A Coherent Multi-Antenna Shortwave Receiver with Application in Direction Finding

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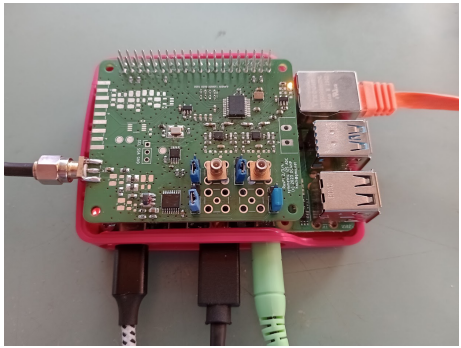
Outline

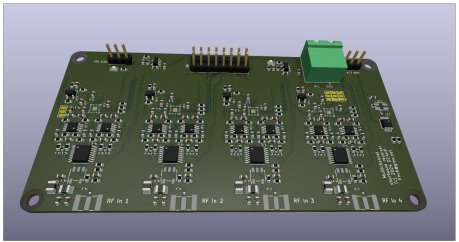
Motivation

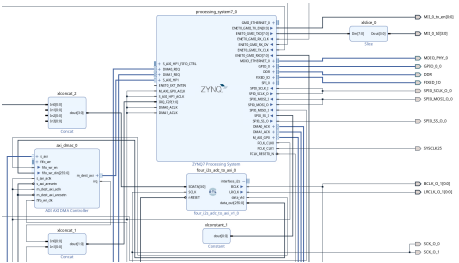
- Built a SDR hat for the Raspberry Pi inspired by the QDX
- Receiver based on SN74CBT3253 switching mixer and stereo I2S ADC
- Square wave LO generated by Si5351A
- Transmitting possible through rpitx and gr-rpitx (Many thanks to Evariste F5OEO and Jean-Michel Friedt)
- Presented at DARC's Nordsee-Workshop 2024 and received suggestion as feedback to scale up system to several antennas



Approach

- Researched suitable multi-channel ADCs
- Criteria:
  - ease of configurability - either through existing Linux driver or pin-strapping
  - digital interface: SPI or TDM
  - price tag
- Considered AD7768, but driver support on Raspberry Pi was dire
- Decided to use 4 I2S ADCs instead and shoehorn them together using an FPGA
- Went for 4x PCM1820 (192kSps, 32bit)
- Audio interface isn't really suitable for more than 2 ADC channels, so I wrote an IIO driver

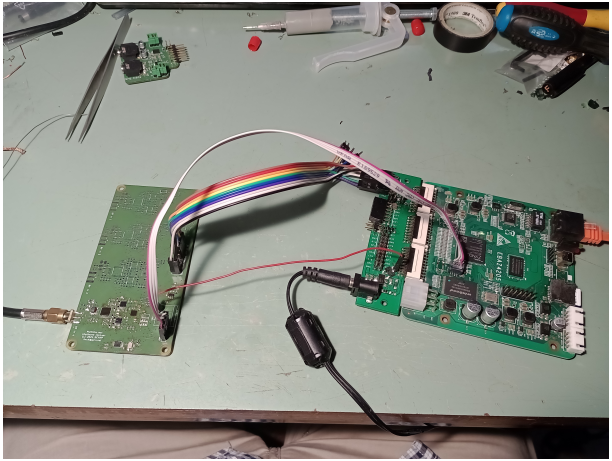




Outline

Testing the receiver board

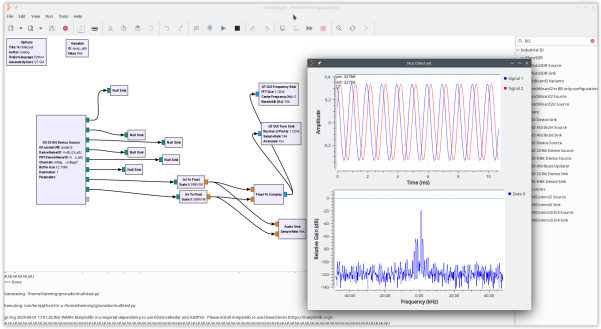
- FPGA board of choice was the trusty EBAZ4205
- "EBAZ4205 Minimal Breakout" `https://git.sr.ht/~ajk/ebaz4205_minimal_breakout`[1] was used for testing (24.576MHz XO needed to be bodged in as clock source, as well as 5V linear regulator)

