# Cognitive Synthetic ApertureRadar (CoSAR) Prototype

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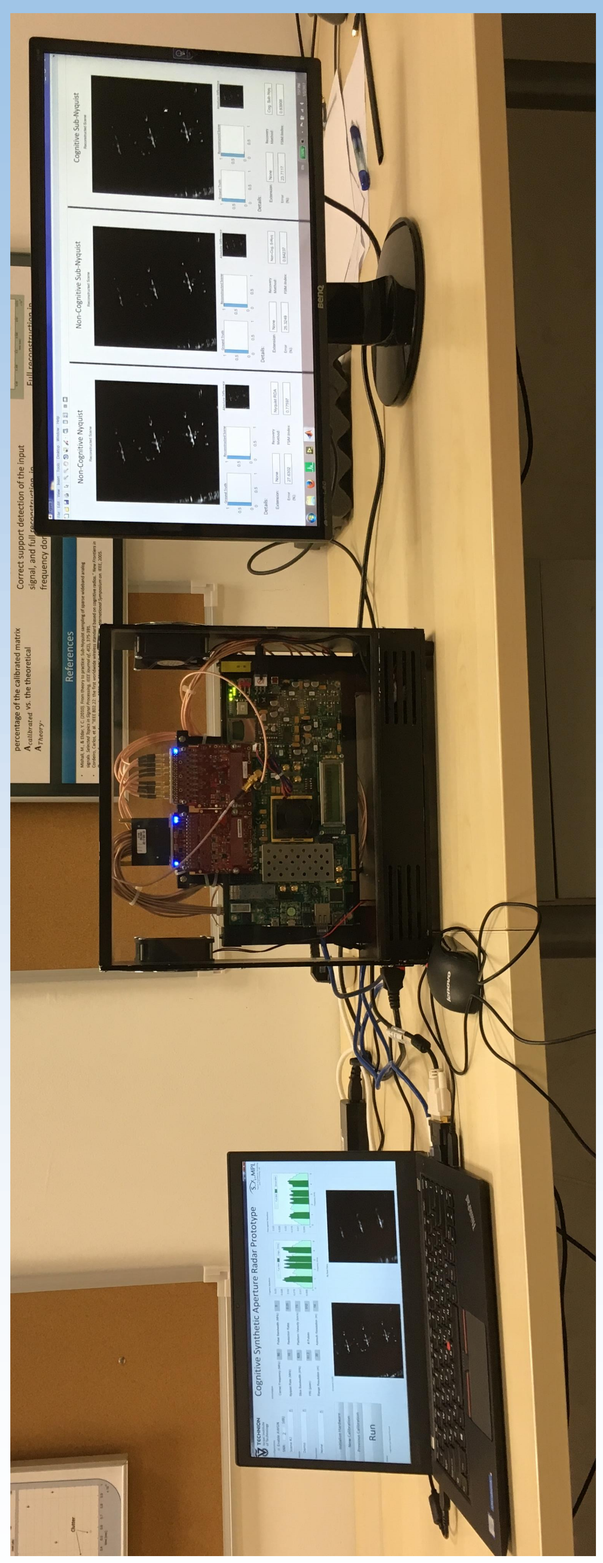

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# Theoretical Background

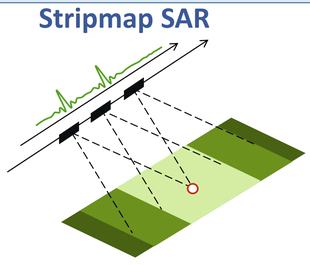
## Synthetic Aperture Radar (SAR)

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

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

- 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.

**Stripmap SAR**

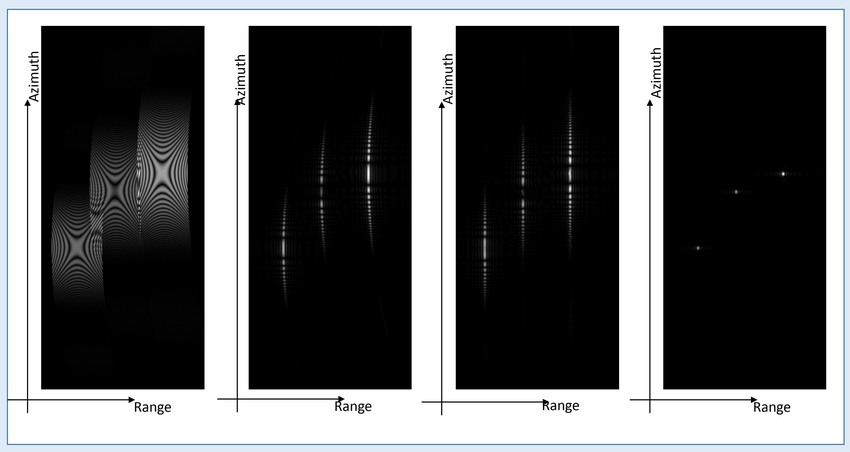


**Our contributions**

- 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.

