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DSTO's Passive Radar Research

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Defence Science and Technology Organisation of Australia

17th September, 2014

The Pros and Cons - Standard Bistatic Radar

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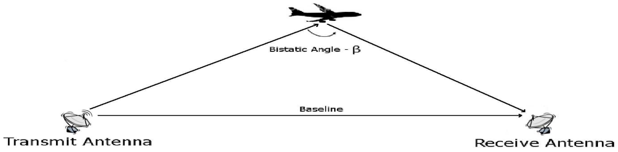

- Advantages
  - Passive receiver
    - No RF emissions at RX
    - Covert surveillance
    - Difficult to jam
  - Cheaper (?)
  - Location

- Disadvantages
  - Increased complexity
    - Geometry
    - System (Coherence issues)
  - Decreased detection range
  - Pulse Chasing
  - Can exploit dedicated/cooperative transmitter(s) only

The Pros and Cons - Passive Radar

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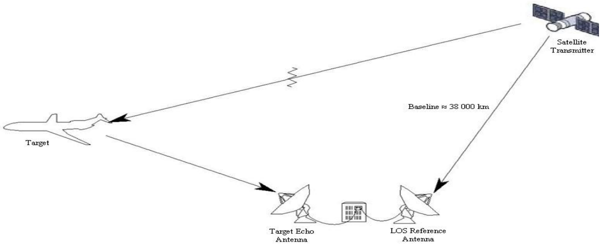
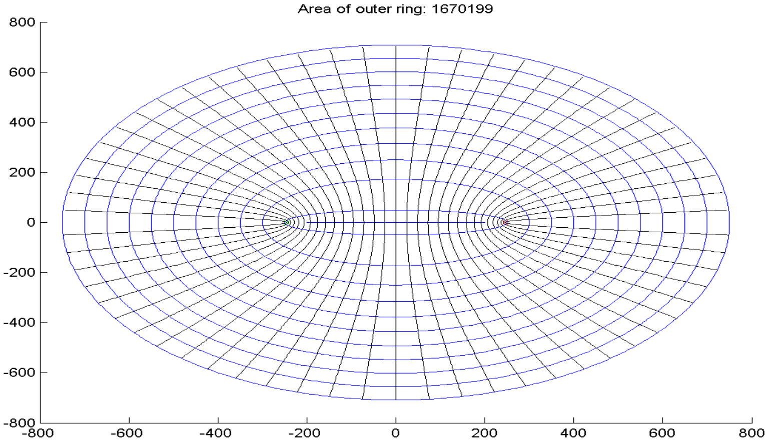


- Advantages
  - Passive system
    - No new RF emissions
    - Covert surveillance
    - Very difficult to jam
  - Cheaper (no new Transmitter)
  - CW transmission (?)
  - Multitude of Signal Sources:
    - TV, radio, cell phones
    - Satellites
    - ...
- Disadvantages
  - Increased complexity
    - Geometry
    - System (Coherence issues)
  - Dependence on Transmitter
    - Waveform
    - Location & Coverage (Spatial & Temporal)
    - Transmitter power
    - Bandwidth

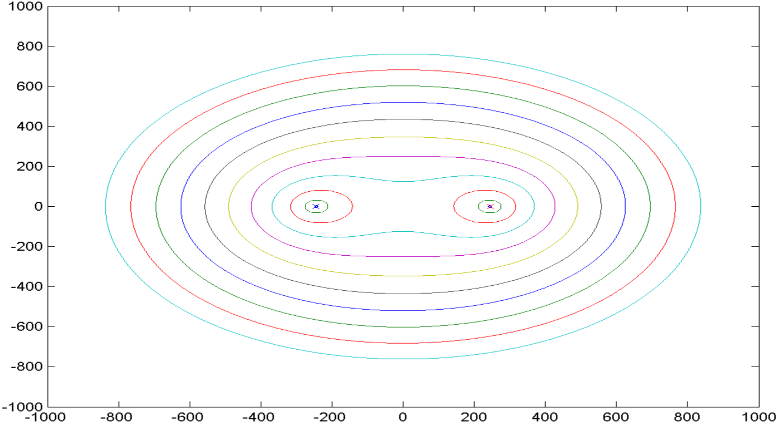
Baseline's Impact on Geometry

Range and Doppler Resolution



Baseline's Impact on Geometry

Signal-to-Noise Ratio



Passive Radar's History

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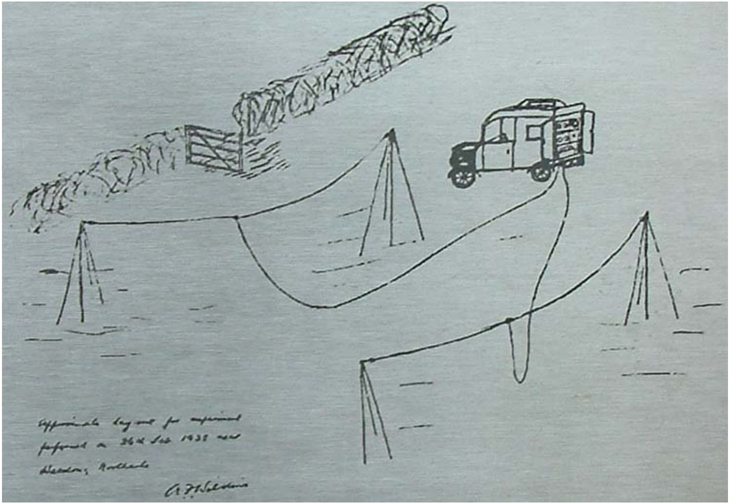
26th of February, 1935 - The Daventry Experiment



http://en.wikipedia.org/wiki/File:Daventry_expt.jpg

Pressure from all around - Spectrum

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Australian Spectrum Allocation