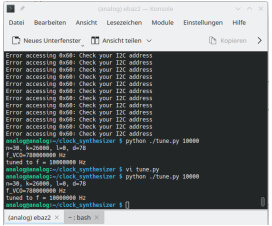


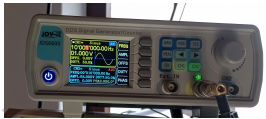
[1] Thanks DL7KAY for the spare PCBs!

Testing the receiver board

- 32 bit format required new IIO source block (available at `https://github.com/hennichodernich/gr-iio`)
- First test with signal generator successful
- Si5351A controlled using Python running directly on EBAZ4205 for now (later `https://github.com/hennichodernich/si5351-iio` got a quadrature mode added)

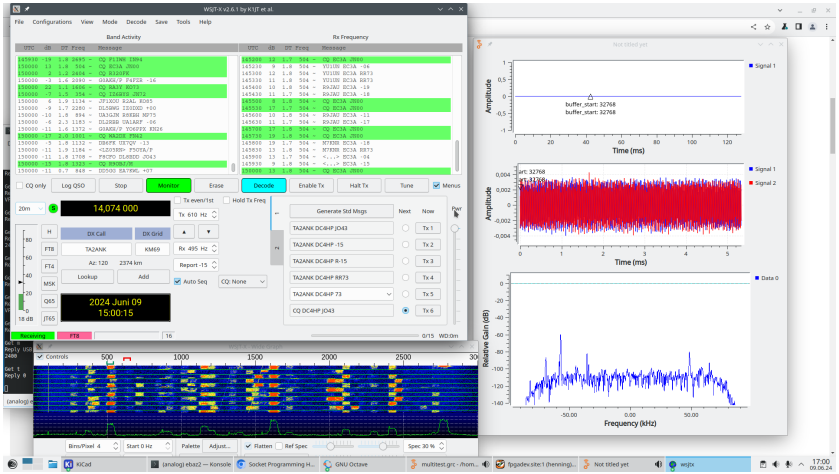






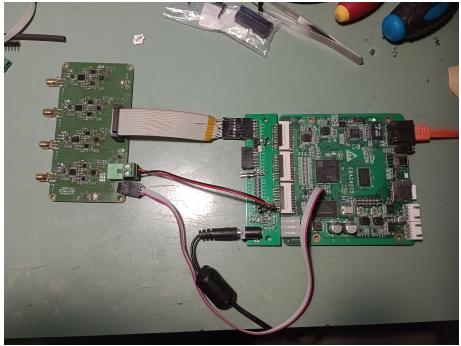
First test with receive antenna

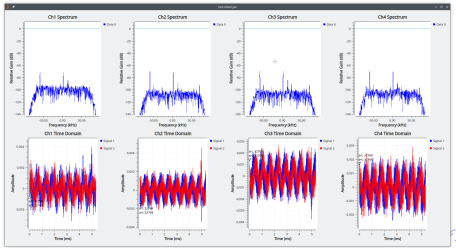
- First single-channel smoke test on my EFHW



Finishing the board

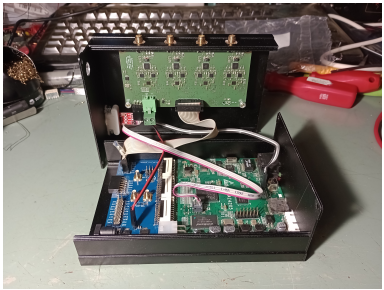
- Missing channels added
- First quick receive test with four 5.6m telescopic vertical antennas in “Foursquare” constellation





First field testing

- Made a proper breakout board (future fitted for possible multi-channel TX) and put the boards into an enclosure
- (Passive) PoE injector and extractor allow powering the receiver from remote
- First real field test on DARC District India's "Distriktscamp"[1] in September 2024

