I See Airplanes:
How to build your own radar system

Eric Blossom
eb@comsec.com

More fun with GNU Radio...

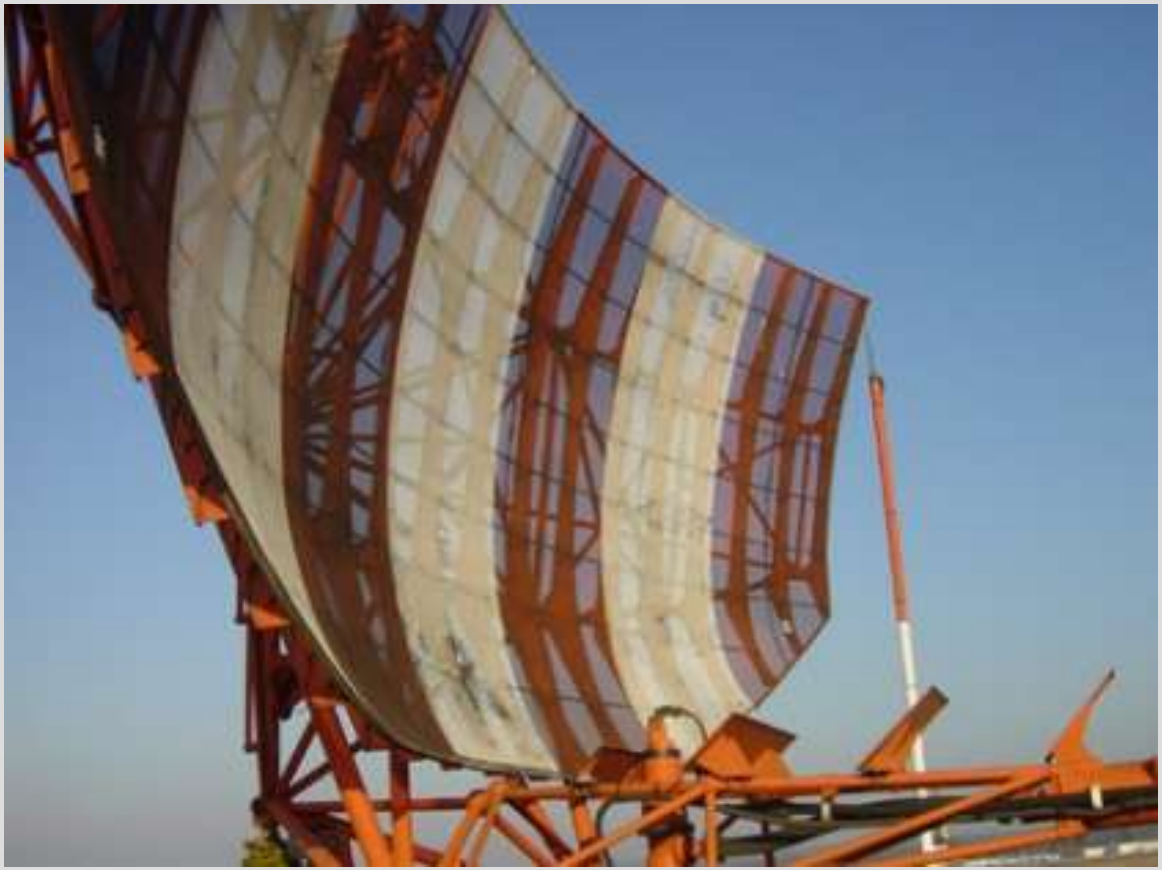
What is radar?