Frequency Band	ADF dedicated	Shared	Not available to ADF
29.7 MHz - 312 MHz	7.99%	28.25%	**63.76%**
312 MHz - 3.1 GHz	1.58%	8.21%	**90.21%**
3.1 GHz - 31 GHz	11.33%	21.38%	**67.29%**

The Underlying Technology

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Bistatic real-time processing is now fairly straight-forward

- In 2005 Howland demonstrated 'real-time' target detection using a 100kHz wide signal (FM radio)
  - Required 6 x 2.6GHz Pentium-4 PCs running in parallel
  - Only able to process 1s worth of data every 5s
- At DSTO we have a real-time demonstration system too
  - 8MHz wide signal (DVB-T - 80x more bandwidth than FM radio)
  - On a single i7 PC (circa March 2009)

Waveforms

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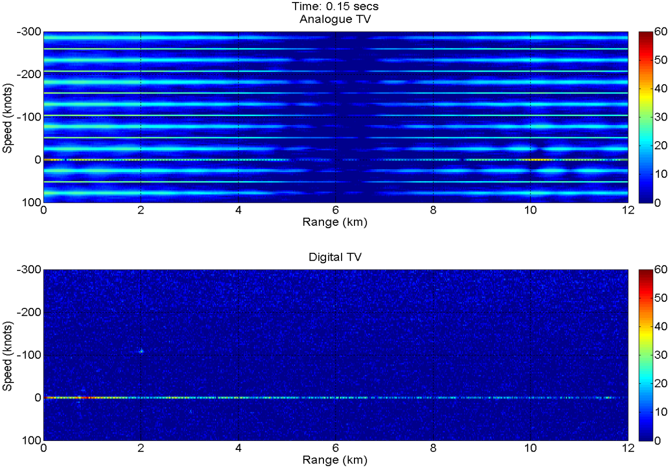
Real data showing Analogue TV and Digital TV range Doppler maps with an airborne target present...



Digital TV around the World (as at May 2014)

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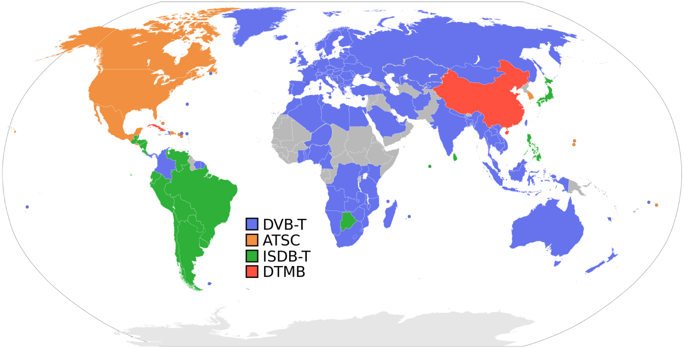

http://en.wikipedia.org/wiki/File:Digital_broadcast_standards.svg

DVB-T Coverage Map

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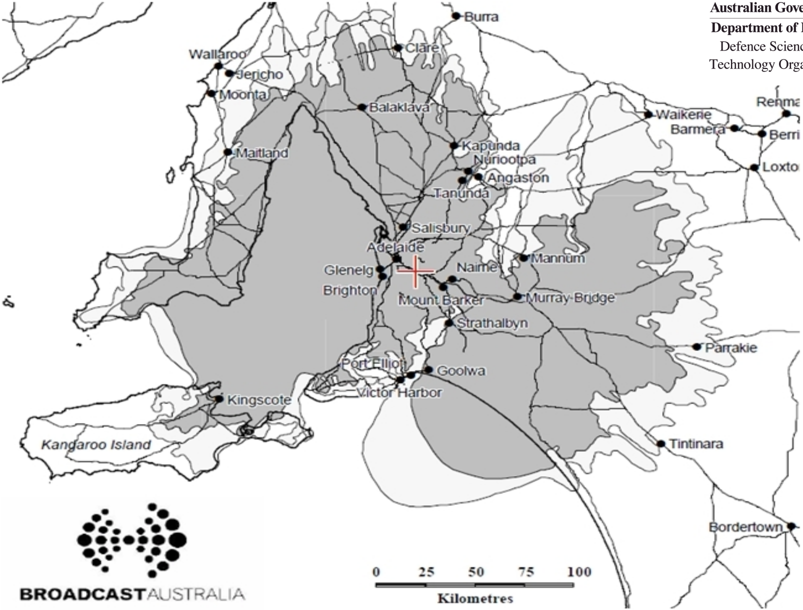

DVB-T Experiments

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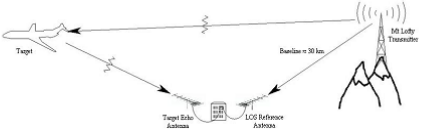
- Antenna pointed at reference source
- Antenna pointed in direction of interest



- All COTS hardware:
  - Readily Available receivers (typ. non-ITAR)
  - Domestic grade kit
- Cost for 2 Channel System: $<$ \$60k

