Direction Finding with Passive Phase Radar
EE123 Final Project

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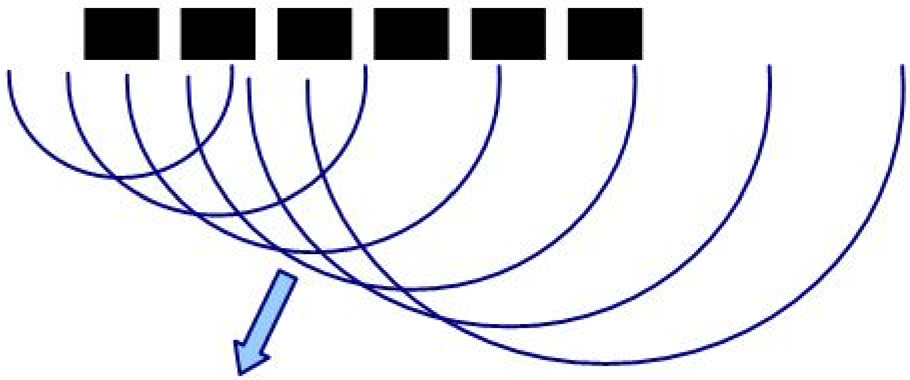
Goal

Use two SDRs to determine the direction that a RF source is coming from

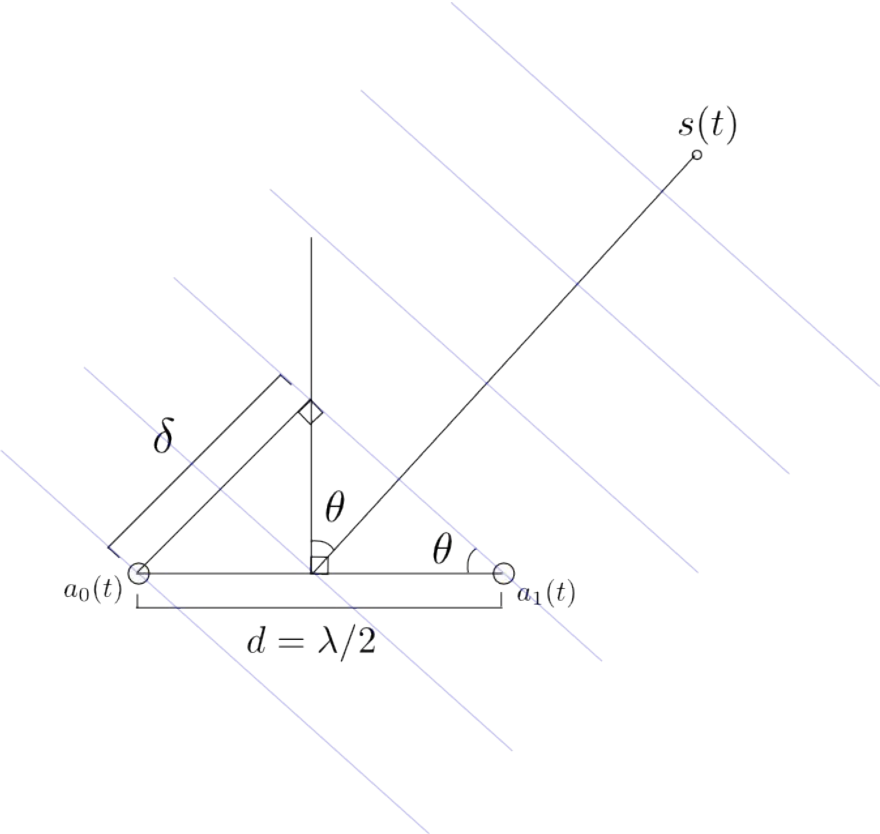
Create a maximum likelihood map to determine where the source is relative to the antennas

Phased Arrays

- Beamforming
  - Steer the reception wavefront by changing the relative phases of antennas in a linear array
- Active radar changes the phase between receivers beforehand
- Passive radar applies phase to signals digitally afterwards
- Want phase resulting in maximal combined energy

