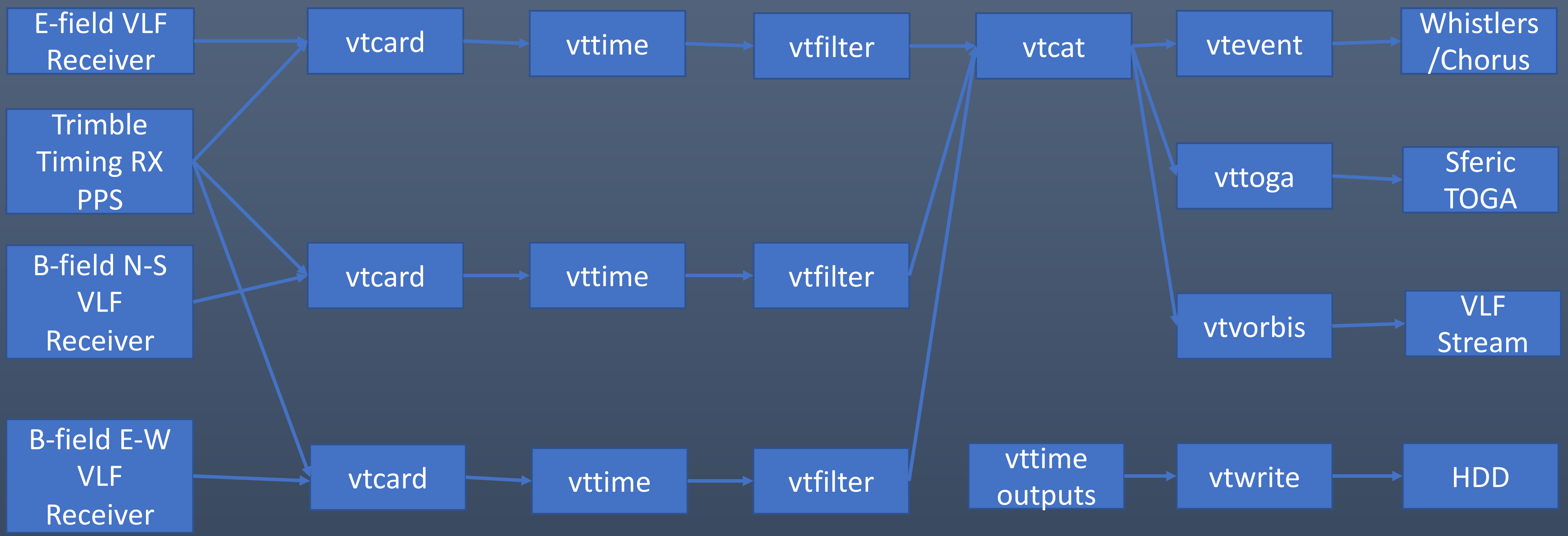
VLF Module: Inspiration

- 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 (author of vlfrx-tools) 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.

vlfrx-tools

- Open source VLF radio toolkit for capture, analysis, and storage.
- VLF receiver 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.
- Audio streaming via icecast server of VLF audio for live listening.

vlfrx-tools System Diagram



VLF Module: Inspiration

- For the VLF 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 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 module.
- In the Behringer UMC404HD, two CS4272s were used for 4 input channels. A single IC will simplify design and can offer the same performance.

VLF Module: Initial Design

- Uses 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 Module: Operation

- VLF receiver 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 against system clock.
- FPGA streams the samples to a TCP/UDP socket via the Ethernet port compatible with vlfrx-tools.
- FPGA combines channels into a single multichannel stream in the same way as vtcat. (timestamps aligned and required on ALL channels)

VLF Module: 100 kHz limitations

Sampling speed modes of the CS5364:

Single-Speed Master

Double-Speed Master

Quad-Speed Master

Note: Master clock fed from GPSDO

For 100 kHz operation, the sampling rate needs to be 200 kHz or more (Nyquist frequency)

