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

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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 F50E0 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





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Testing the receiver board

- FPGA board of choice was the trusty EBAZ4205
- "EBAZ4205 Minimal Breakout" https://git.sr.ht/~ajk/ ebaz4205_minimal_breakout¹ was used for testing (24.576MHz XO needed to be bodged in as clock source, as well as 5V linear regulator)



¹Thanks 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

NX < 🖉 👗 🖬 🔹 🗄 Band Activity Rx Frequency und do no re-Signal 1 6 1.9 1134 - JF1X0U B2AL E085 buffer.start: 32768 E .0.5 buffar start: 32768 143630 17 1.7 504 - CO BUJA 2010 143630 10 1.6 504 - R9JAJ BUJA -11 143630 11 1.7 504 - R9JAJ BUJA -13 - -----100 120 Time (ms) 145900 13 1.7 504 - <...> BC3A :04 Signal 1 0.7 848 -0.004 Jart 32768 Signal 2 5000 Enable Tx Halt Tx Merrus 14.074.000 20 Next Now -0.004 ETR. Rx 495 Hz Time (ms) Bennet -15 Add Data 0 Auto Seg CQ: None 🗸 -20 2024 Juni 09 Tx6 - 0.05 - 20.04 .00 -80 -100 -120 0.00 Frequency (kHz) C Palette Adjust. V Ratten Ref Spec 🔳 (analog) ebaz2 — Konsole 👩 Socket Programming H... 🌖 GNU Octave 💲 multitest.org - (hom., 🐠 🧭 fooadewsites) (hermino)... 💲 Not titled yet P 4 4 A 17:00 R KOCad di 🗿 write

• First single-channel

smoke test on my

FFHW

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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

¹Photo credit: Daniel DL2AB H. Paul

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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

- 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:

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 $[0^{\circ}, 64^{\circ}, 127^{\circ}, 64^{\circ}]$

- 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

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- Actual examples: Albania

ZA5G Loc: 303.55° Beam: 298.25° Delta 5.30°

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- Actual examples: Ireland

El2JVB Loc: 182.34° Beam: 195.25° Delta -12.91°

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- Actual examples: Spain

EA4FPZ Loc: 225.84° Beam: 231.75° Delta -5.91°

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- Actual examples: Finland

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- Actual examples: Italy

IK4RVY Loc: 285.27° Beam: 288.25° Delta -2.98°

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- Actual examples: Ukraine

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- Actual examples: Texas, US

W5XO Loc: 148.99° Beam: 313.50° Delta -164.51°

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- 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

