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Electronics
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Communications

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S_X_MPL
Signal Acquisition Modeling and Processing Lab

Cognitive Sub-Nyquist Radar Prototypes

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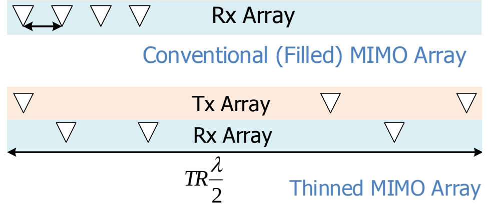
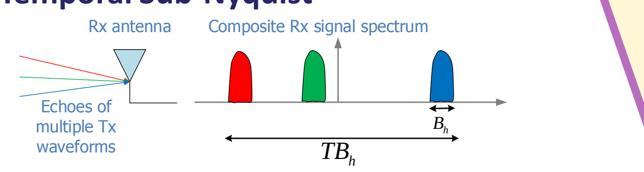
Cognitive Sub-Nyquist MIMO Radar (SUMMeR)

SUMMeR Concepts

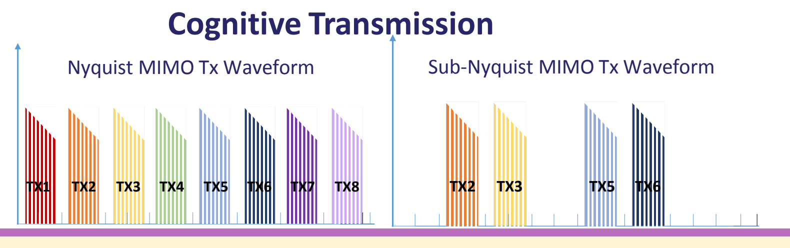
Spatial Sub-Nyquist



Temporal Sub-Nyquist



Cognitive Transmission



Spatio-Temporal Xampling and Doppler Processing

- Received signal for P pulses at the qth antenna after demodulation:

$$x_q(t)=\sum_{p=0}^{P-1}\sum_{m=0}^{M-1}\sum_{l=1}^{L}\alpha_l h_m(t-\tau_l-p\tau)e^{j2\pi\beta_{m,q}\theta_l}e^{j2\pi f_l^D p\tau}$$

Total number of Targets; Doppler Shift; Target time delay; Element location factor; Target Azimuth

- Fourier coefficients of the mth transmitter channel at the qth receiver:

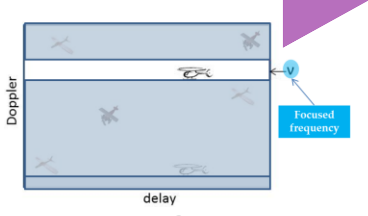
$$y_{m,q}^{p}[k]=\sum_{l=1}^{L}\alpha_l e^{j2\pi\beta_{m,q}\theta_l}e^{-j\frac{2\pi}{\tau}k\tau_l}e^{-j2\pi f_m\tau_l}e^{j2\pi f_l^D p\tau}$$

Target reflectivity; Operating frequency

- Xampling retrieves the Fourier coefficients from low rate samples

- Doppler focusing for a specific frequency v

$$\Phi_{m,q}^{\nu}[k]=\sum_{l=1}^{L}\alpha_l e^{j2\pi\beta_{m,q}\theta_l}e^{-j\frac{2\pi}{\tau}(k+f_m\tau)\tau_l}\times\begin{cases}P & |f_l^D-\nu|<1/2P\tau\\ 0 & else\end{cases}$$