## Range Doppler Processing

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



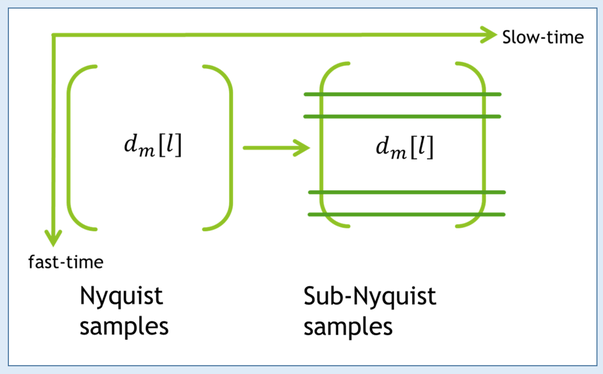

Raw data → Range Compression → RCMC → Azimuth Compression

## Fourier-Domain Range Doppler

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

## Sub-Nyquist SAR

- 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




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

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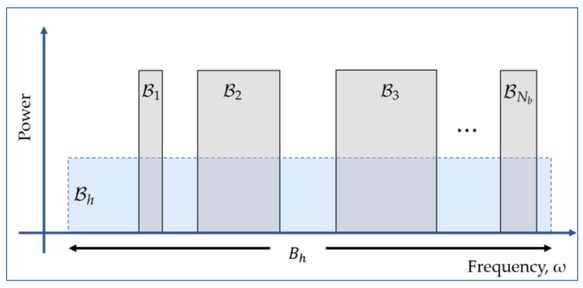
# Cognitive Synthetic Aperture Radar (CoSAR) Prototype

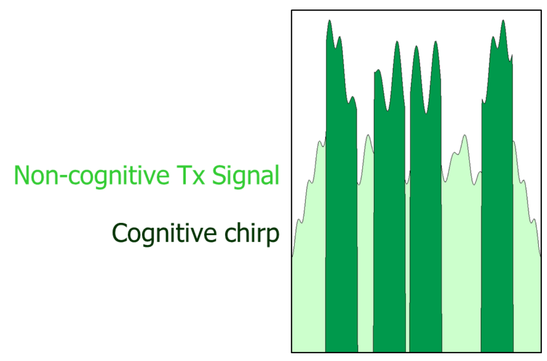
## Cognitive SAR (CoSAR)

### CoSAR Transmitter



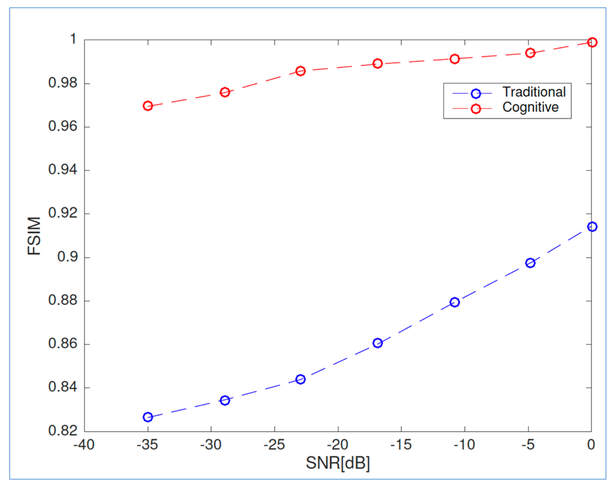

- CoSAR leverages sub-Nyquist receiver design
- CoSAR transmits only in a few narrow disjoint subbands
- A framework for adaptive transmission and reception of SAR signals