2008: DVB-T Performance - Receiver 30 km from Transmitter

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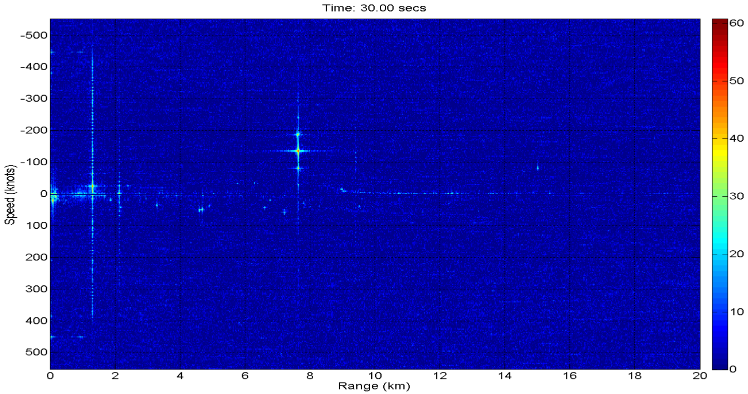

DVB-T Performance - Receiver 88km from Transmitter - 1

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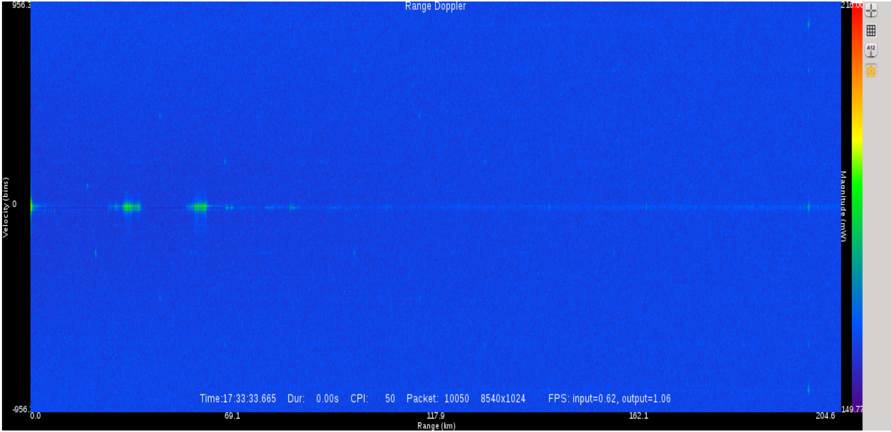

DVB-T Performance - Receiver 88km from Transmitter - 2

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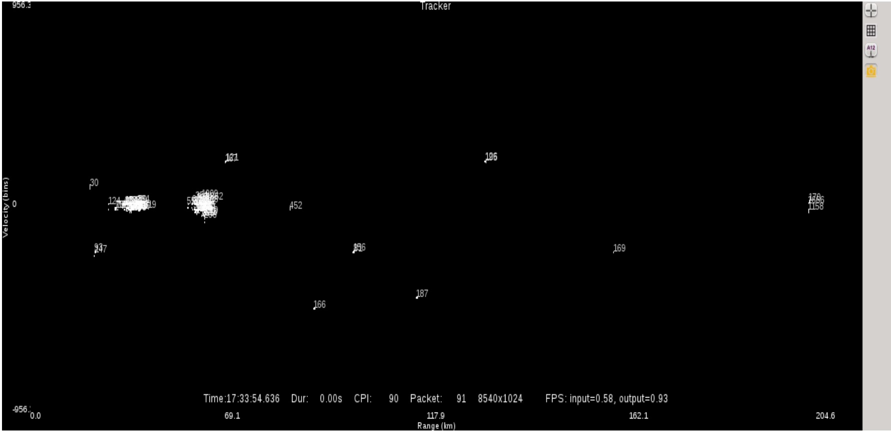

DVB-T Performance - Receiver 88km from Transmitter - 3

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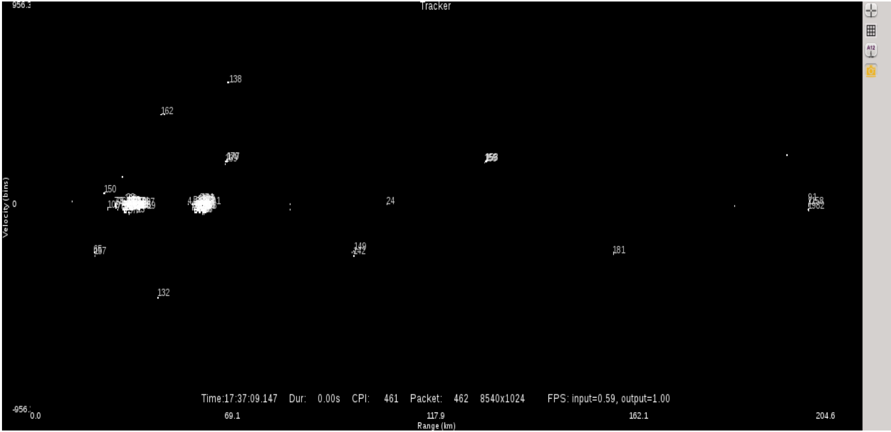

