Electrical Engineering Department
Electronics
Computers
Communications

TECHNION
Israel Institute
of Technology

Cognitive Synthetic Aperture Radar (CoSAR) Prototype

Kumar Vijay Mishra   Andrey Zhitnikov   Eli Shoshan   Moshe Namer
Maxim Meltsin   Eran Ronen   Yonina C. Eldar

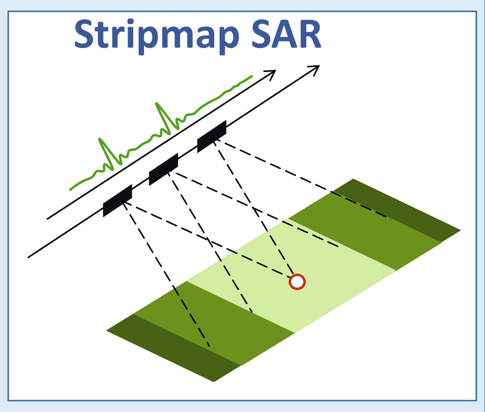
erc
646804-BNYQ

Main Contributions

- Stripmap synthetic aperture radar (SAR) prototype that demonstrates sub-Nyquist sampling in radar imaging and reconstruction of target scene using a faster 2D recovery algorithm.
- Cognitive transmission is employed to further enhance SNR for sub-Nyquist SAR and adaptive frequency allocation.
- Cognitive sub-Nyquist SAR recovers the target scene at low SNRs with lesser error and greater feature similarities than non-cognitive Nyquist processing.

Stripmap SAR

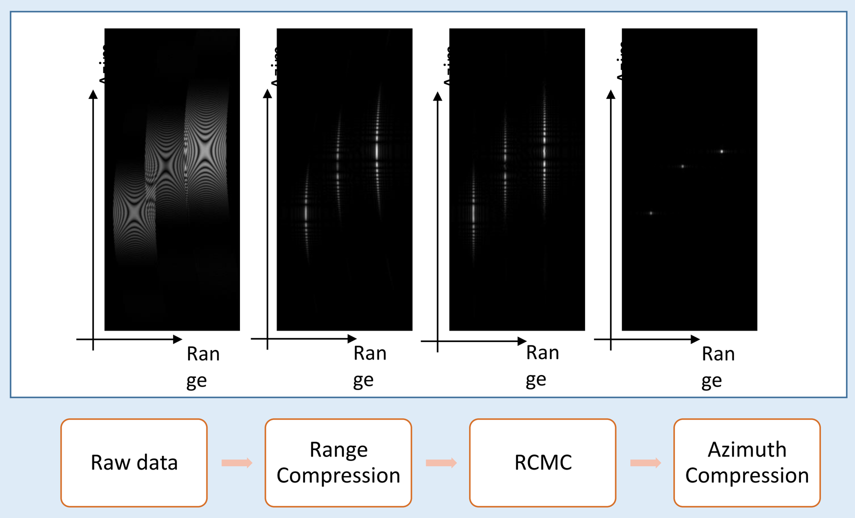
- Conventional SAR strip mapping mode
- A fixed pointing direction antenna broadside to the platform track with the beam pattern:



$$w_a(\mathbf{x}_m, \mathbf{r}) = \mathrm{sinc}^2\left(\frac{|x - x_m|}{r}\cot\frac{\Theta_a}{2}\right)$$

- Strip map is an image formed in width by the swath of the SAR and follows the length contour of the flight line of the platform itself.