### CoSAR Cognitive Chirp



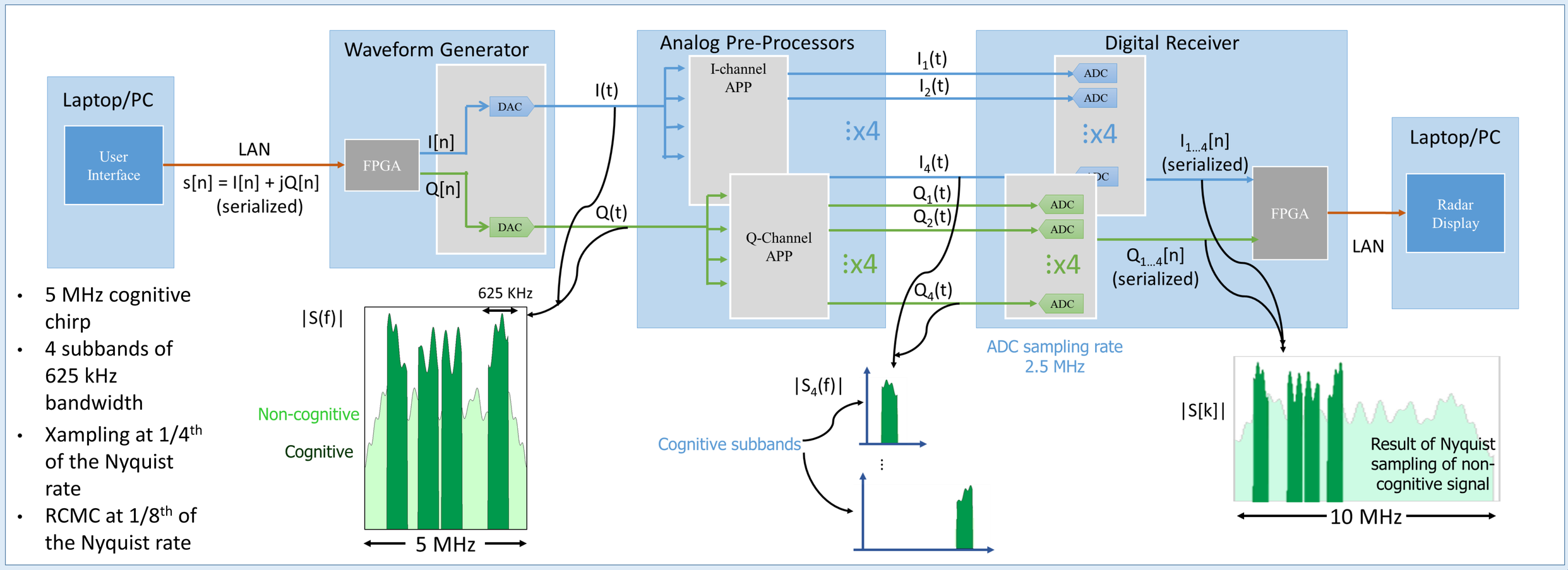

- Cognitive chirp signal is obtained by filtering a few subbands of the stripmap SAR Tx signal
- The total power is same for both cognitive and non-cognitive signals