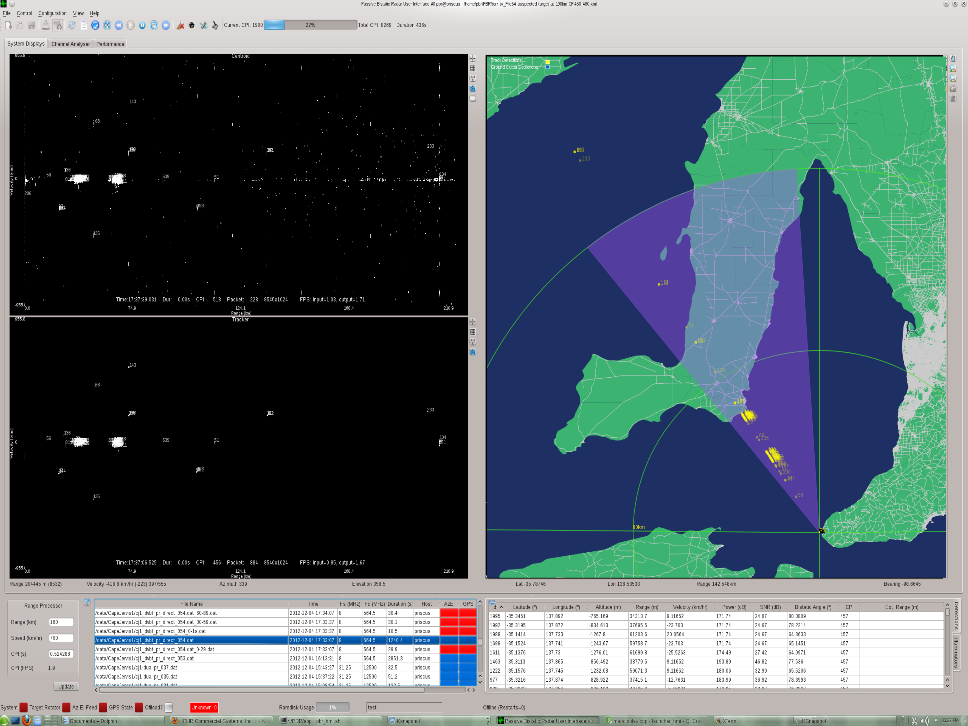
Passive Bistatic Radar User Interface #0 pbr@priscus - /home/pbr/PBR/terr-tv_File54-suspected-target-at-190km-CPI450-480.xml
File Control Configuration View Help
Current CPI: 1900
22%
Total CPI: 8269 Duration 436s
System Displays
Channel Analyser
Performance
Centroid
Time:17:37:39.031 Dur: 0.00s CPI: 518 Packet: 228 8540x1024 FPS: input=1.03, output=1.71
Range (km)
Tracker
Time:17:37:06.525 Dur: 0.00s CPI: 456 Packet: 884 8540x1024 FPS: input=0.85, output=1.67
Velocity (bins)
Track Detections
Ground Clutter Detections
80km
Range 204445 m (8532)
Velocity -416.6 km/hr (-223) 397/555
Azimuth 339
Elevation 358.5
Lat -35.78746
Lon 136.53533
Range 142.548km
Bearing -98.6645
Range Processor
Range (km) 160
Speed (km/hr) 700
CPI (s) 0.524288
CPI (FPS) 1.9
Update
File Name | Time | Fs (MHz) | Fc (MHz) | Duration (s) | Host | AzEl | GPS
/data/CapeJervis1/cj1_dvbt_pr_direct_054.dat_60-89.dat | 2012-12-04 17:34:07 | 8 | 564.5 | 30.4 | priscus
/data/CapeJervis1/cj1_dvbt_pr_direct_054.dat_30-59.dat | 2012-12-04 17:33:37 | 8 | 564.5 | 30.1 | priscus
/data/CapeJervis1/cj1_dvbt_pr_direct_054_0-1s.dat | 2012-12-04 17:33:37 | 8 | 564.5 | 10.5 | priscus
/data/CapeJervis1/cj1_dvbt_pr_direct_054.dat | 2012-12-04 17:33:07 | 8 | 564.5 | 1240.4 | priscus
/data/CapeJervis1/cj1_dvbt_pr_direct_054.dat_0-29.dat | 2012-12-04 17:33:07 | 8 | 564.5 | 29.9 | priscus
/data/CapeJervis1/cj1_dvbt_pr_direct_053.dat | 2012-12-04 16:13:31 | 8 | 564.5 | 2851.3 | priscus
/data/CapeJervis1/cj1-dual-pr_037.dat | 2012-12-04 15:43:27 | 31.25 | 12500 | 32.5 | priscus
/data/CapeJervis1/cj1-dual-pr_035.dat | 2012-12-04 15:37:22 | 31.25 | 12500 | 51.2 | priscus
Id | Latitude (°) | Longitude (°) | Altitude (m) | Range (m) | Velocity (km/hr) | Power (dB) | SNR (dB) | Bistatic Angle (°) | CPI | Ext. Range (m)
1995 | -35.3451 | 137.892 | -765.169 | 34313.7 | 9.11652 | 171.74 | 24.67 | 80.3809 | 457
1992 | -35.3195 | 137.872 | -834.613 | 37695.5 | -23.703 | 171.74 | 24.67 | 78.2214 | 457
1988 | -35.1414 | 137.733 | -1267.8 | 61203.6 | 20.0564 | 171.74 | 24.67 | 64.3633 | 457
1698 | -35.1524 | 137.741 | -1243.67 | 59758.7 | -23.703 | 171.74 | 24.67 | 65.1451 | 457
1611 | -35.1376 | 137.73 | -1276.01 | 61699.8 | -25.5263 | 174.49 | 27.42 | 64.0971 | 457
1463 | -35.3113 | 137.865 | -856.492 | 38779.5 | 9.11652 | 193.89 | 46.82 | 77.536 | 457
1222 | -35.1576 | 137.745 | -1232.08 | 59071.3 | 9.11652 | 180.06 | 32.99 | 65.5206 | 457
977 | -35.3216 | 137.874 | -828.922 | 37415.1 | -12.7631 | 183.99 | 36.92 | 78.3993 | 457
Detections
Illuminators
System
Target Rotator
Az El Feed
GPS State
Offload?
Unknown! 0
Ramdisk Usage
1%
test
Offline (Restarts=0)