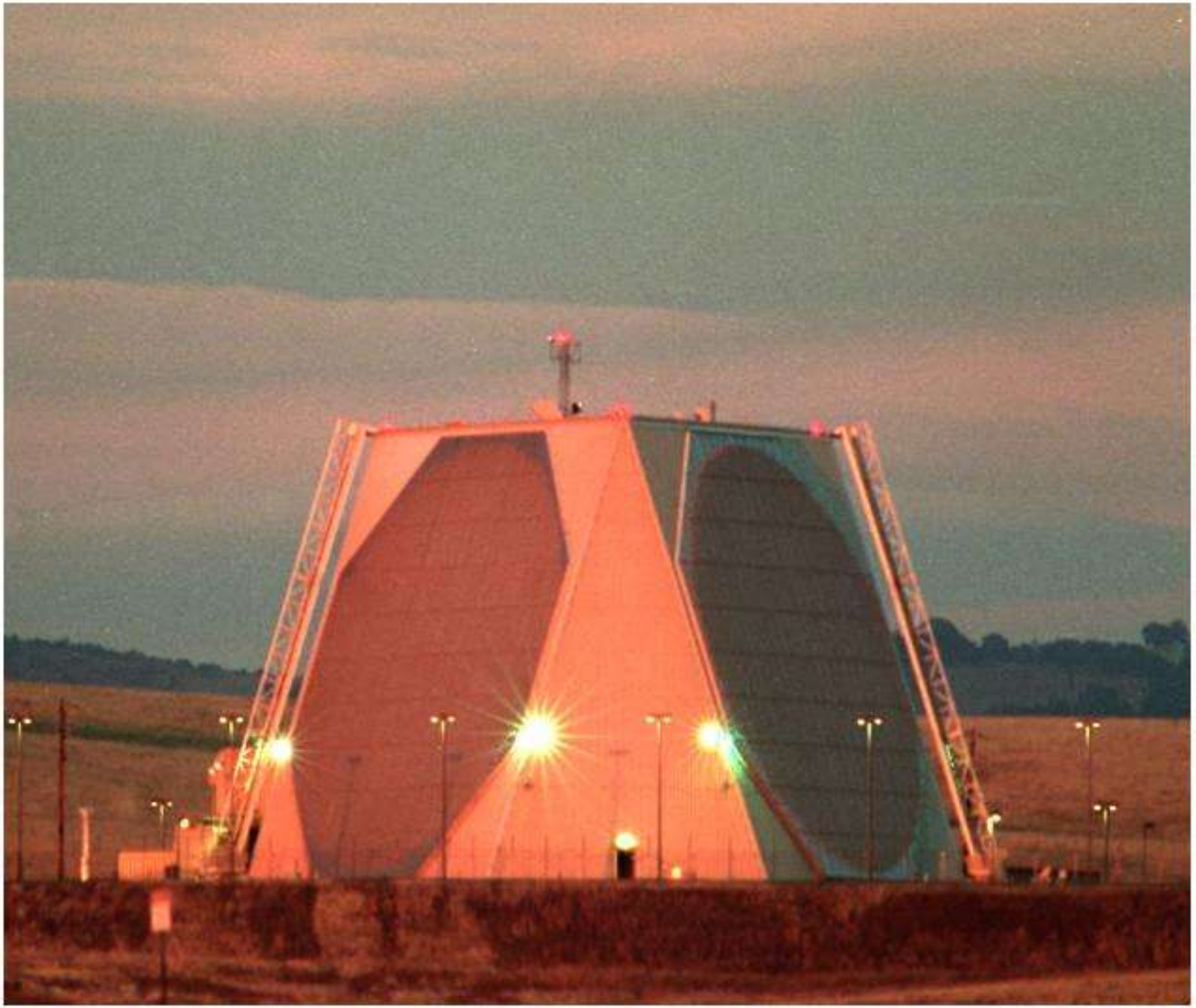
- “Radio Detection and Ranging”
- Watches the reflection of radio waves off of objects and figures out:
  - How far away
  - Velocity of object
  - Bearing (direction) to object
  - Type of object (classification)

A bit of history

- First radar 1904 Christian Helsmeyer:
  - Spark gap; 40 – 50 cm; detected ships
- First unambiguous bistatic detection:
  - Sept 1922, Holt & Young, 50W 60 MHz
  - Observed reflections from trees and wooden steamer (boat)
- UK 1935 “Daventry experiment”
  - Demonstrated aircraft detection
- WWII, ...

Airport surveillance radar





Busted!