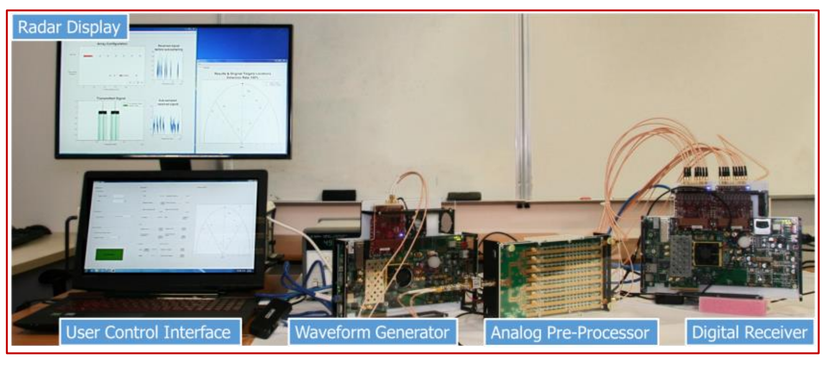
- Goal: Recover delay, azimuth, Doppler and reflectivity from $\phi_{m,q}^{\nu}[k]$
  - Fourier coefficients for the mth transmission in matrix form

$$\mathbf{Z}^m=\left(\bar{\mathbf{B}}^m\otimes\mathbf{A}^m\right)\mathbf{X}_D\mathbf{F}^H$$

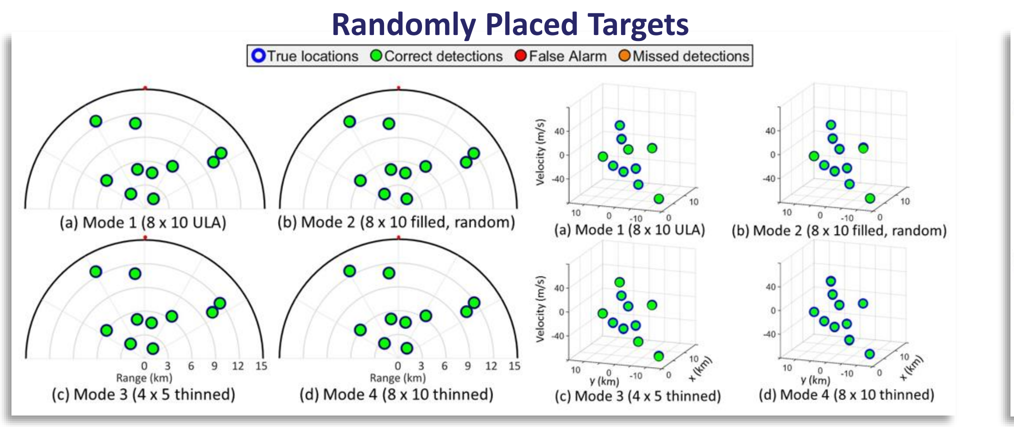
Azimuth dictionary; Range dictionary; Sparse matrix whose elements are located at the targets' range-azimuth-Doppler.; Doppler dictionary

  - Use OMP for simultaneous sparse 3D recovery with focusing

Hardware Prototype and Measurement Results

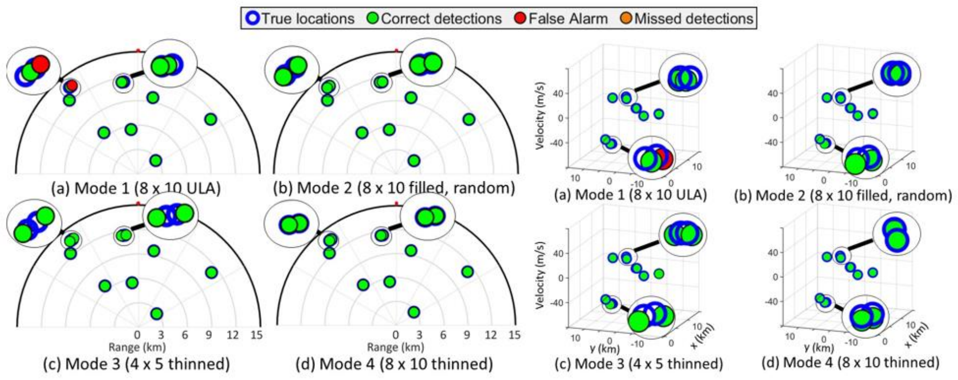


Randomly Placed Targets



Sub-Nyquist mode (3) detection performance is same as Nyquist mode (1)