### CoSAR Cognitive Chirp




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

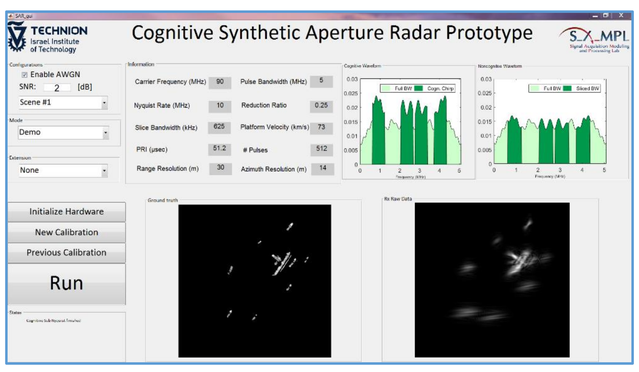
## CoSAR System Design




- 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

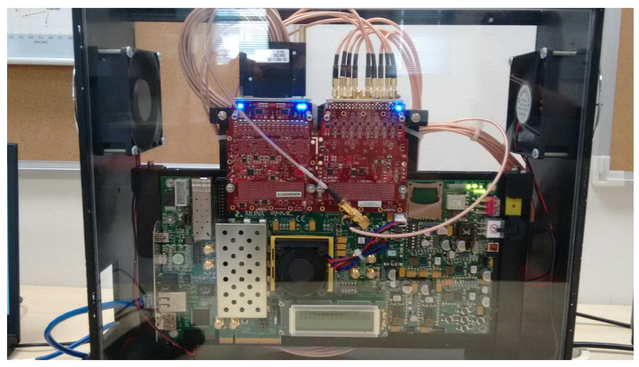
## CoSAR Submodules

### Radar Controller



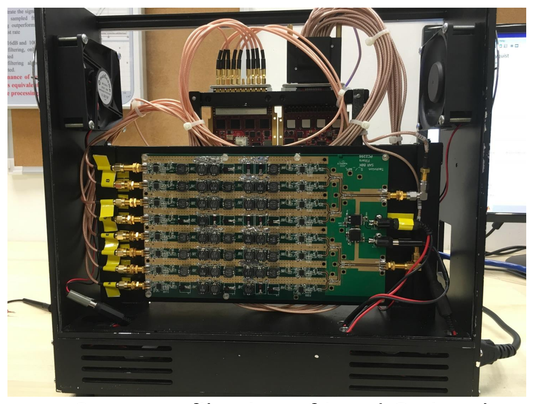

Allows selection of scenes, algorithms and other parameters

### Waveform Generator and Digital Receiver



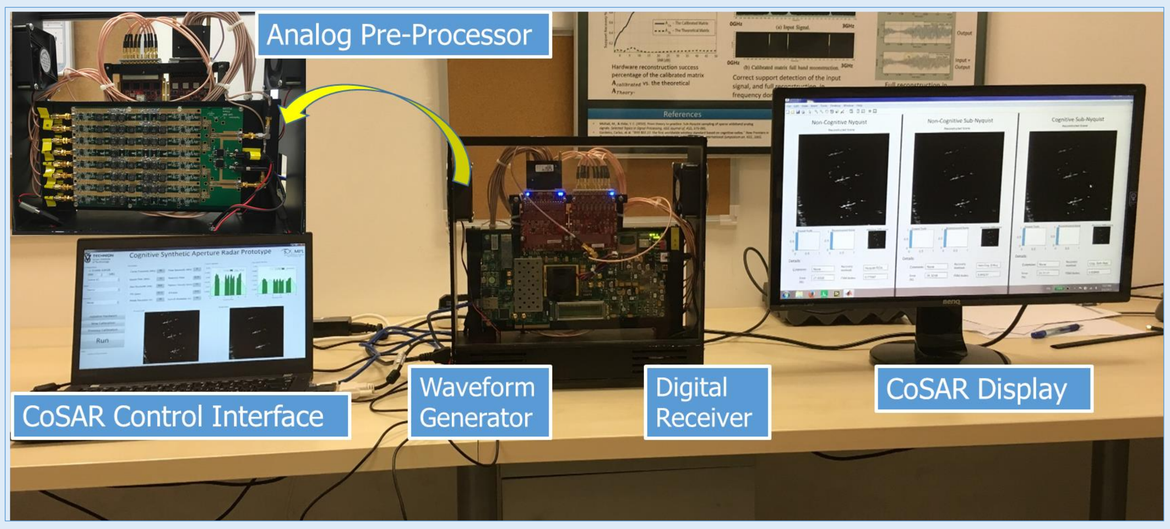
Xilinx VC707 board with 4DSP DAC and ADC daughter cards

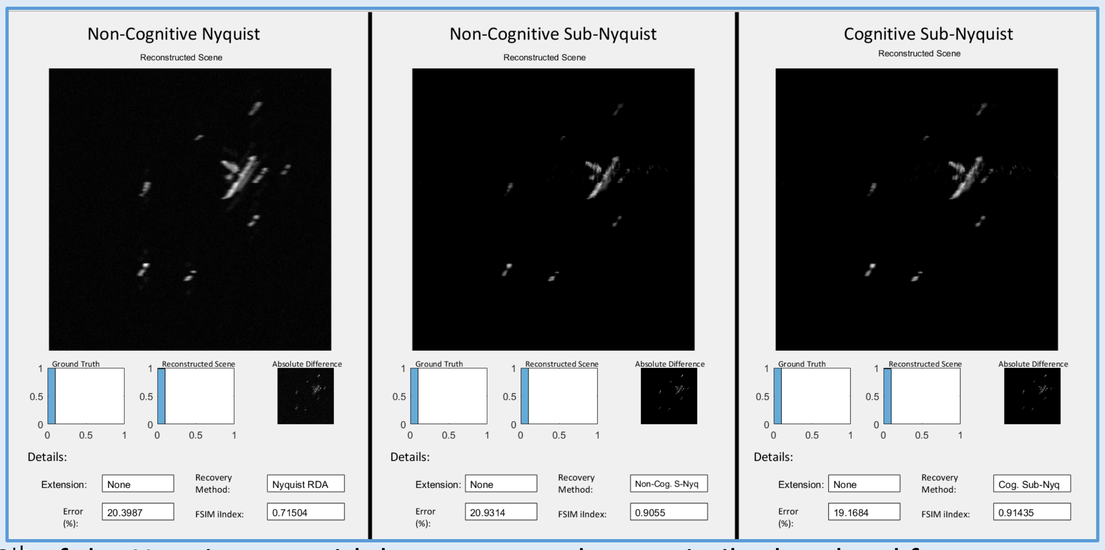
### Analog Pre-Processor



Separate filtering of 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