DVB-S Coverage Map (Optus C1)

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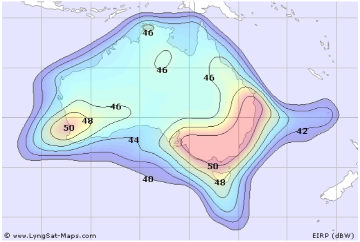

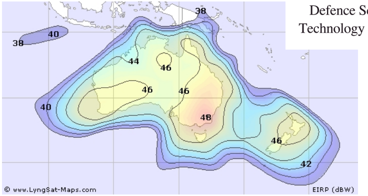

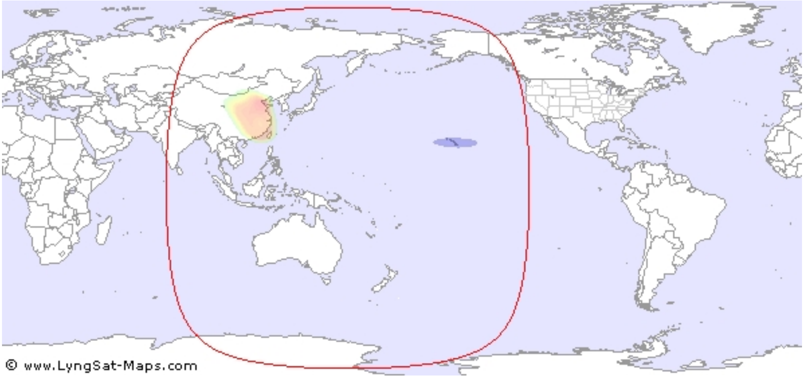

DVB-S Experiments

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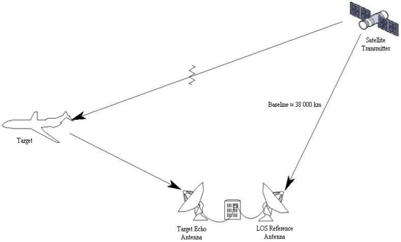
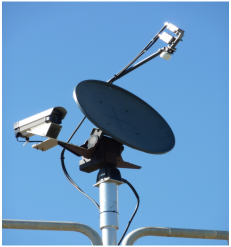
- Antenna pointed at reference source
- Antenna pointed in direction of interest
- All COTS hardware
    - Domestic grade kit
- Replacement cost of ~$70k





2008: Geo-sat based aircraft detection

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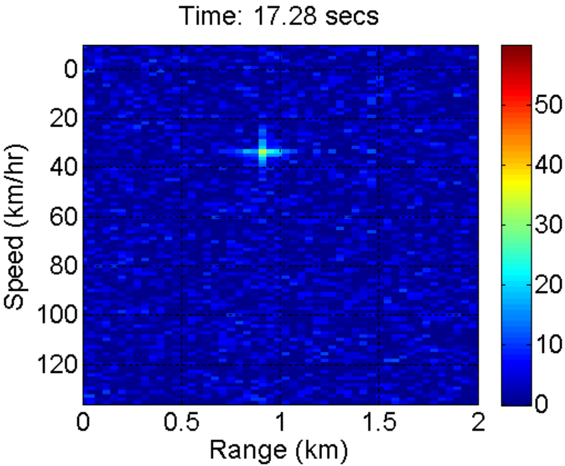

2012: Geo-sat based people detection

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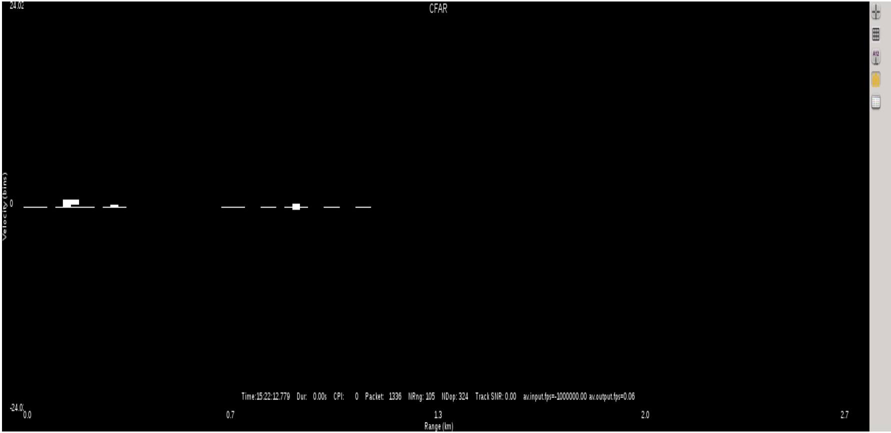