Radar configurations

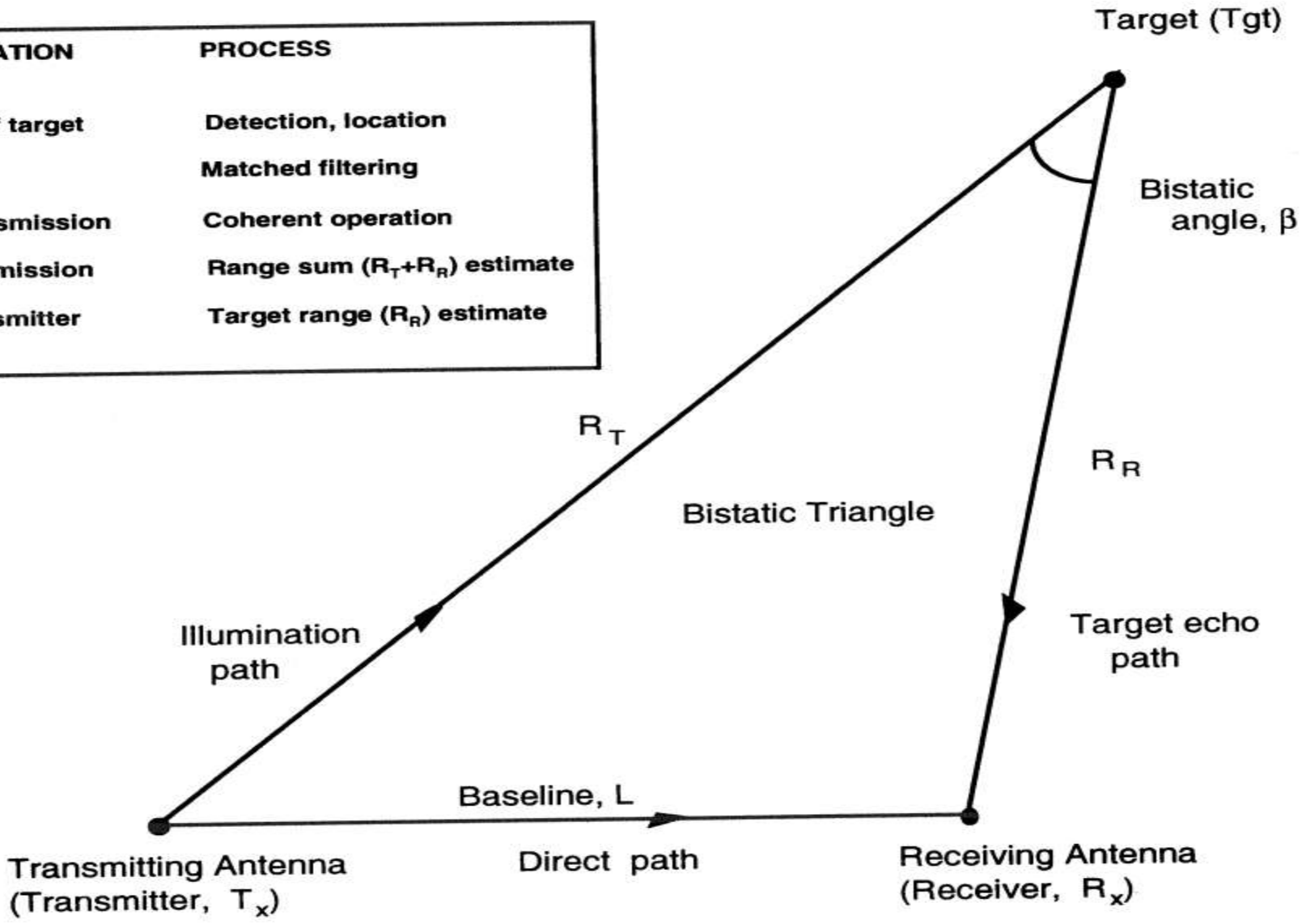
- Monostatic
- Bistatic
- Multi-static (networked)