The FPGA will set the appropriate mode for the desired sampling rate (user selectable sampling rate)

Digital filter limitation ~0.5Fs

M1	M0	Mode	Frequency Range
0	0	Single-Speed Master Mode (SSM)	2 kHz - 54 kHz
0	1	Double-Speed Master Mode (DSM)	54 kHz - 108 kHz
1	0	Quadruple-Speed Master Mode (QSM)	108 kHz - 216 kHz
1	1	Auto-Detected Speed Slave Mode	2 kHz - 216 kHz

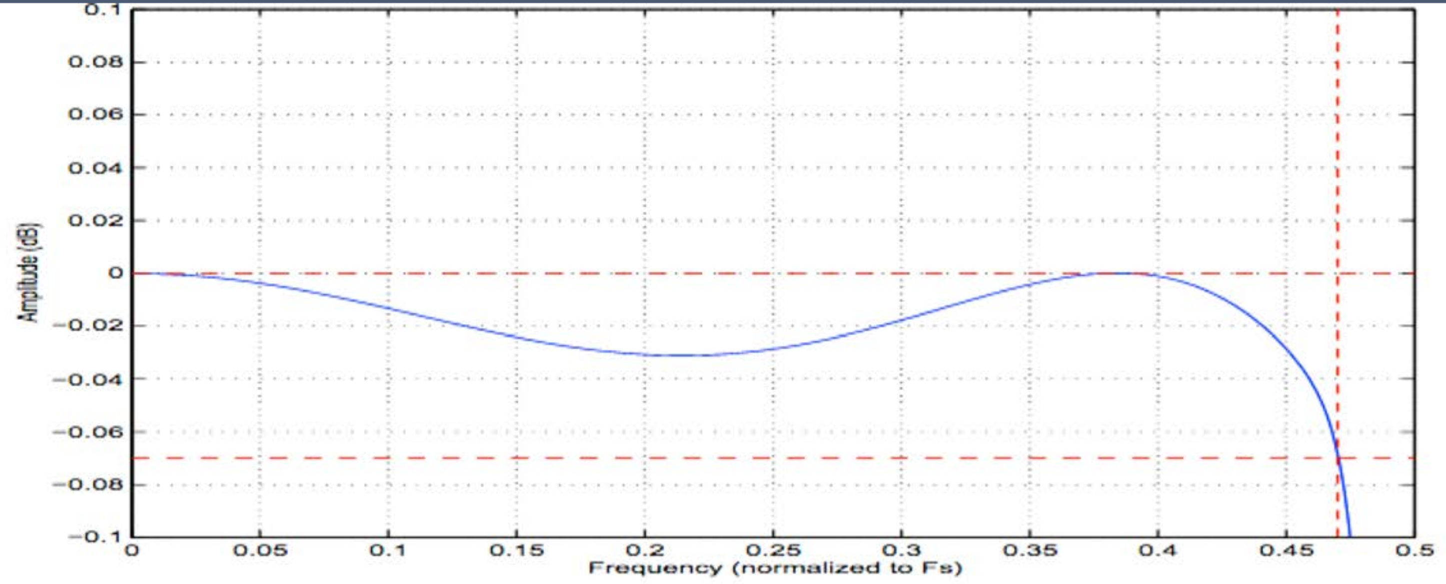