Direct Path Interference and Clutter

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- DPI is a big issue for DVB-T[1]:
  - Thumbtack ambiguity constrains available "detection" dynamic range
  - Average peak-to-sidelobe ratio: $10 * log_{10}(B * T_{cpi})$
- A number of mitigation approaches are available, including:
  - Analogue beamforming
  - Digital beamforming
  - Polarisation diversity
  - Digital filters, including:
    - LMS (inc. NLMS and Fast LMS (or block LMS))
    - RLS (inc. EDS and Fast EDS)
    - Wiener filter
    - Conjugate Gradient
    - Steepest Descent
  - Other DSP techniques
    - E.g. The CLEAN technique

[1] Less of an issue for DVB-S due to high directivity of antennas

Before and After application of Wiener Filter

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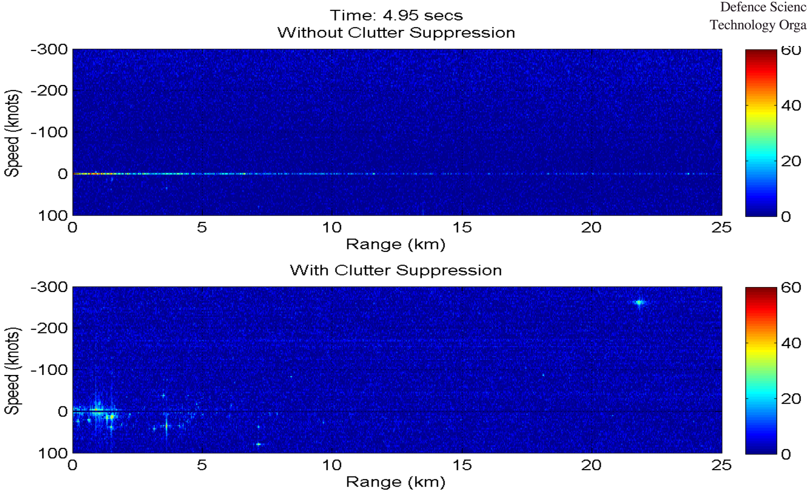

Results: removal of DPI only

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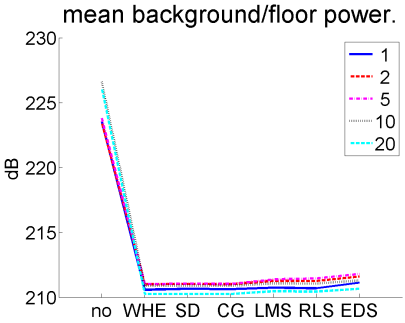
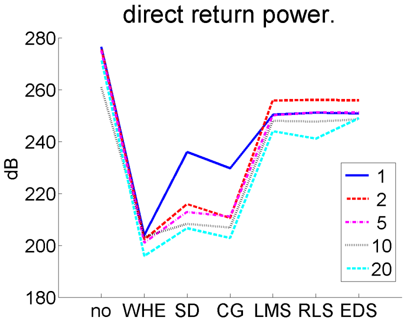
Filter length $M = 100$





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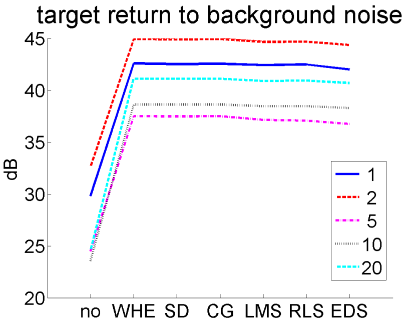

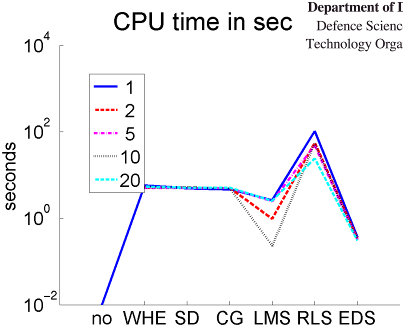

- All methods reduce noise floor $\sim$ 15 dB
- All methods increase target power/noise $\sim$ 12 dB
- SD and CG approach same DPI suppression of WHE
- LMS, RLS, EDS achieve partial mitigation of DPI
- LMS and EDS require least CPU time
- SD & CG use same CPU time as WHE

Results: removal of DPI and ZDC

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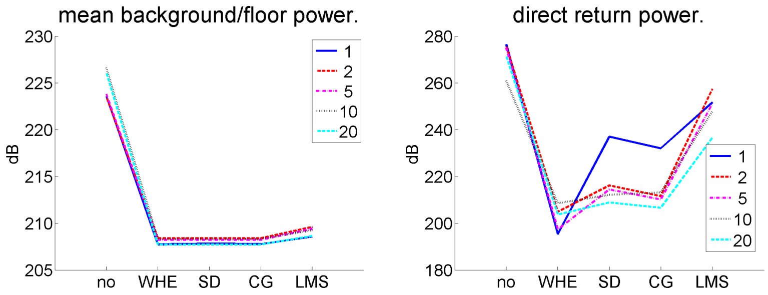
Filter length $M = 2917$.

RLS and EDS not used due to prohibitively large runtime.