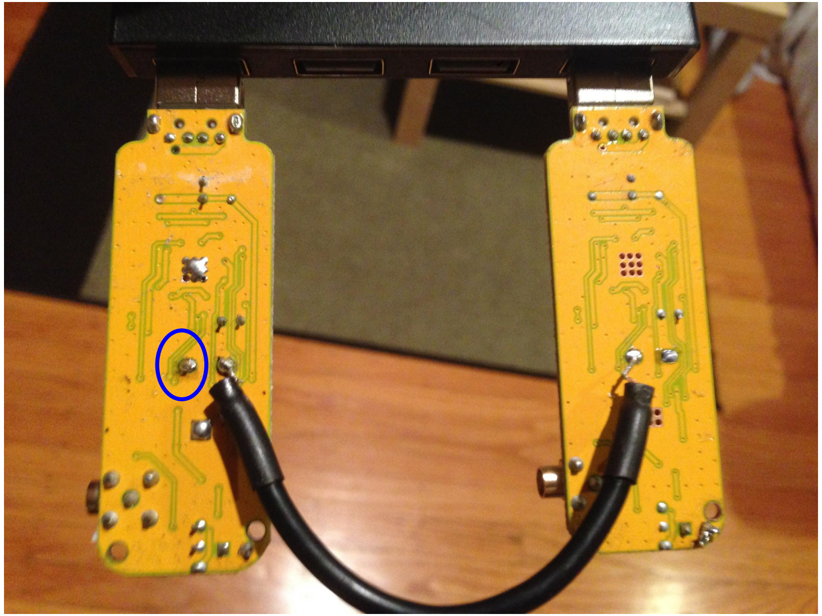


Derivation



$$s(t) = e^{j\omega_c t}$$
$$\delta = d\sin(\theta)$$
$$\phi_{dir}(\theta) = -\frac{\delta}{c}\omega_c = -\frac{\delta\omega_c}{c}\sin(\theta)$$
$$a_0(t) = G_0 e^{j(\omega_c(t-\delta t) - \phi_{dir} - \phi_0)}$$
$$a_1(t) = G_1 e^{j(\omega_c(t-\delta t) - \phi_1)}$$
$$\phi_{tuner} = \phi_0 - \phi_1$$
$$\hat{\theta} = \max_\theta \|a_0(t) + a_1(t)e^{j(\phi_{dir}(\theta) + \hat{\phi}_{tuner})}\|_2^2$$

Hardware (SDRs)



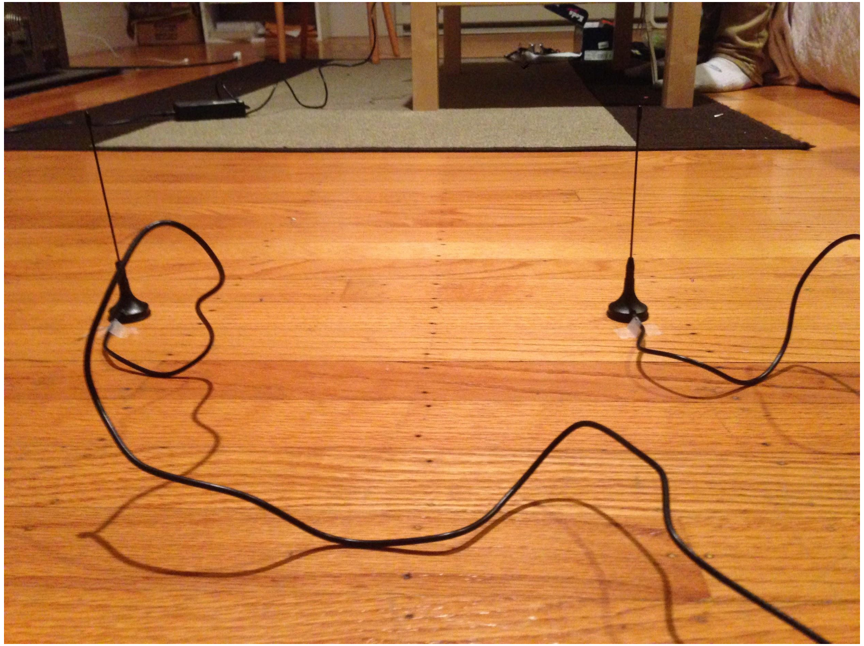
- Remove the clock (crystal oscillator) from one SDR
- Connected Clk-out (from the “master” SDR) to Clk-in (on the “slave” SDR)
- Connecting Clk-in (master) to Clk-in (slave) [blue circle] also works