Figure 19. SSM Passband

VLF Module: Digital Filter Limitations

DSM Passband: Roll off at 0.45Fs

QSM Passband: Roll off at 0.25Fs

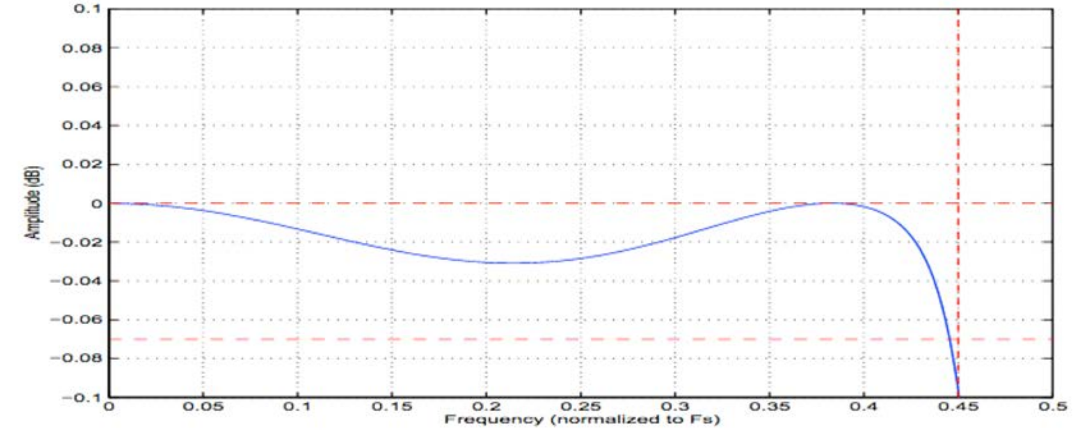


Figure 20. DSM Passband

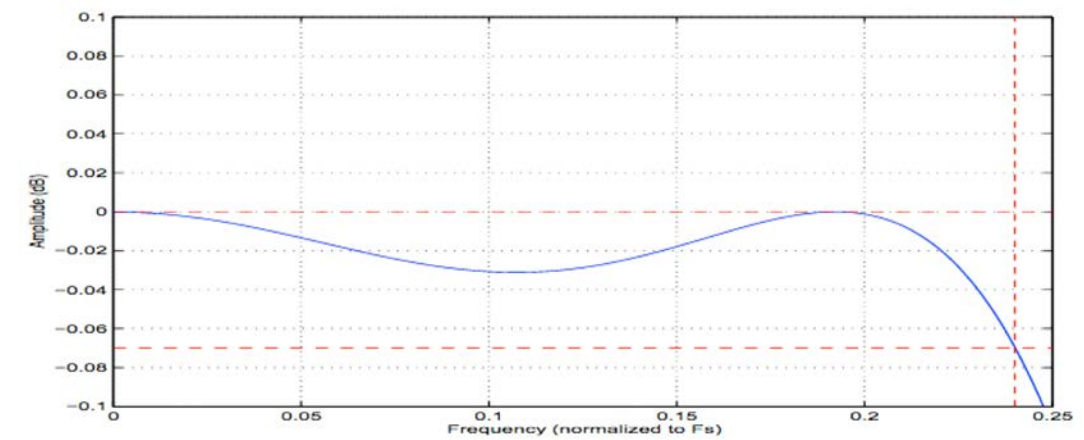
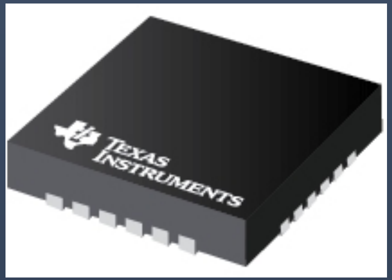


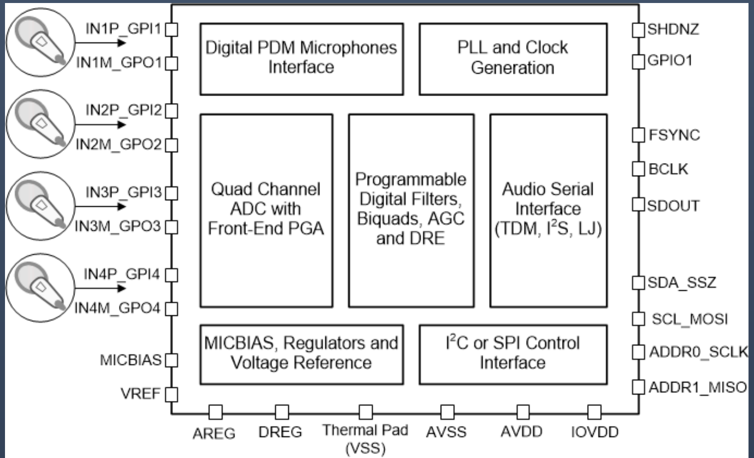
Figure 21. QSM Passband

Conclusion: Never base your design on the datasheet’s first page!