Results: removal of DPI and ZDC

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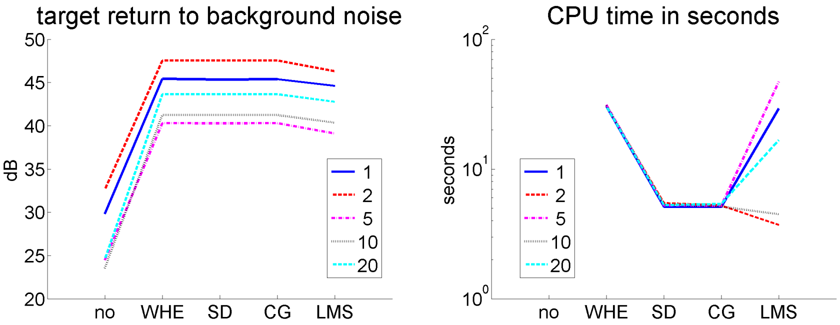

- CG suppresses 1–3 dB more ZDC than SD
- SD & CG requires consistently less CPU time than WHE
- CPUtime required by LMS highly variable.

Demod / Remod - Multipath mitigation, noise reduction and ambiguity control

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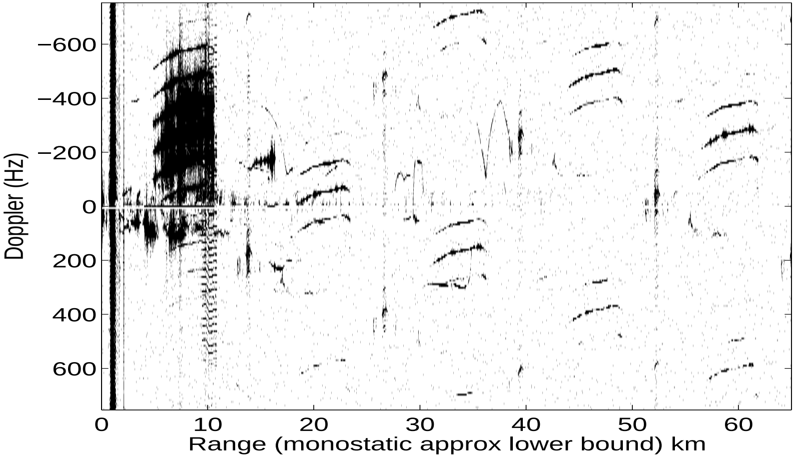
CFAR Detection History - *Before* and After...



Demod / Remod - Multipath mitigation, noise reduction and ambiguity control

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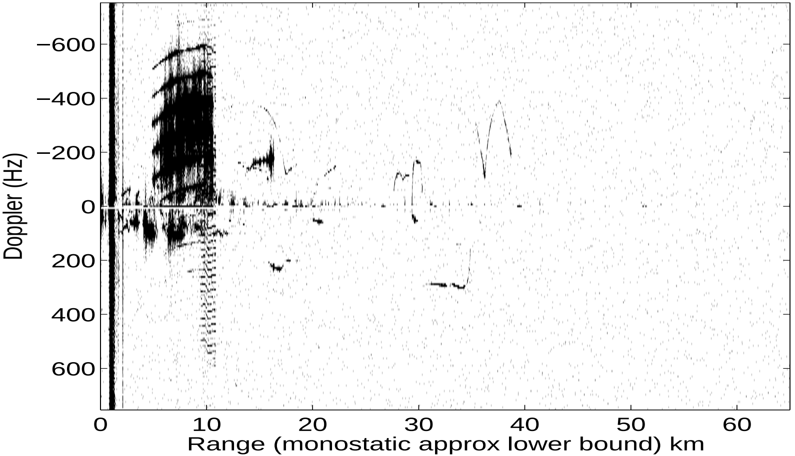
CFAR Detection History - Before and *After*...



Processing time constraints - CPI

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To achieve real-time performance:

- **Ideal: Finish all processing calculations in less time than a CPI!** This includes:
    - DPI and clutter suppression
    - RD map formation
    - Target detection
    - Target tracking*
    - Geolocation*
    - Display*

System Overview

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- Our computing platform (circa 2012) consists of:
  - a multi-core Intel processor (Core i7 x980 @ 3.3GHz CPU)
  - OpenSuse 11.4 Linux
  - 24GB RAM
  - Either a GTX285 or a Tesla C2075 NVIDIA GPU card
- Using one core (non-parallel implementation)
  - More than 2x slower than realtime

Parallel CPU Results - no clutter suppression

- Achieves realtime with 6 threads
- Performance is worse if range/Doppler increased
- Shortcomings:
    - Many cores of CPU in use
    - No capacity for other processing

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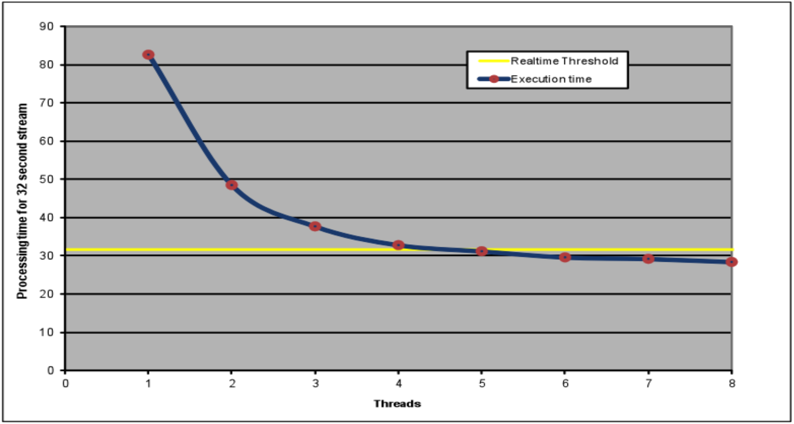