Cognitive Sub-Nyquist Mode



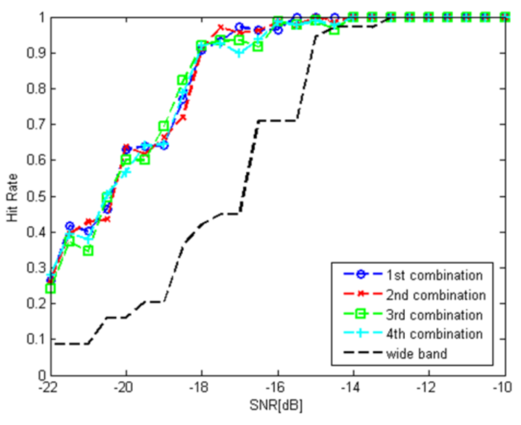
Cognitive Sub-Nyquist (3) performs better that Nyquist in low SNR

Spectral Coexistence via Xampling (SpeCX)

Cognitive Radar (CRr)

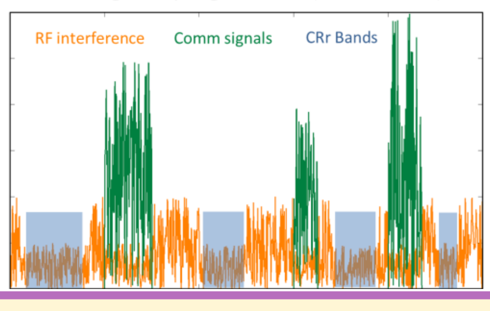
- Transmitter:
  - Only in the available bands
  - Dynamic changes in frequency bands location
- Receiver:
  - Sampling only transmitted bands
  - Xampling techniques to accurately detect targets despite low total bandwidth
  - Recovery process: identical
- Advantages:
  - Reduced transmitted bandwidth: coexistence with communication signals
  - Inherent high SNR system: all the power that was spread along the wideband is now concentrated in the narrow bands
  - Preservation of resolution: Xampling recovery techniques

By transmitting only the bands to sample, we achieve better performance without trade-off

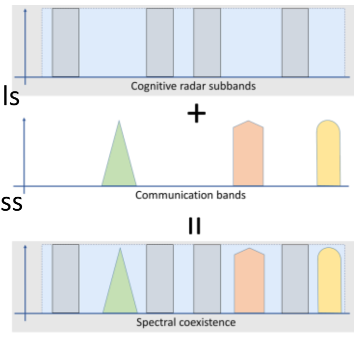


Spectral Coexistence

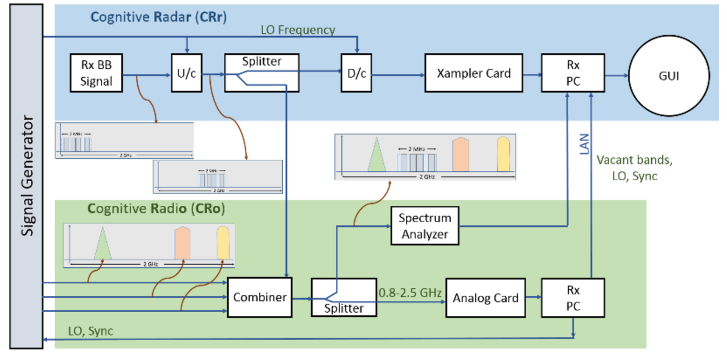
- Radio Environment Map (REM) is assumed to be known
- Goal: Select bands with minimal interference
- Finding a block sparse vector
- Known length blocks (receiver passband is known *a priori*)
- Structured greedy algorithms (StructOMP) for recovery