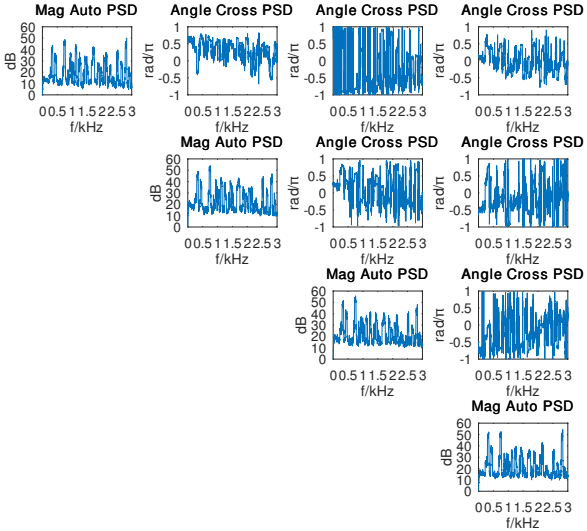


[1] Photo credit: Daniel DL2AB

Outline

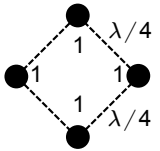
Spectral Estimation

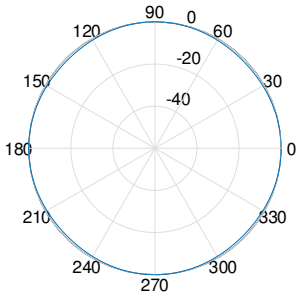
- Offline processing using GNU Octave
- Test scenario: 20m FT8 band (14074kHz)
- Approach: Calculate auto and cross power spectral densities for each 15 second slot over all antennas
- Call `decode_ft8` (on single channel) to determine center frequencies of stations
- Read out auto PSD / cross PSD at individual center frequencies to create correlation matrices for each station in each slot



Theoretical Beampatterns

- Perform eigenvalue decomposition of correlation matrices and determine eigenvector of largest eigenvalue
- Use this eigenvector as hypothetical beamsteering vector and plot resulting beampattern (in horizontal plane, assuming perfect radiators)
- Angle of maximum is estimate for direction of arrival (reciprocity assumed)
- Theoretical examples:





$$[1,1,1,1] \triangleq [0°, 0°, 0°, 0°]$$

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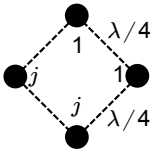

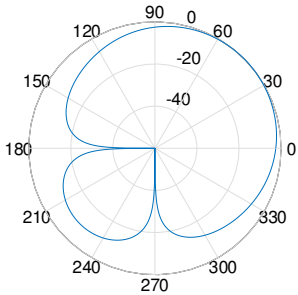

$$[1, 1, j, j] \stackrel{\wedge}{=} [0°, 0°, 90°, 90°]$$

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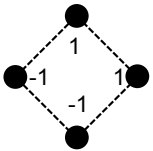

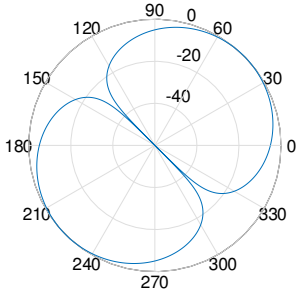

$$[1, 1, -1, -1] \stackrel{\wedge}{=} [0°, 0°, 180°, 180°]$$

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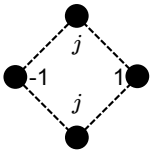