Parallel CPU Results - with clutter suppression

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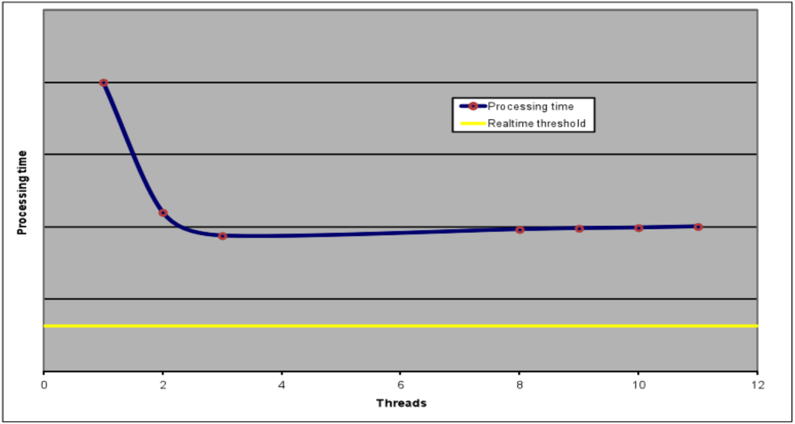
- Single threaded processing now 6 times slower than realtime
- Because clutter filtering works on entire CPI time series:
  - Filter not as easily parallelised - no parallel CPU FFT at the time
  - This is a bottleneck at the input
  - Manifestation of Amdahls law



Reasons for non-scalability

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- We moved to CUDA and achieved realtime
  - So no business case for in-depth analysis
- Speculation as to likely reasons includes:
  - Thread/IPC overhead
  - Cache overflow effects
  - Amdahl's law:

"The speedup of a program using multiple processors in parallel computing is limited by the time needed for the sequential fraction of the program[2]"

[2] http://en.wikipedia.org/wiki/Amdahl's_law

GPU Results - no clutter suppression

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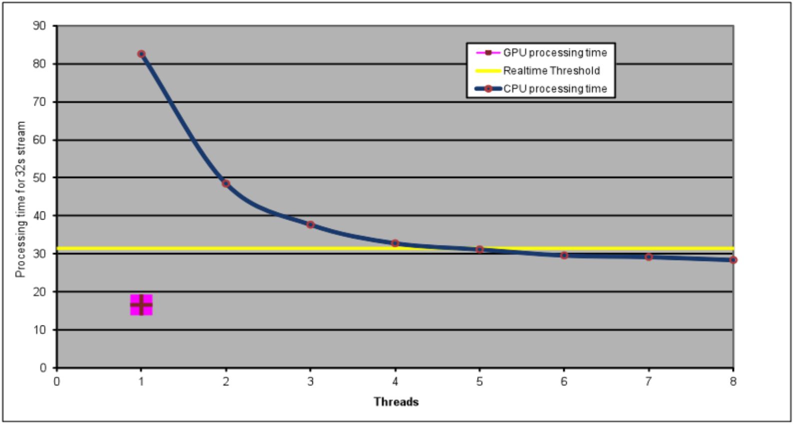
- Achieve realtime in one thread
- Saves four cores for other processing



GPU Results - with clutter suppression

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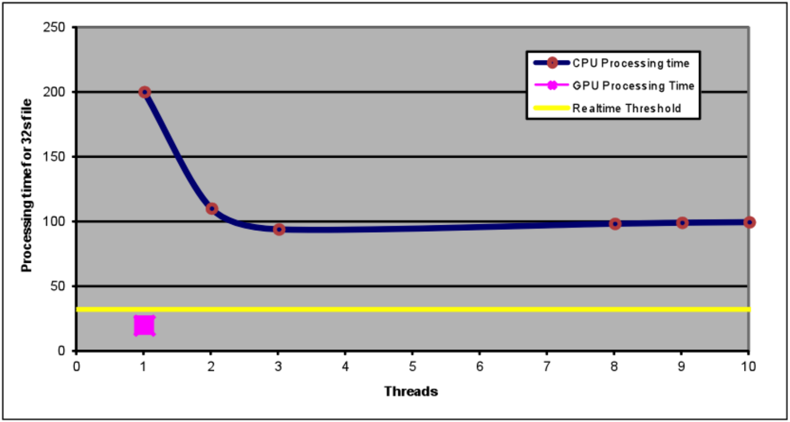
- Achieve realtime in one thread
  - Clutter uses large FFTs which can be parallelised in GPU
  - Was not possible in CPU for given configuration



Where to next?

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- CTD - bigger, better, faster, more...
- Phased Array NPP - multi-element arrays for wide field of view and large effective aperture
- Understanding the practical limits of processing and hardware
- Investigate significant unknowns:
  - Bistatic RCS
  - Bistatic Clutter
  - Propagation effects

Acknowledgements:

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A *lot* of people have contributed to this work over the years. Special thanks go to:

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