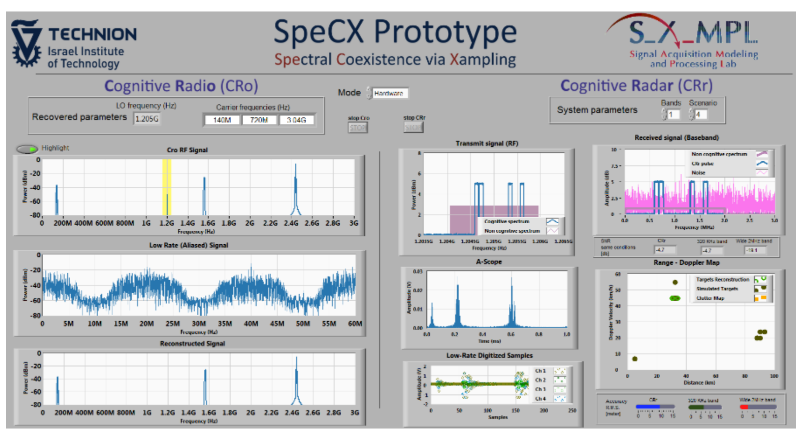


- Comm systems can share the unused cognitive radar transmit spectrum
- Recovery for CRo and CRr signals is via Xampling
- Spectral coexistence without loss of range resolution in CRr
- CS-based blind sensing in CRo



Hardware Prototype and Measurement Results





Mode: Hardware

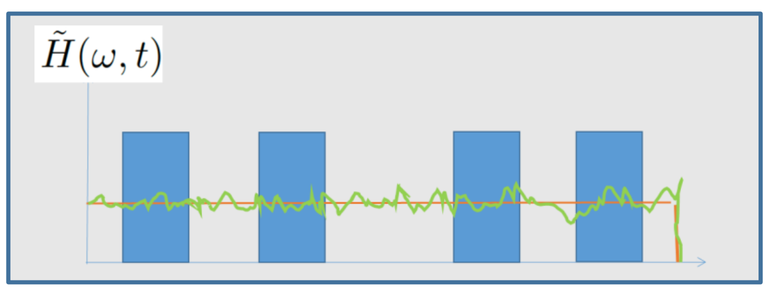
Recovered parameters: LO frequency (Hz) 1.205G; Carrier frequencies (Hz) 140M, 720M, 3.04G

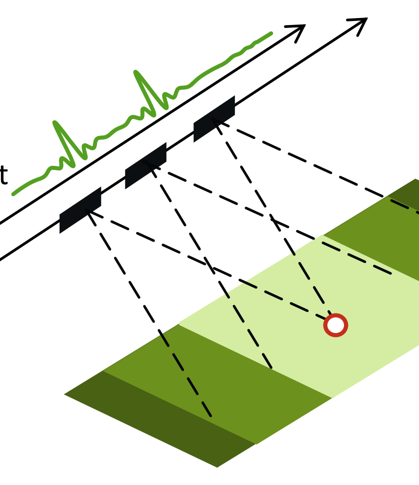
System parameters: Bands 1; Scenario 4

Cognitive Synthetic Aperture Radar (CoSAR)

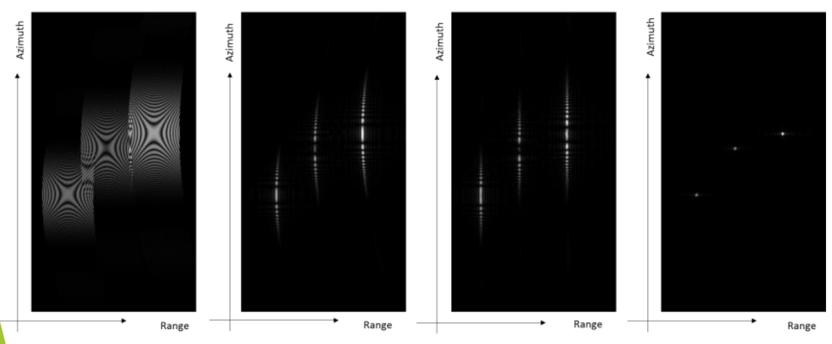
Cognitive SAR Concepts

- Frequency adaptive transmitter that senses SAR target scenes based on available frequency bands
- Sub-Nyquist receiver based on Xampling and compressed sensing
- Transmission, reception and processing of only a few disjoint narrow subbands
- Improved SNR due to restriction of all available transmit power in the subbands