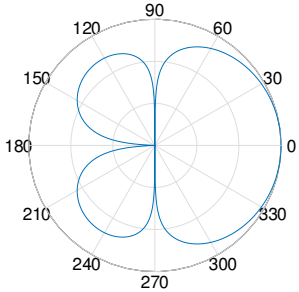

$$[1, j, -1, j] \triangleq [0°, 90°, 180°, 90°]$$

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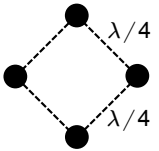
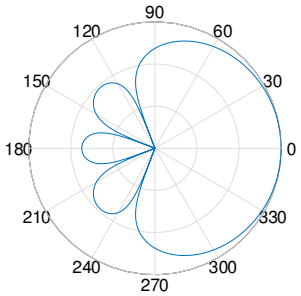
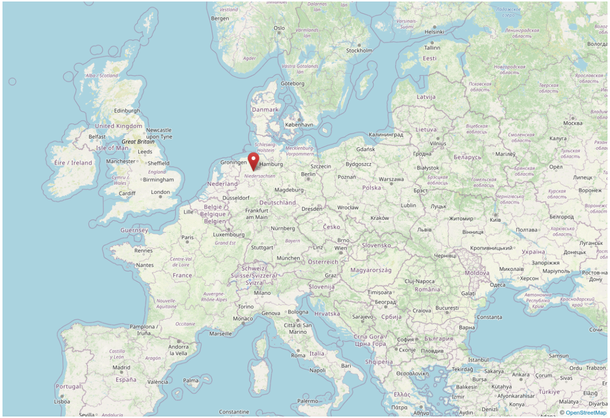




$[0°, 64°, 127°, 64°]$

Results from the Field Day

- Angle of shortest path can be calculated from Maidenhead locator
- Goal was comparison between angles, but array wasn't perfectly aligned in north-south/east-west direction



Results from the Field Day

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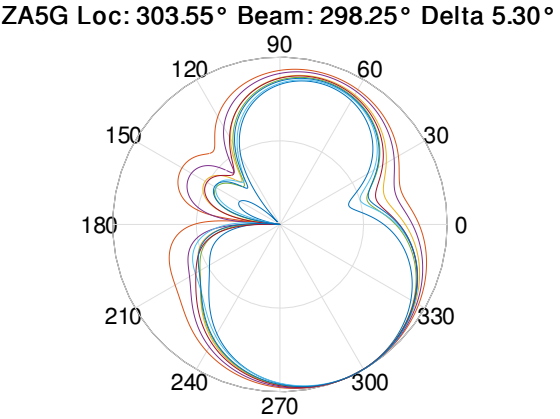
- Actual examples: Albania



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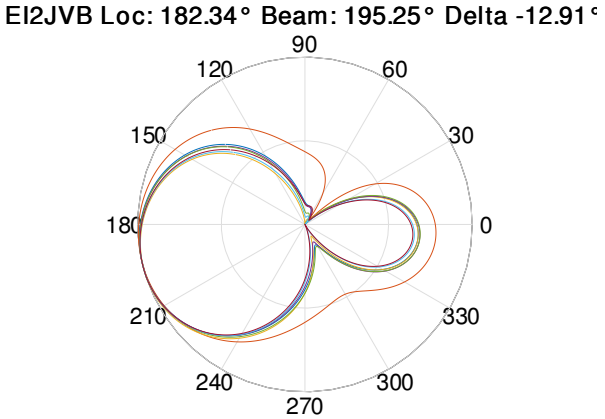
- Actual examples: Ireland



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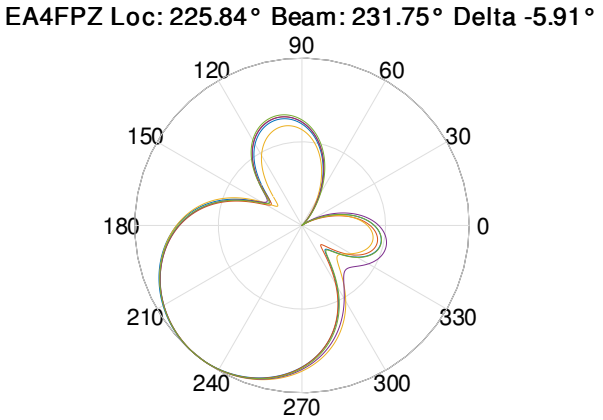
- Actual examples: Spain