Bistatic radar

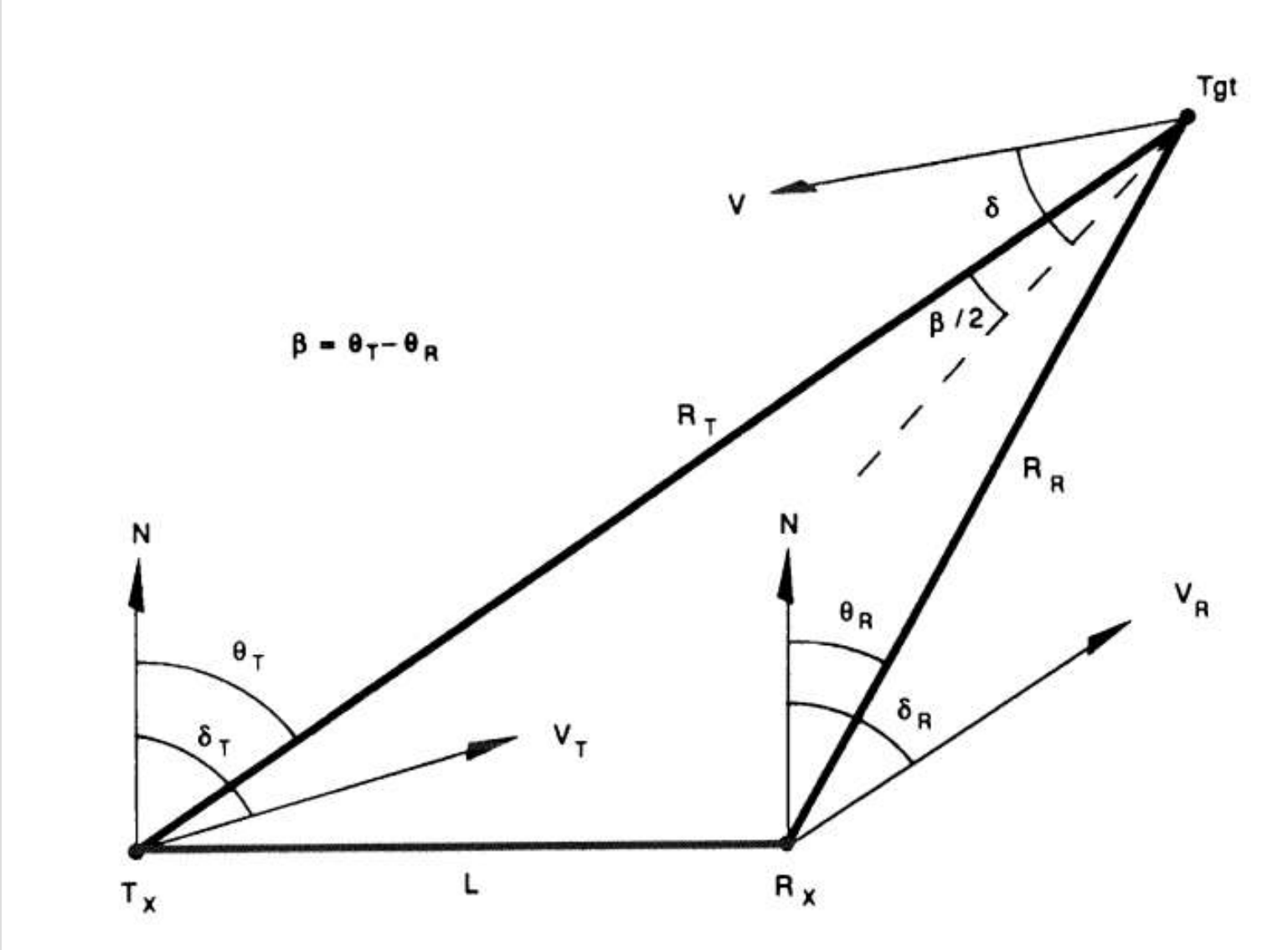
- Transmitter & Receiver are at different locations.
- Original motivations:
  - Avoiding anti-radiation missles
  - Remote target illumination

Bistatic triangle

DATA / OPERATION	PROCESS
Illumination of target	Detection, location
Waveform	Matched filtering
Phase of transmission	Coherent operation
Time of transmission	Range sum (R_T+R_R) estimate
Relative transmitter position	Target range (R_R) estimate