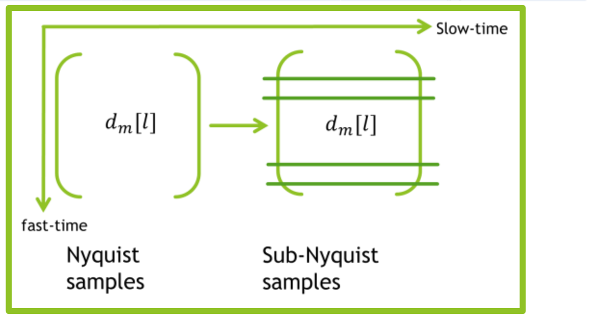
Signal Model and Sampling Scheme



Raw data → Range Compression → RCMC → Azimuth Compression

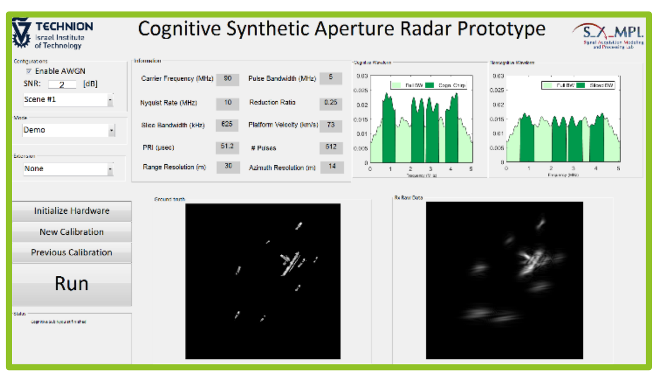
- The returned echoes are sampled in the Fourier domain under the Nyquist rate using Xampling
- Fast 2D recovery by extended FISTA

	Conventional RDA	Fourier Domain RDA
Range Compression	$s[n,m]=d[n,m]*h^{*}[-n]$	$\tilde{d}_m[l]=T\cdot d_m[l]*h^{s^*}[l]$
Azimuth DFT	$S[n,k]=\sum_{m=0}^{M-1}s[n,m]e^{\frac{-j2\pi km}{M}}$	$s_k[l]=\sum_{m=0}^{M-1}\tilde{d}_m[l]e^{\frac{-j2\pi km}{M}}$
RCMC	$\tilde{S}[n,k]=S[n+n\cdot ak^2,k]$	$c_k[l]=\sum_{n\in\nu(k,l)}s_k[n]Q_{k,l}[-n]$
Azimuth Compression	$Y[n,k]=\tilde{S}[n,k]e^{-j\pi\frac{k^2}{K_a[n]}}$	$Y[n,k]=\left(\sum_{l=-N/2}^{N/2}c_k[l]e^{\frac{j2\pi nl}{T}}\right)\cdot\left(e^{-j\pi\frac{k^2}{K_a[n]}}\right)$
Azimuth IDFT	$I[n,m]=\frac{1}{M}\sum_{k=0}^{M-1}Y[n,k]e^{\frac{j2\pi mk}{M}}$	$I[n,m]=\frac{1}{M}\sum_{k=0}^{M-1}Y[n,k]e^{\frac{j2\pi mk}{M}}$