Range-Doppler Processing



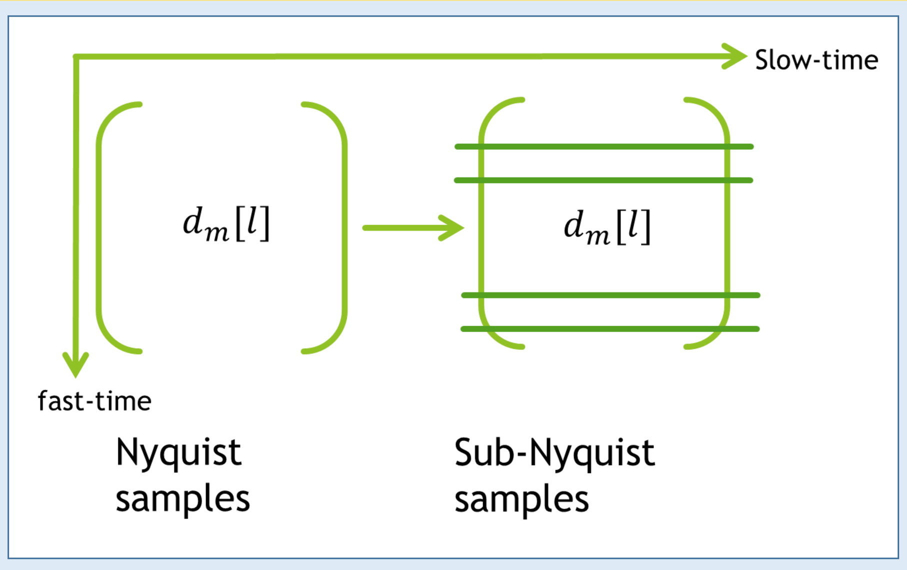
- Range Cell Migration Correction (RCMC) decouples dependency between the azimuth and range axes and corrects the hyperbolic trajectory of the targets' echoes.
- RCMC requires digital interpolation effectively increasing the sampling rate.

Fourier-Domain Range-Doppler

	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	$I[n,m] = \frac{1}{M}\sum_{k=0}^{M-1} Y[n,k] e^{\frac{j2\pi mk}{M}}$	$I[n,m] = \frac{1}{M}\sum_{k=0}^{M-1} Y[n,k] e^{\frac{j2\pi mk}{M}}$

- Fourier domain RCMC is similar to beamforming in frequency
- Interpolation is replaced by a weighted sum of Fourier coefficients (weights are characterized by a rapid decay)
- No over-sampling required at the receiver

Sub-Nyquist SAR



- The returned echoes are sampled in the Fourier domain under the Nyquist rate using Xampling
- Xampling requires analog pre-processing

Fast 2D Recovery

- Having the partial Fourier processed measurements, C_p, the image, I, is reconstructed by solving the optimization problem:

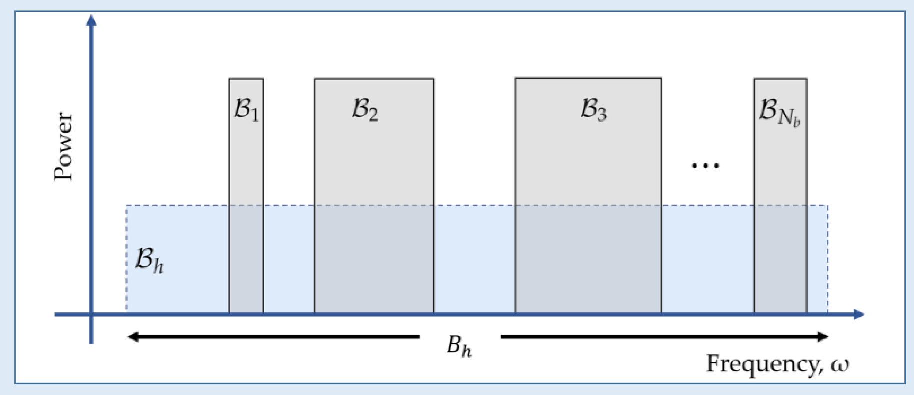
$$\min \|\Psi(I)\|_1 \; s.t \; \left\|C_p - F^S{}_p[B \circ (IF)]\right\|^2 < \varepsilon$$

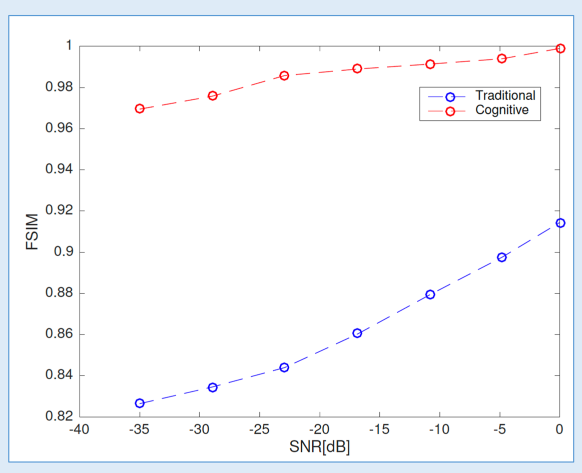
F – DFT matrix
F^S – Sampled Fourier series transformation
B – Azimuth Compression matrix
Ψ – Sparsifying transform