Bistatic doppler

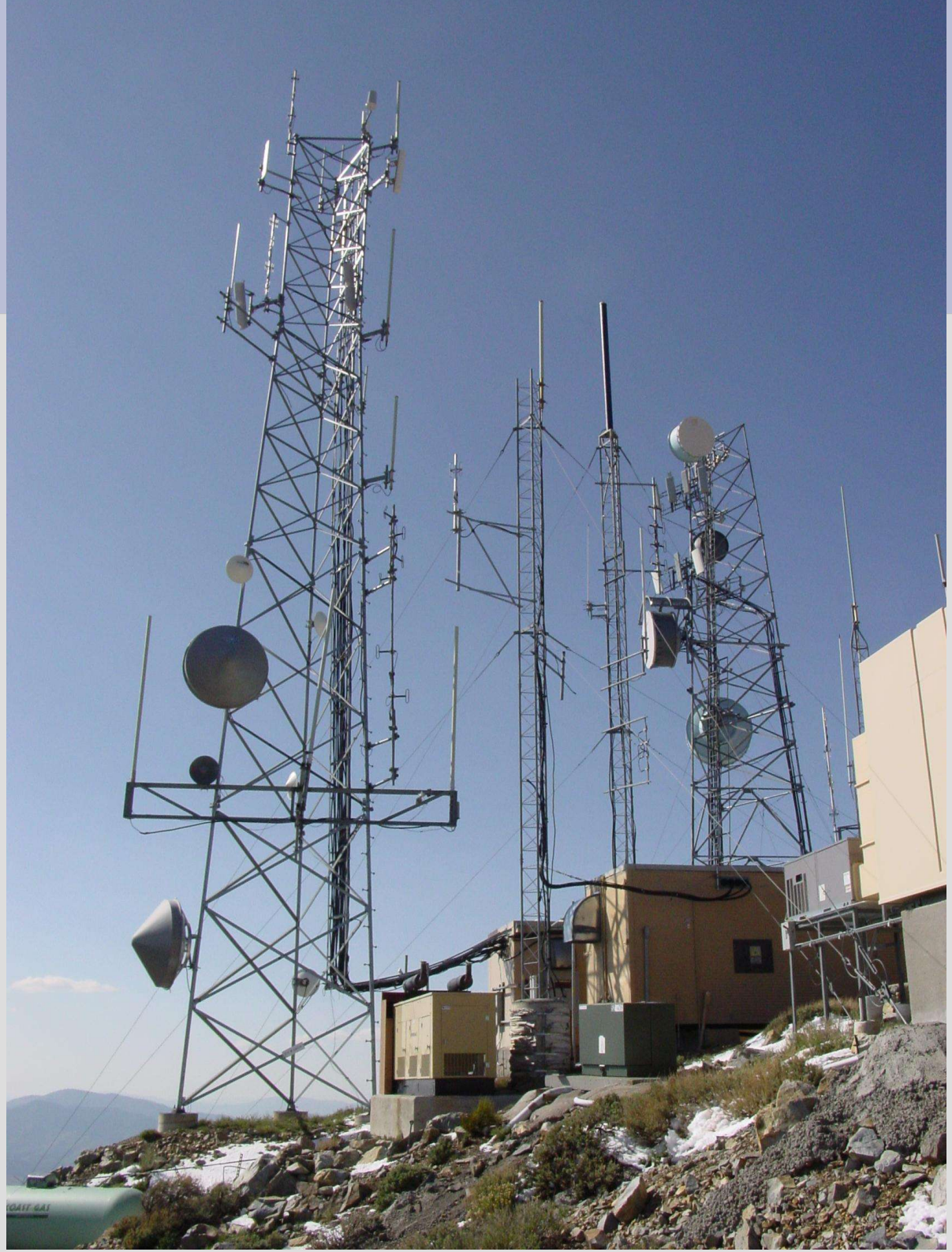


Bistatic radar equation

$$P_r = \frac{P_t G_t A_r \sigma}{(4\pi)^2 R_t^2 R_r^2}$$

Passive radar

- A subclass of of Bistatic Radar
- Use somebody else's transmitter!




park inn

The basic idea

- Use other people's transmitters
- Use multiple coherent receivers
- One or more Tx and/or Rx locations
- Watch reflections
- Do a bunch of math
- Detemine position and velocity