Results from the Field Day

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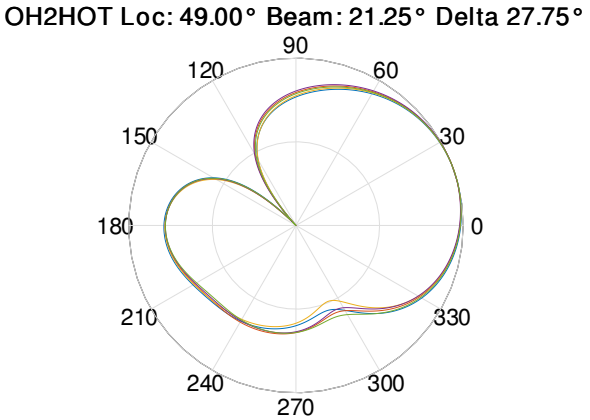
- Actual examples: Finland



Results from the Field Day

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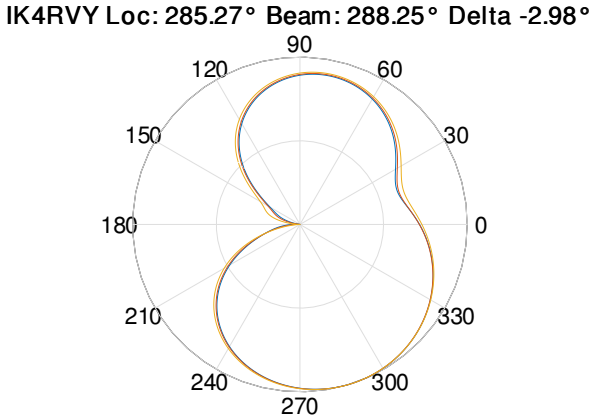
- Actual examples: Italy



Results from the Field Day

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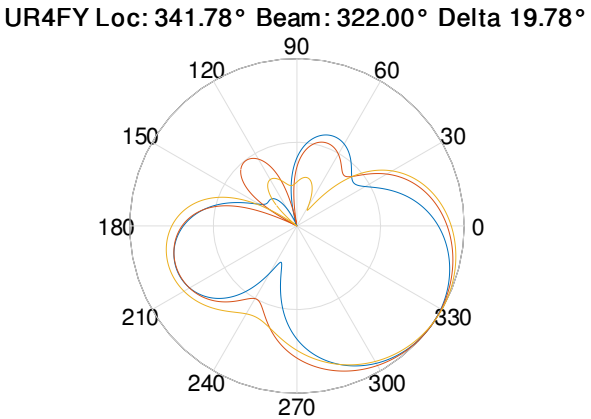
- Actual examples: Ukraine



Results from the Field Day

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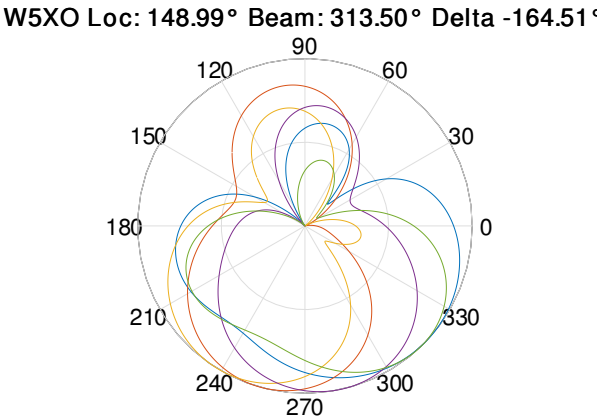
- Actual examples: Texas, US



Outline

Conclusion and Outlook

- Results are quite promising: General direction usually correct
- Beamforming using maximum ratio combining (MRC) (implemented on the FPGA) on a per-station basis could be used to increase receive SNR, creating a virtual directional antenna
- Eigenvector can be used as beamsteering vector to actually transmit into particular direction of QSO partner - requires digital phase shifting mechanism implemented in the FPGA (work in progress)

Sneak preview

- 8 channel 77.76MSps coherent SDR based on Pavel Demin's QMTECH SDR
- Goal: Individual beamforming for each Rx session
- For updates follow me on Mastodon: `@hennichodernich@radiosocial.de`