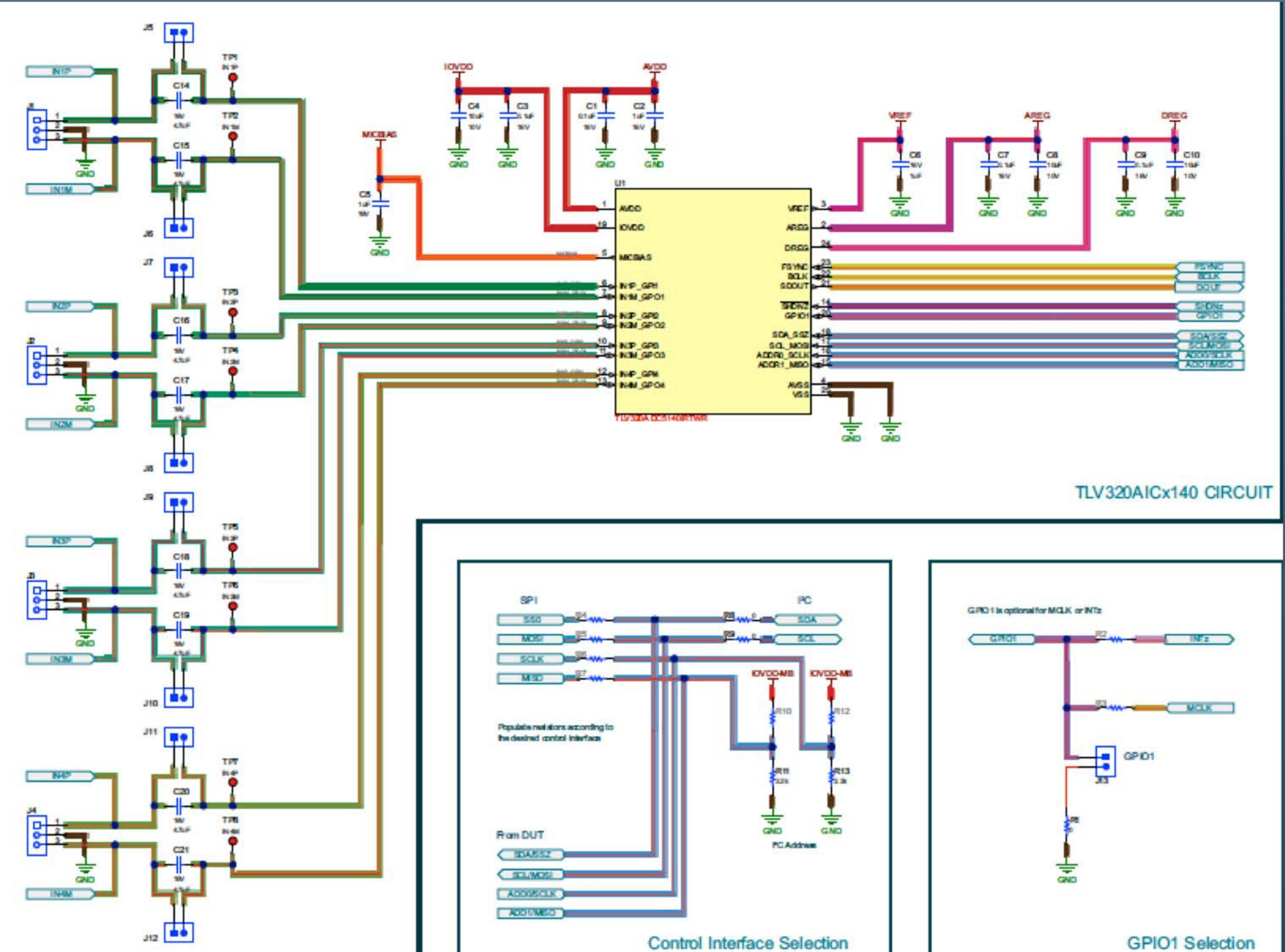
VLF Module: Improved Design

- Texas Instruments TLV320ADC6140: Quad-channel 768-kHz Burr-Brown™ audio analog-to-digital converter (ADC) with 122-dB SNR
- 4-channel ADC inputs
- Sampling rates of up to 768 kHz (384 kHz for 100 kHz VLF operation)
- 122 dB dynamic range with dynamic range enhancer (112dB without)
- 3V3 or 1V8 IOVDD operation (1V8 IOVDD required for LEAF Module)
- Much better digital filter performance