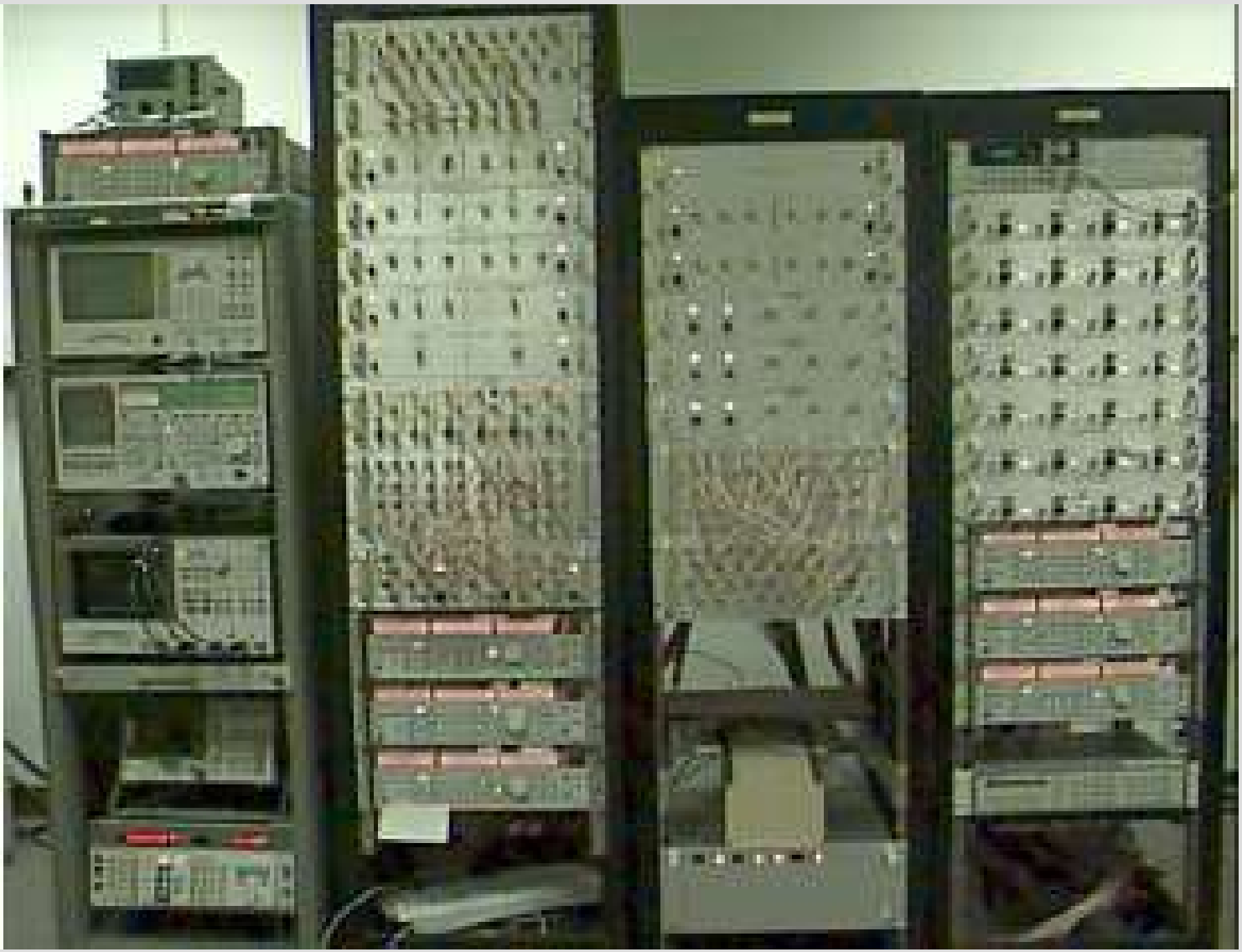
Choice of transmitter

- Don't control signal, but know the general characteristics
- Obvious choices:
  - Broadcast FM (100 kHz wide)
  - Analog and/or digital TV (6-8 MHz wide)
  - GSM cellular / UMTS
- Other choices:
  - High power satellites (DBS)
  - GPS satellites
  - Existing radar transmitters
    - Primary and/or secondary surveillance

Existence proofs:

- Lockheed “Silent Sentry”
- Manastash Ridge Radar

Lockheed “Silent Sentry”



Manastash Ridge radar

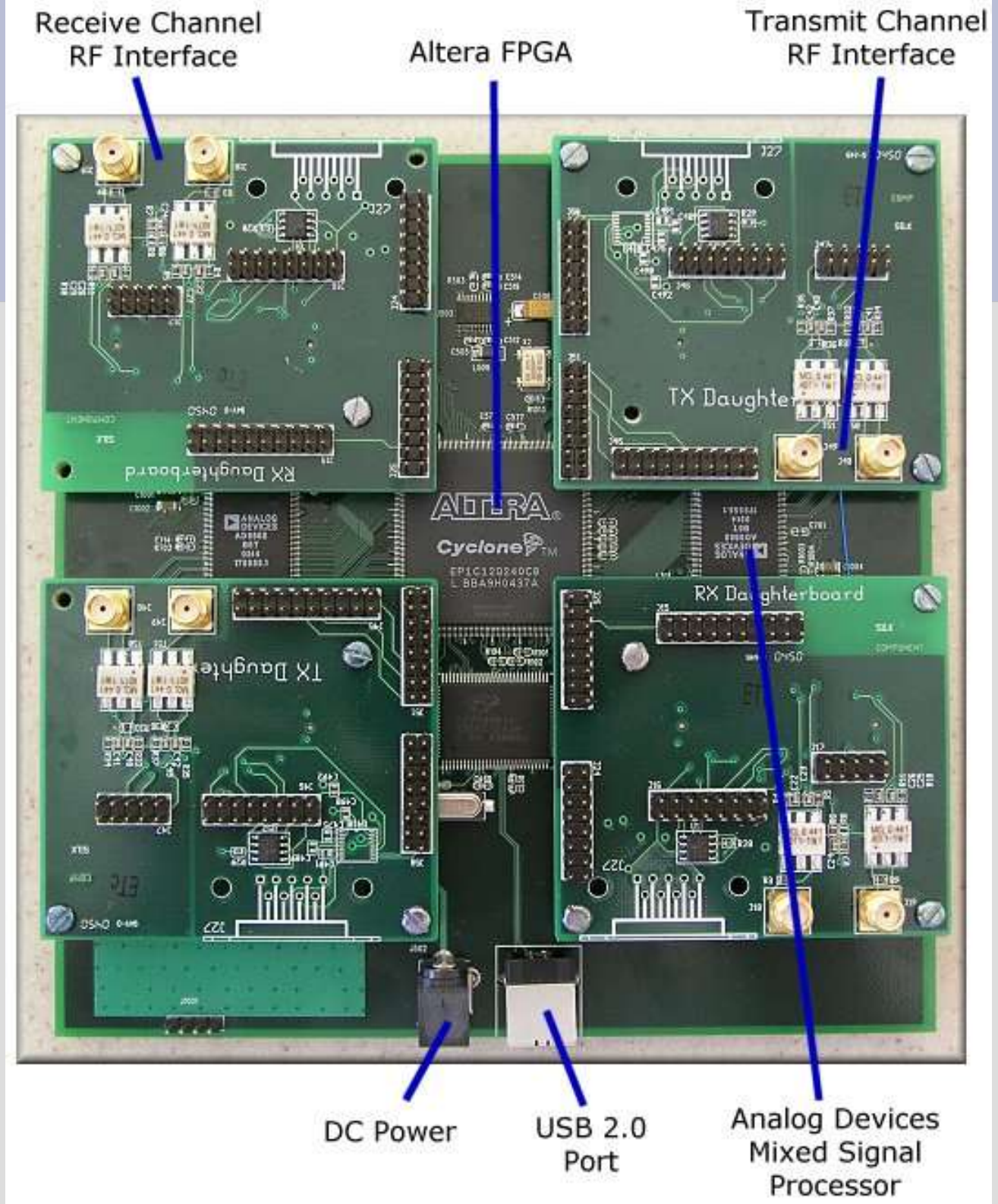
- University of Washington
  - Prof John Sahr & students
  - Interested in ionospheric phenomenon
- Very simple
- Two locations separated by 150 km
- Takes advantage of mountains
- GPS synced time references
- Sees stuff up to 1200 km away!