- Recovery by extended Fast Iterative Soft Thresholding Algorithm (FISTA)

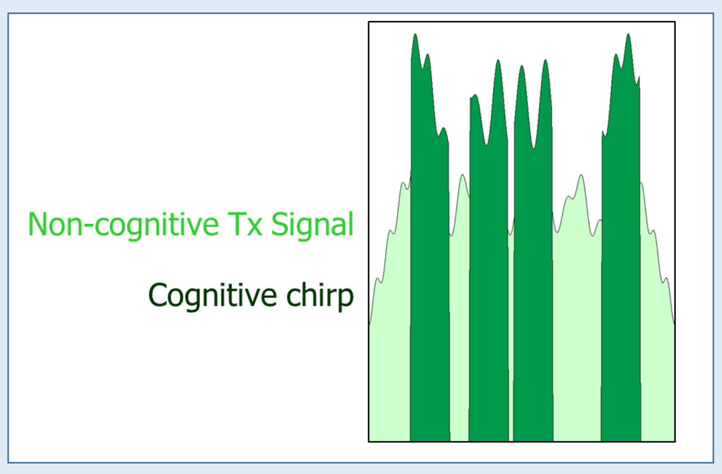
Cognitive SAR (CoSAR)

- Cognitive SAR sub-Nyquist receiver design
- CoSAR transmits only in a few narrow disjoint subbands
- A framework for adaptive transmission and reception of SAR signals