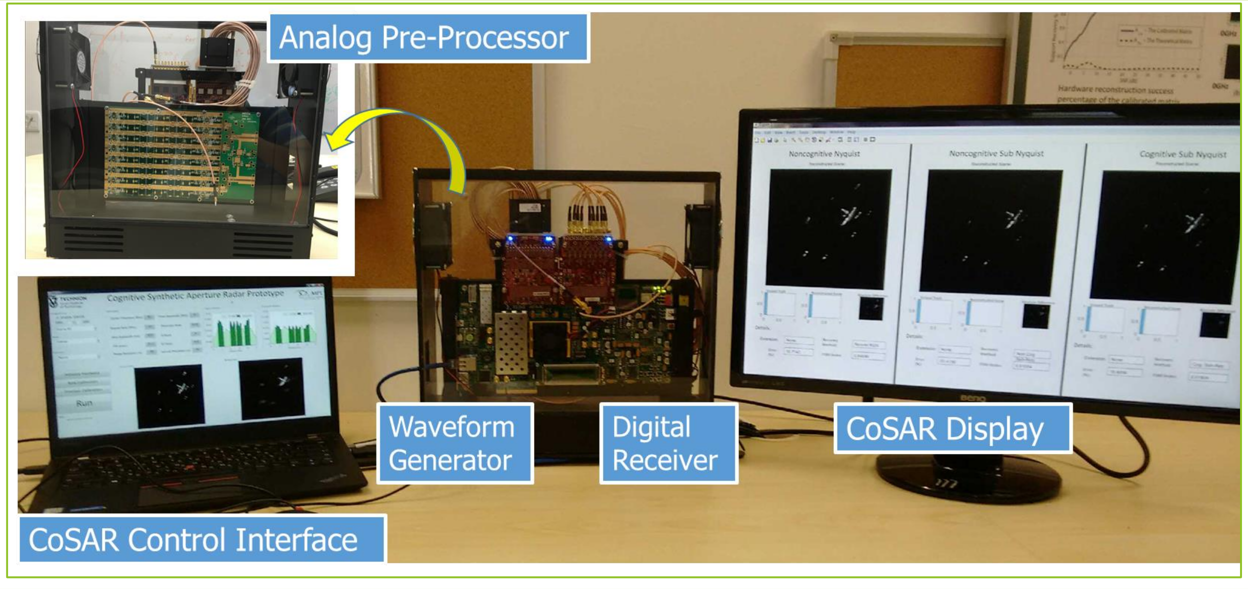
Algorithm, Hardware Prototype and Results

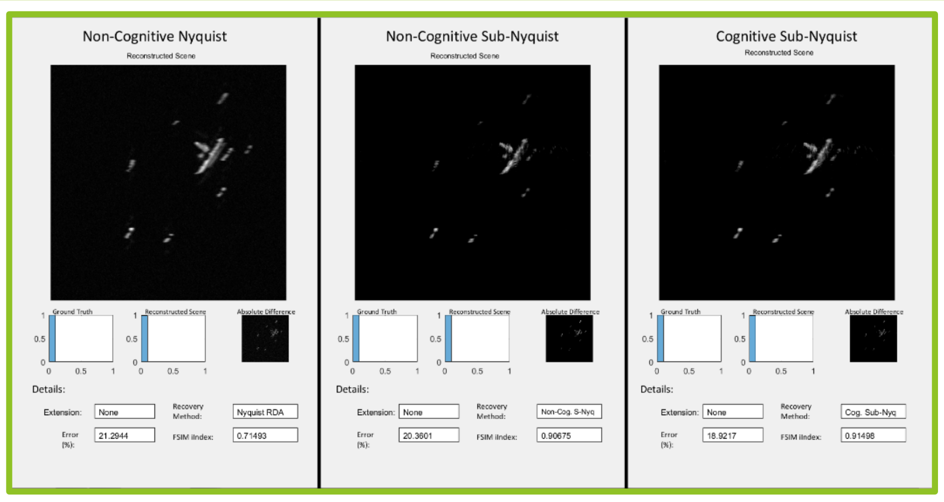
- 5 MHz cognitive chirp
- 4 subbands of 625 kHz bandwidth
- Xampling at 1/4th of the Nyquist rate
- RCMC at 1/8th of the Nyquist rate



Configurations: ☑ Enable AWGN; SNR: 2 [dB]; Scene #1
Mode: Demo
Extension: None

Information			
Carrier Frequency (MHz)	80	Pulse Bandwidth (MHz)	5
Nyquist Rate (MHz)	10	Reduction Ratio	0.25
Slice Bandwidth (kHz)	625	Platform Velocity (km/s)	73
PRI (µsec)	51.2	# Pulses	512
Range Resolution (m)	30	Azimuth Resolution (m)	14





	Non-Cognitive Nyquist	Non-Cognitive Sub-Nyquist	Cognitive Sub-Nyquist
Extension	None	None	None
Recovery Method	Nyquist RDA	Non-Cog. S-Nyq	Cog. Sub-Nyq
Error (%)	21.2944	20.3601	18.9217
FSIM index	0.71493	0.90675	0.91498

Cognitive sub-Nyquist SAR recovers the target scene sampled at 1/4th of the Nyquist rate with least error and most similar low-level features