What we chose

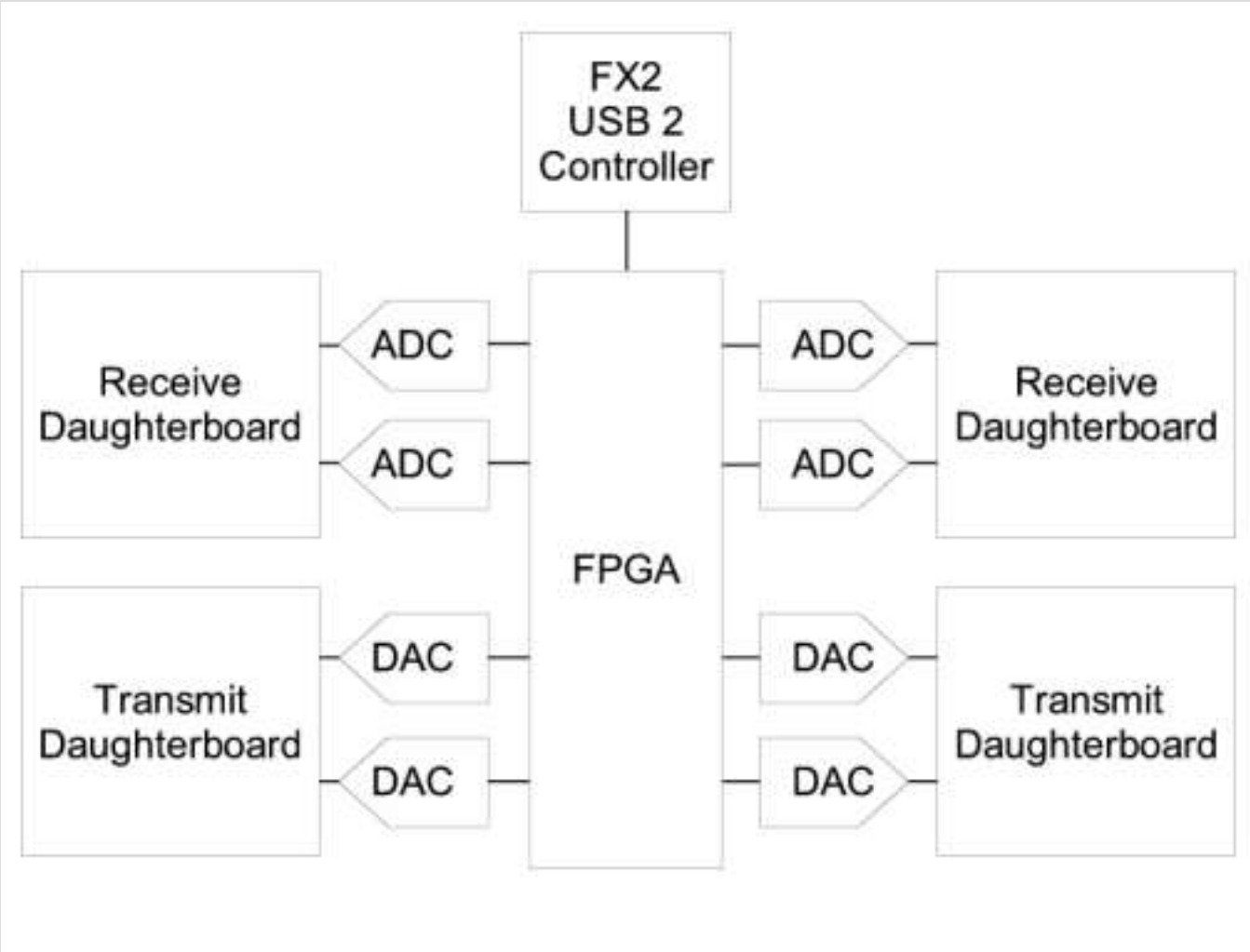
- FM broadcast
  - About 100 MHz (3m wave length)
  - Bandwidth about 100 kHz
  - Theoretical distance resolution 3 km
    - (but see also “super-resolution” techniques)
- Why:
  - Simplest h/w that could possibly work.
  - Need to sample multiple antennas coherently.
  - Bandpass sampling eliminates requirement for coherent analog LO