Setup

- Antennas half wavelength apart (pure or pulsing tone ~434MHz)

Assumptions

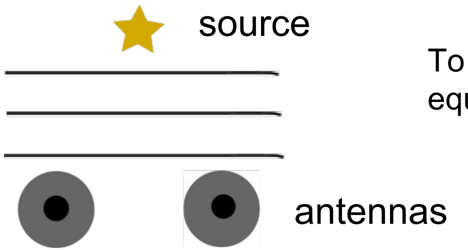
- Both antennas received same frequencies
- The frequencies of interest contribute the majority of the signal energy (BP → FFT → Max Magnitude Peak)
- Transmitted signals are sinusoids or sinusoidal pulses
- Constant phase between antennas
- Planar wavefronts



How it works

1. Acquire the samples from the dongles in parallel
2. Time align the two signals
   - USB interfaces causes signals to be misaligned after acquisition
   - Use cross-correlation to find the delay between acquired samples from each antenna
3. Bandpass filter signal of interest
4. Calibrating - determine phase tuner offset (should be constant when a tone is emitted)
   - Use a matched filter to detect tone
   - Average the regions of (very nearly) constant phase
5. Determine direction by digitally steering the antennas. Subtract (tuner) offset. Choose the angle that yields the maximal combined signal power.

Calibration setup:



To calibrate, we placed the source equidistant from the two antennas.

Simulations

Simulated our pipeline with generated (“received”) IQ modulated pulse (or pure tone) signals

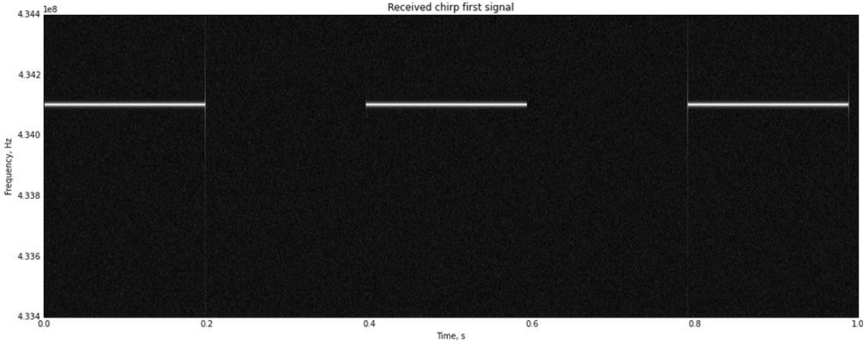
Fairly accurately and consistently:

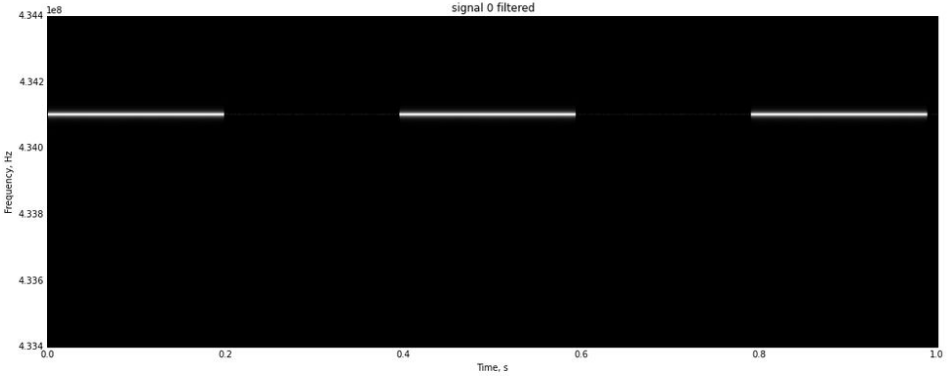
- Bandpass filtered signals, pulling out the pure tone
- Detected time-series delay (successful cross-correlation)
- Calculated the phase difference for calibration
- Recovered the angle (aside from inherent ambiguity)