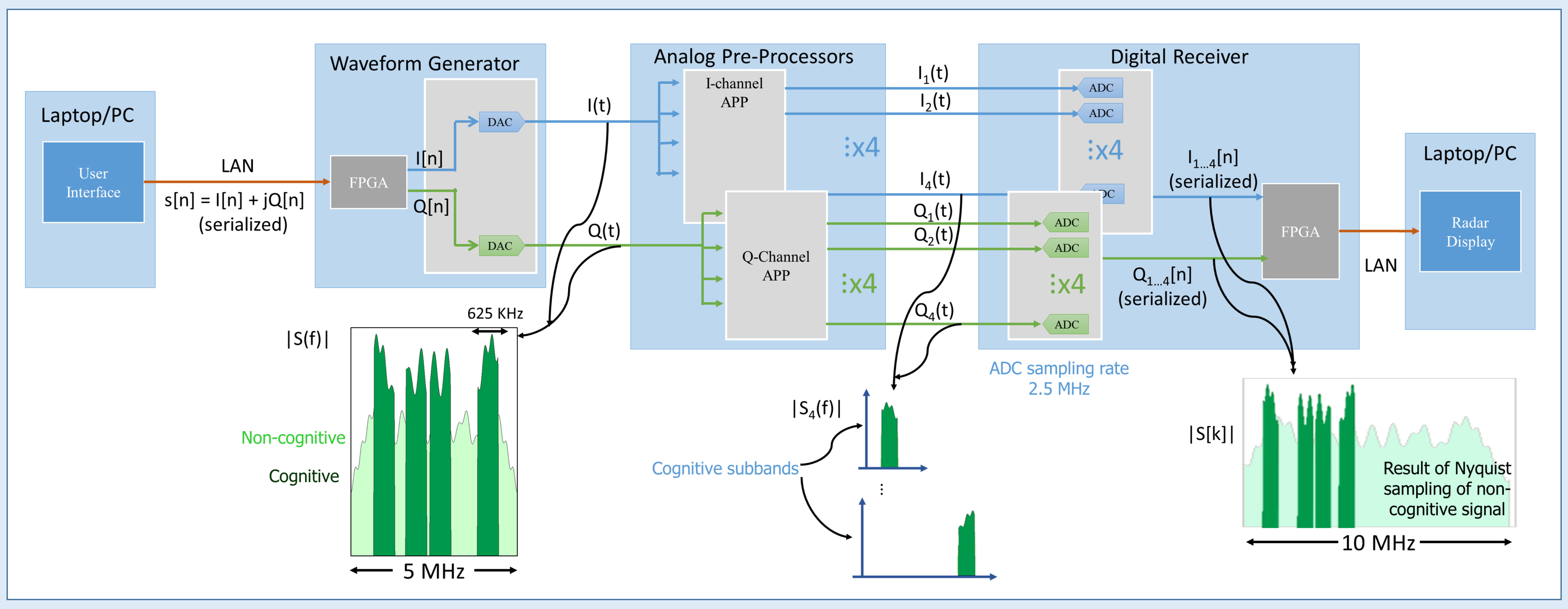




All Tx power can be focused in narrower bands → high SNR



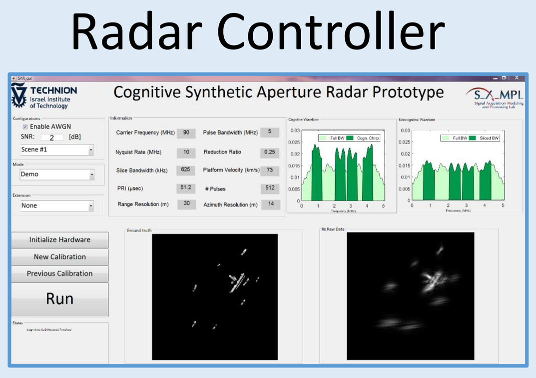
CoSAR System Design



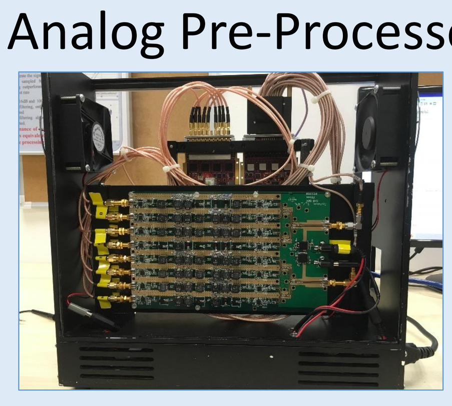
- 5 MHz cognitive chirp
- 4 subbands of 625 kHz bandwidth
- Xampling at 1/4th of the Nyquist rate
- RCMC at 1/8th of the Nyquist rate