Universal Software Radio Peripheral (USRP)

- 4 12-bit 64 MS/sec A/Ds
- 4 14-bit 128 MS/sec D/As
- Altera Cyclone FPGA
- USB 2 interface to PC
- Pluggable RF daughterboards
- See http://ettus.com for info


Receive Channel
RF Interface
Altera FPGA
Transmit Channel
RF Interface
RX Daughterboard
TX Daughterboard
ALTERA
Cyclone
RX Daughterboard
DC Power
USB 2.0
Port
Analog Devices
Mixed Signal
Processor

USRP block diagram



Bandpass sampling

- Nyquist sampling criterion:
  - Need 2x the bandwidth of interest
- USRP samples at 64 MS/s
- spectrum “folding” every Fs/2 (32 MHz)
- therefore, folds at 96 MHz, middle of FM band.
- Requires bandpass filter to avoid aliasing. Either:
  - 87 – 95 MHz or
  - 97 – 107 MHz

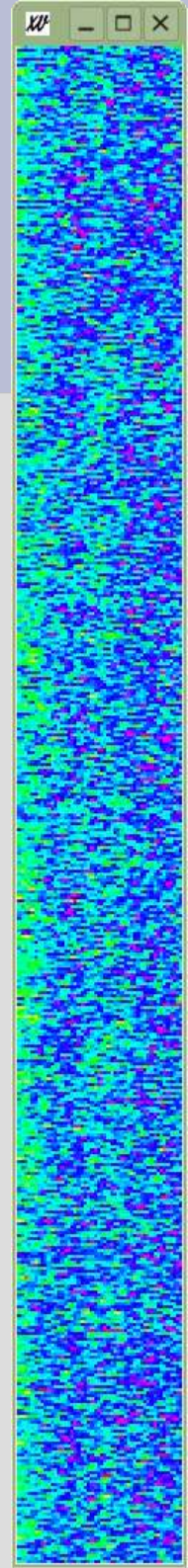
Experimental setup

- Simplest thing that could *possibly* work
- 2 directional antennas
  - 1 pointed at Tx about 45km away
  - 1 pointed about 120° away (towards airport approach)
- 2 broadband LNA's
- 1 USRP with 2 “Basic Rx” d'boards

Procedure

- Watch for nearby airplanes
- Collect the data
- Run the analysis software
- Plot the range/doppler graph

Airplanes?



Hmmm...

- Could be h/w or s/w or both...
- Could be RF/Analog
  - Filtering
  - Gain
  - Antennas
  - Direct path overwhelming reflection (not enough dynamic range)
- Could be signal processing s/w
  - Is it working?

Simulate!

- Simulate the FM transmitter
- Simulate the radar reflections
  - Geometry (Tx, Rx, targets: pos & velocity)
  - Propagation delay
  - Doppler shift
- Run analysis s/w on reference signal and simulated returns.

I see (simulated) airplanes!

Next steps

- Quantitative analysis using simulator:
  - What RF performance do we require for s/w to be able to detect targets?
  - How small (big?) of an object should we expect to see at a give distance
- Design & build low-loss bandpass filters
  - Probably helical filters
- Antenna ideas:
  - Dipoles in front of metal screen
  - “Corner reflectors”

And then...

- Determine angle of arrival
  - Interferometry / phased array
  - Watch multiple Tx's in different locations
  - Use multiple Rx's in different locations
- Target tracking (multiple targets)
- Nice real-time application with GUI
- Try it with digital TV signals
  - Theoretical ~50 m resolution

Resources

- The code is in GNU Radio CVS
- http://www.gnu.org/software/gnuradio
- Mailing list: discuss-gnuradio@gnu.org


CAUTION
Beyond this point:
Radio frequency fields at this site may exceed FCC rules for human exposure.
For your safety, obey all posted signs and site guidelines for working in radio frequency environments.
In accordance with Federal Communications Commission rules on radio frequency emissions 47 CFR 1.1307(b)