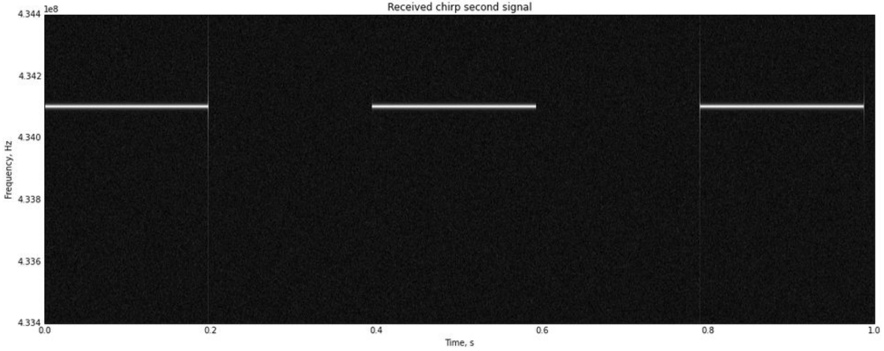
Problems we encountered:

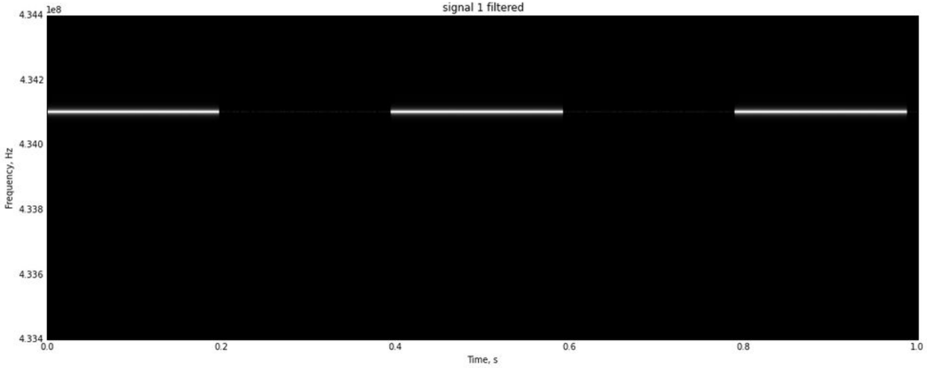
- Slight oddities with lobe plotting
- Occasionally pure tones would yield incorrect delay values (not good for matched filtering)