VLF Module: Preliminary Schematic

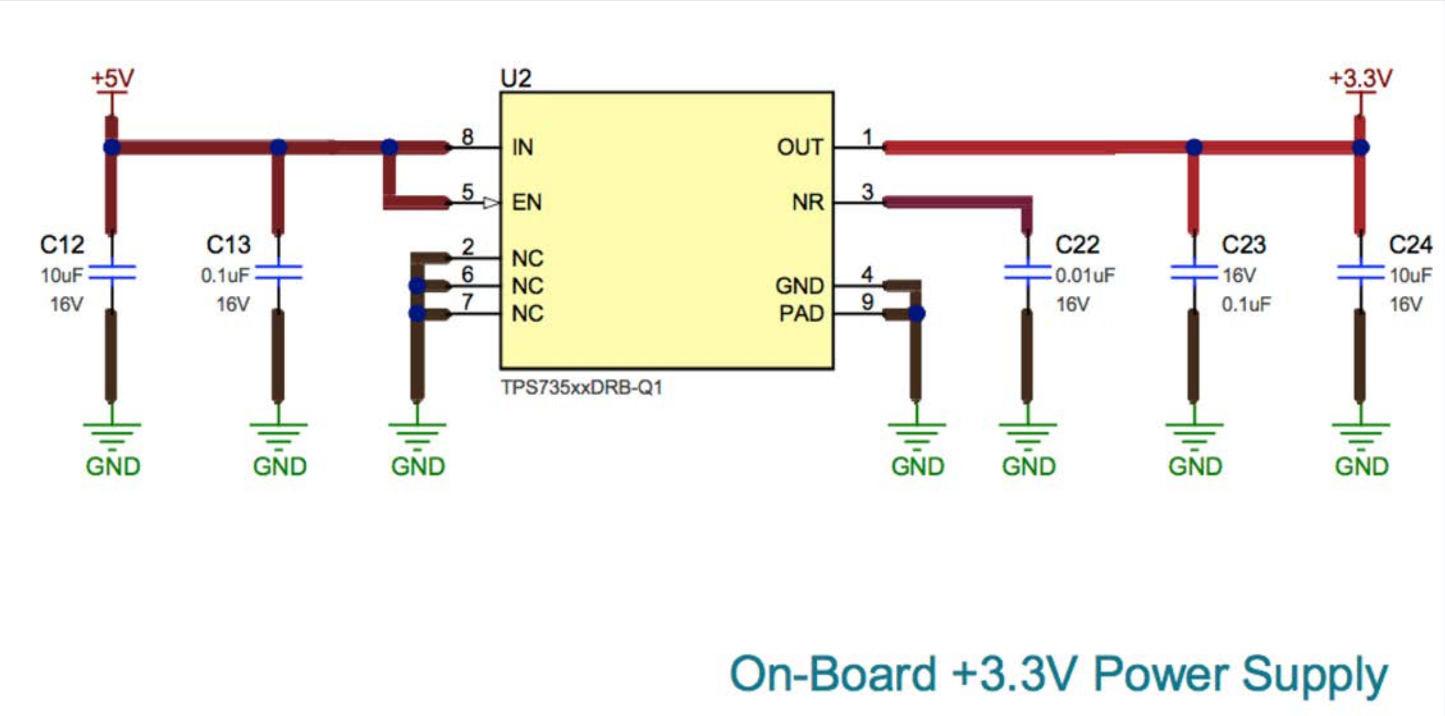


VLF Module: Analog Power

TPS735-Q1 LDO (1.8V Fixed Output Version)

Similar noise and thermal performance and less than half the cost of similar LDOs from Linear Technology

Used on TI's EVB



VLF Module: Raspberry Pi/Onion Omega2+ Soundcard

Separate hat soundcard for the Raspberry Pi that uses the same TLV320ADC6140

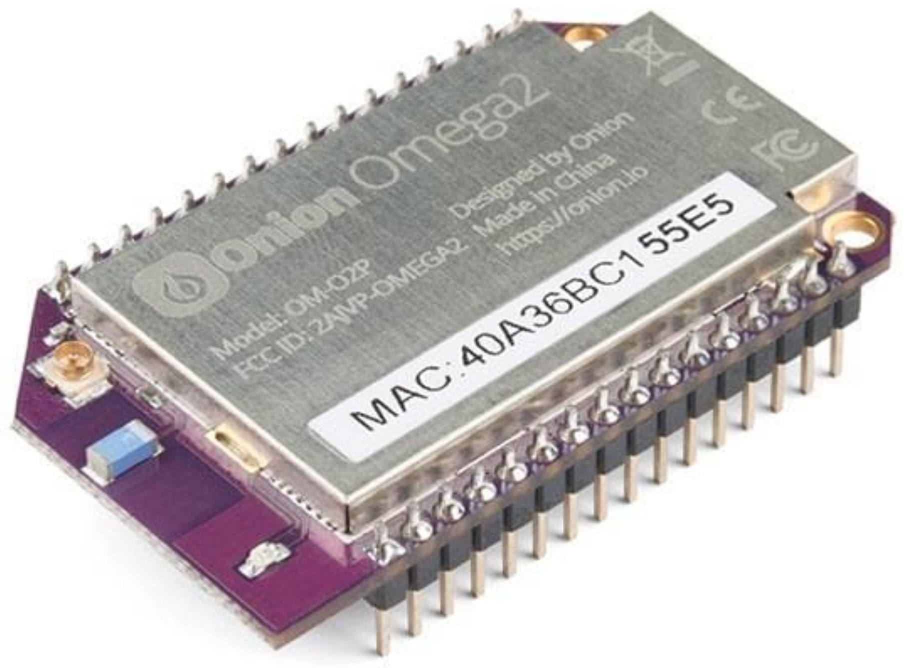
4-channel analog input soundcard primarily for VLF signal capture.

TLV320ADC6140 supported in current Linux kernel with ALSA

“driver” will be a simple device tree overlay because of Linux support

Primarily for use with vlfrx-tools to create a Raspberry Pi VLF SDR

An Onion Omega2+ version for an even smaller footprint



VLF Module: Why VLF Automated Reception Systems are Important

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 Module: Thank you!

- We gratefully acknowledge support to this project from NSF Grants AGS-2002278, AGS-1932997, and AGS-1932972.
- I'd like to offer my gratitude to the following:
    - Paul Nicholson for his endless support, vlfrx-tools, contributions to myself and the VLF community at large.
    - The VLF Community (VLF Natural Radio groups.io group, VLF Facebook Groups)
    - National Science Foundation for financial support.
    - Tom McDermott N5EG and Scotty Cowling WA2DFI for technical support.
    - Dr. Nathaniel Frissell W2NAF for endless support and motivation for this project.