CoSAR Submodules

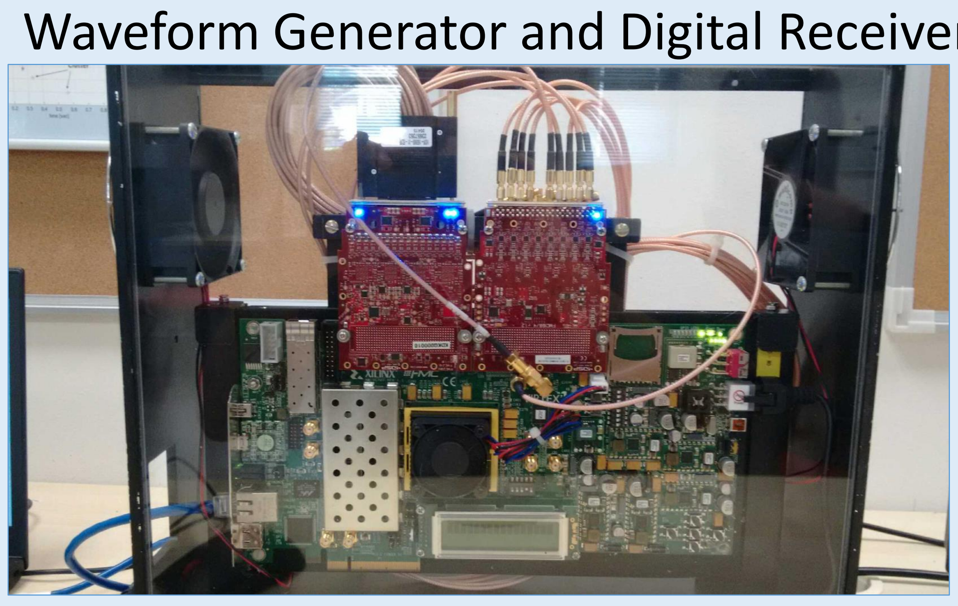
Radar Controller



Analog Pre-Processor

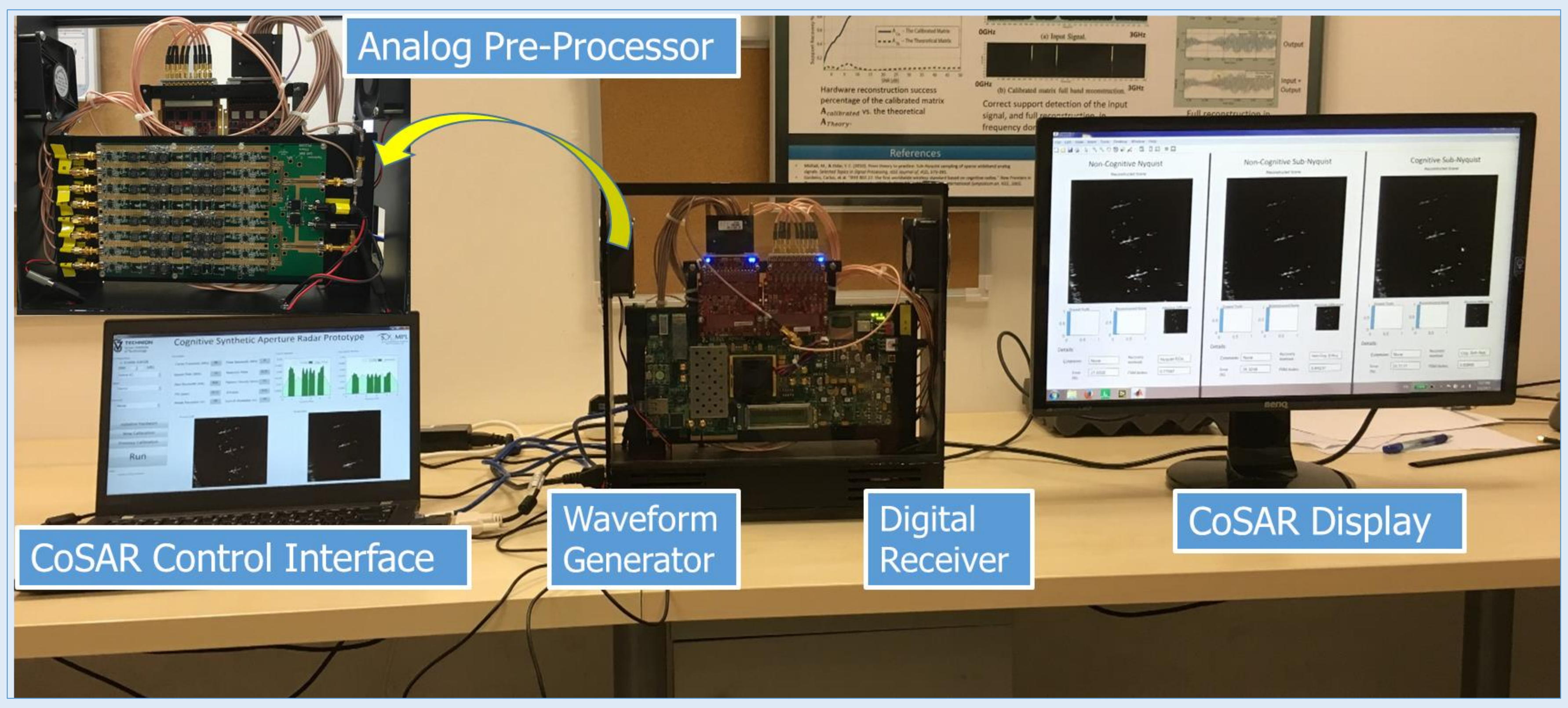


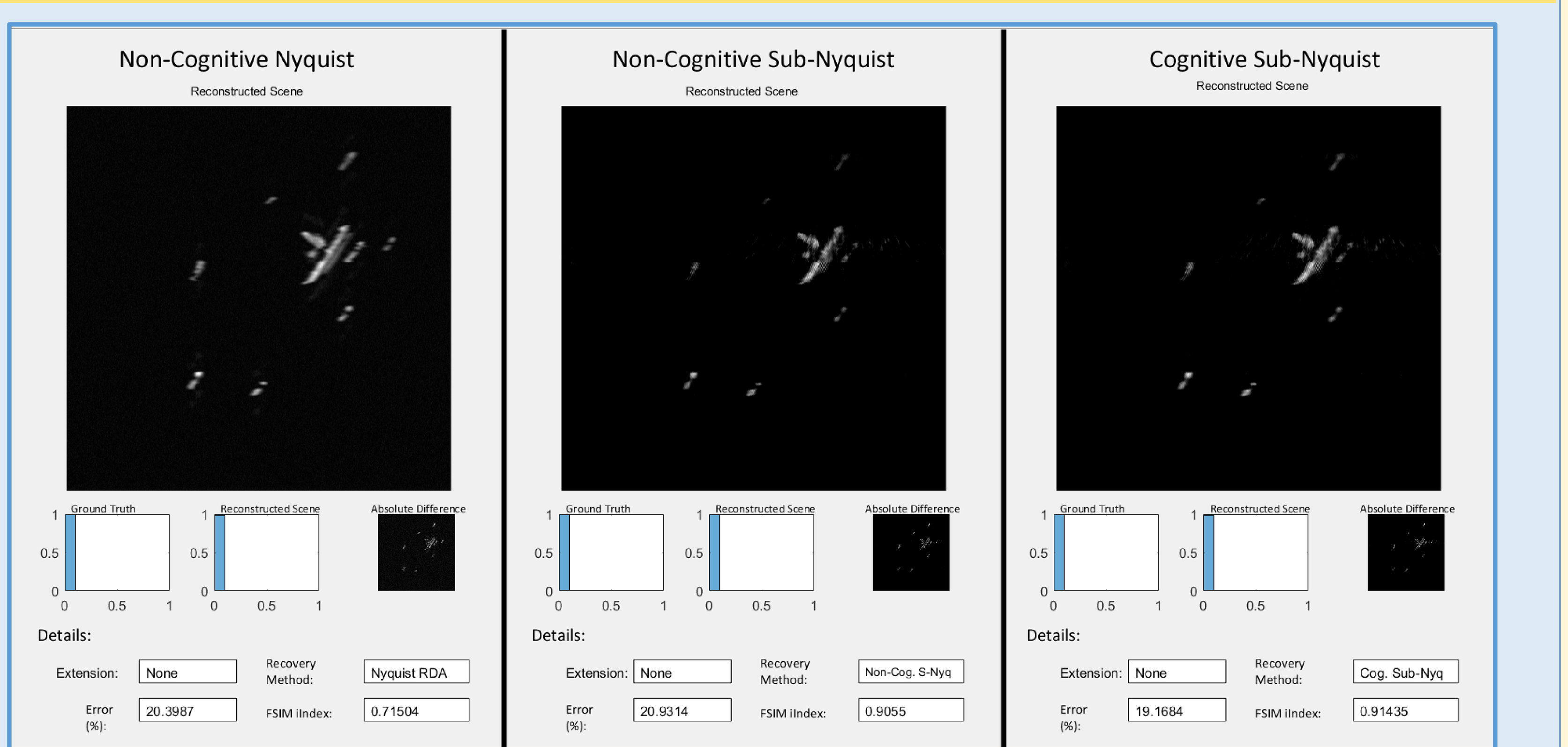
Waveform Generator and Digital Receiver



- Single Xilinx Virtex VC707 Board
- 4DSP DAC and ADC daughter boards for generator and receiver
- Separate streams for I and Q signals

CoSAR Prototype and Measurement Results





CoSAR recovers the target scene sampled at 1/4th and processed at 1/8th of the Nyquist rate with least error and most similar low-level features