Simulations

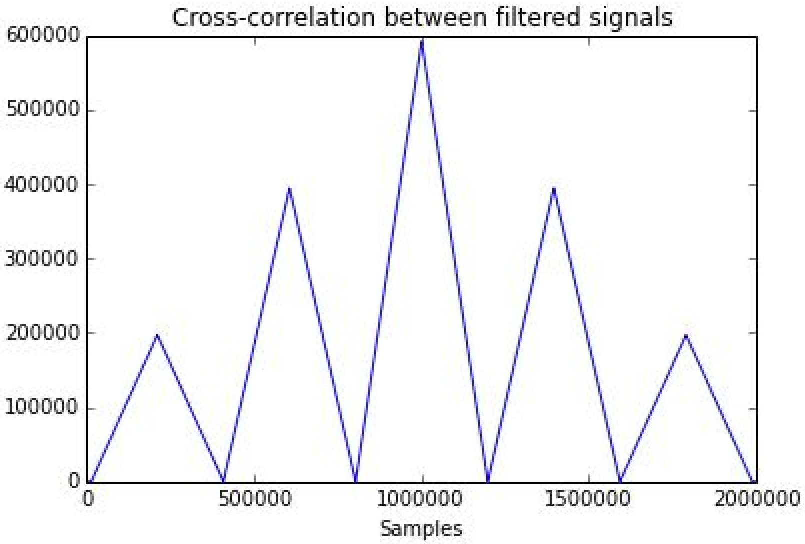


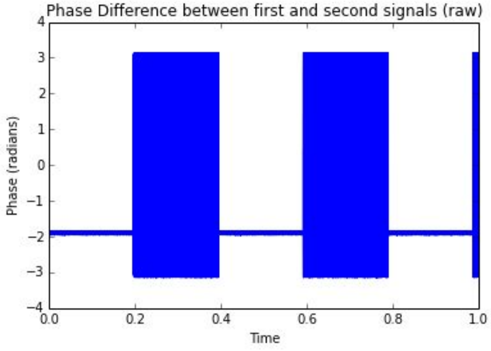


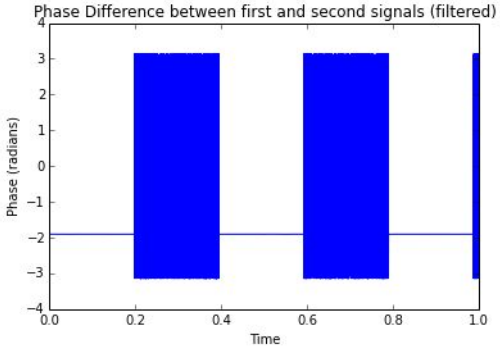




Simulations

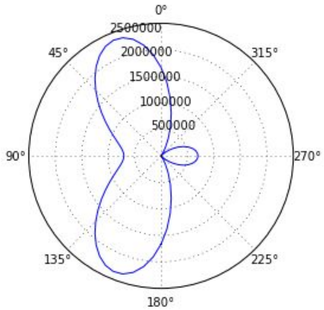


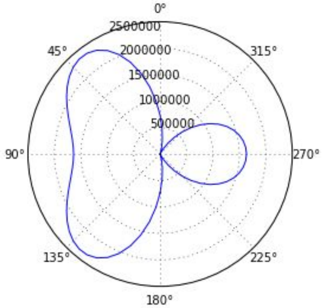


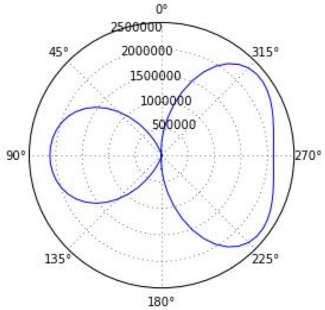


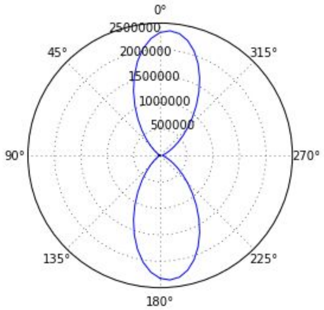
Simulations

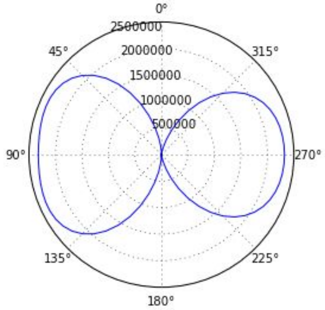
Note that these **aren't** radiation maps. They are polar plots of power as a function of angle (from the source from the line orthogonal to the line between antennas).









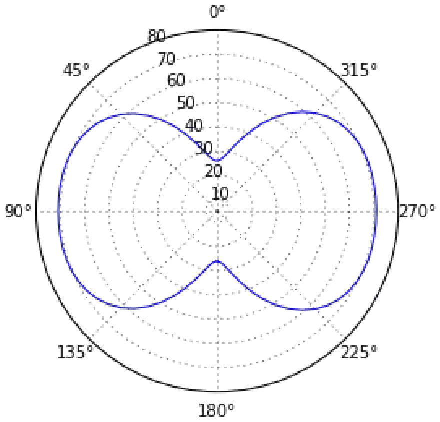


Results

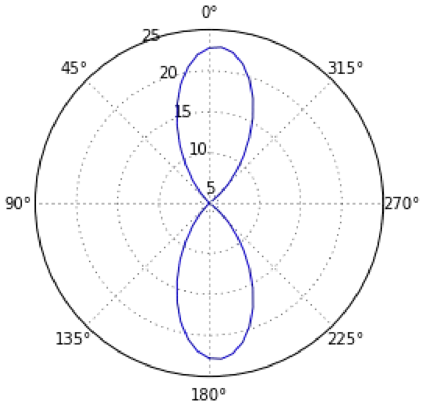
- Phase difference from tuners isn't constant, but are approximately constant for each acquisition
  - The PLL resets for each acquisition
- Need to use a reference transmitter
  - We couldn't find a transmitter that worked well with the little transmitter that could (tried other transmitters, tried radio, no go)
  - Reverted to averaging a crude estimation of phase offset from tuners over 10 trials with gain 1 (both antennas)
- Results with crude estimate:
  - We had 5 trials with frequency mismatch (out of 18)
  - Left hemisphere: 9/18 (ish-es included)
  - Right hemisphere: 9/18
  - So, ~50% success rate

Results

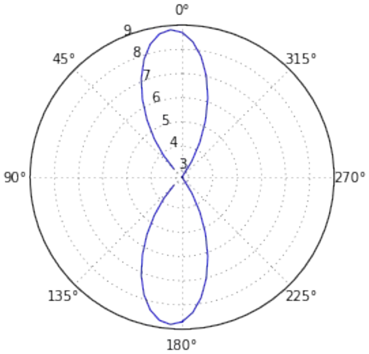
Success:
Left 90 degrees



Failure:
Left 60 degrees



Surprise success:
Left ~20 degrees
(really far back)



Note: These are predicted locations of the source, relative to the receivers. Not radiation fields.

Demo

Future Direction

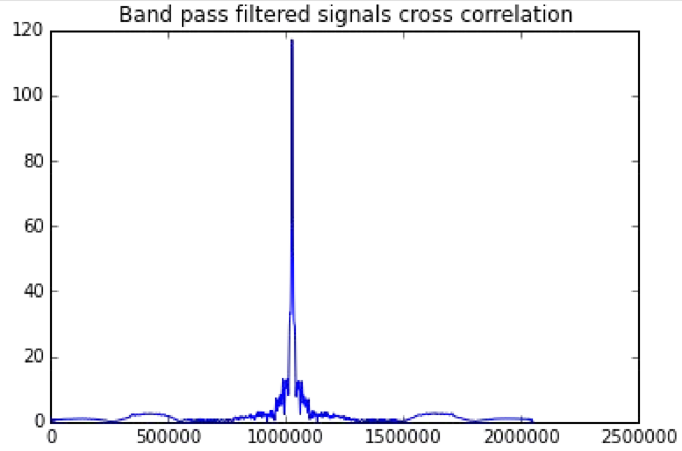
- Take more samples w/ different gains to create radiation map
- Find a reference that transmits near this main frequency (increase accuracy)
- Make a real-time direction finder
- Add third SDR to remove ambiguity from prediction
- Experiment more with using Barker Codes (or other binary codes) to detect time delay better

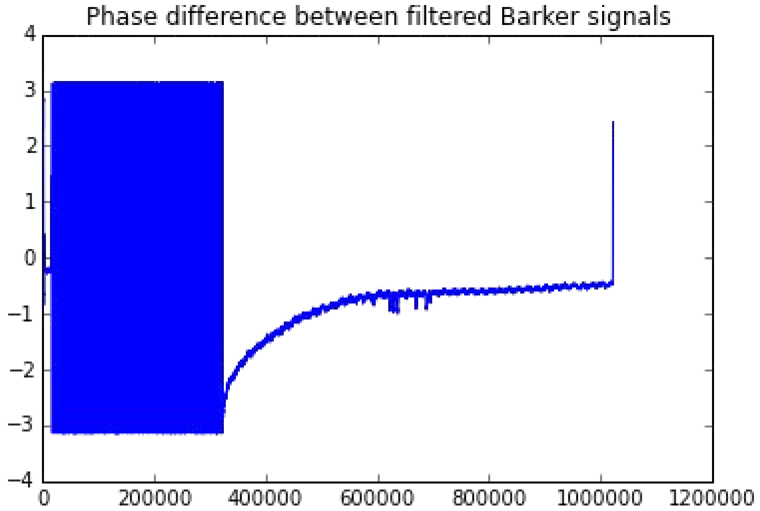
Barker Codes (or other binary codes)

Used Barker codes or on/off keying from radio

More beautiful pulse compression [figure right]

- Pro: better delay detection





Less beautiful phase difference (typically) [insert figure]

- Ramps probably due to the tuner warming up
- Con: would have to approximate phase difference; less accuracy

Acknowledgements

Saul Fuhrmann
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http://kaira.sgo.fi/2013/09/16-dual-channel-coherent-digital.html