# Cognitive Sub-Nyquist MIMO Radar Prototype


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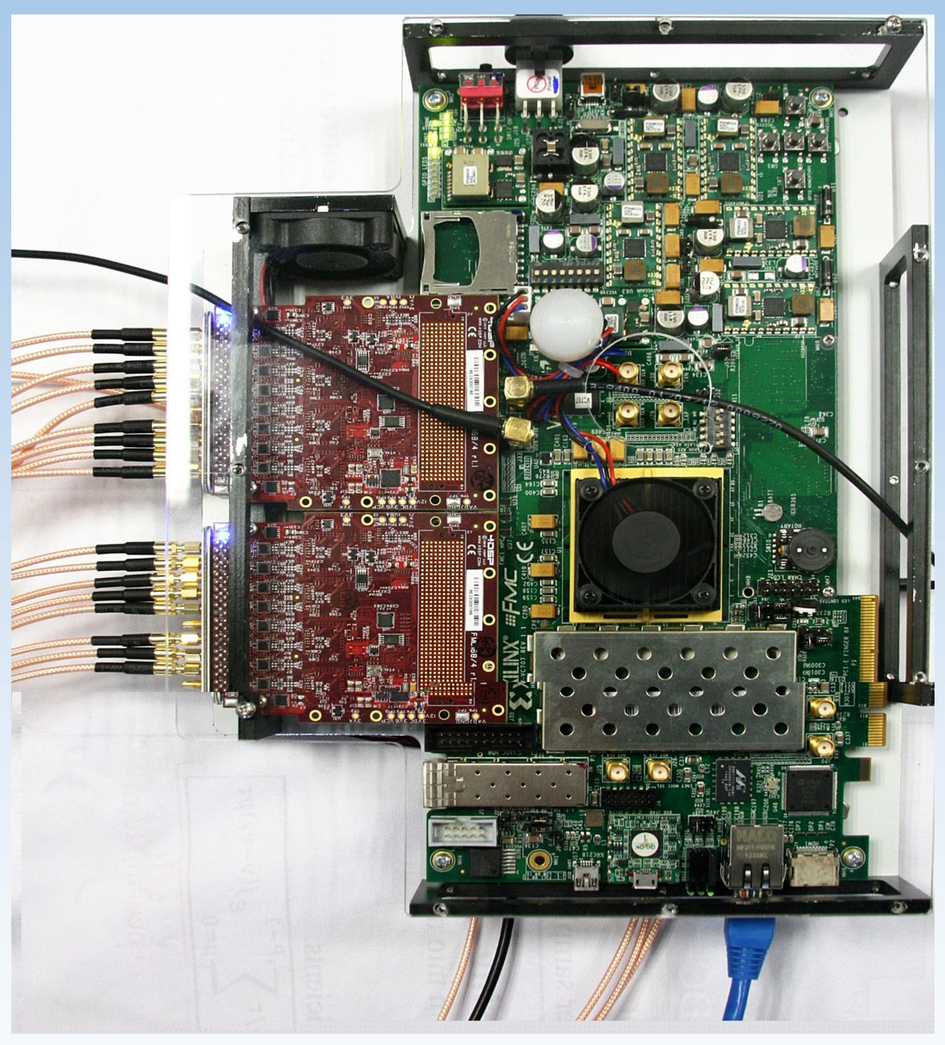


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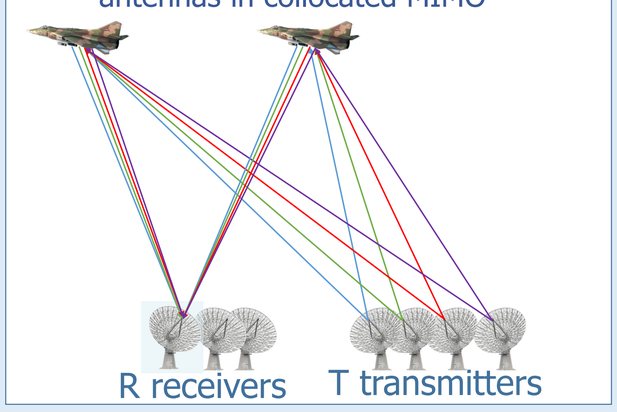
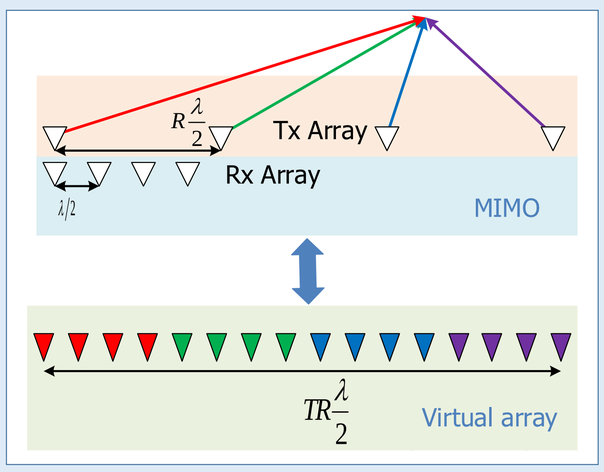
# Theoretical Background

## Conventional Collocated MIMO Radar

Radar cross-section is same for all antennas in collocated MIMO



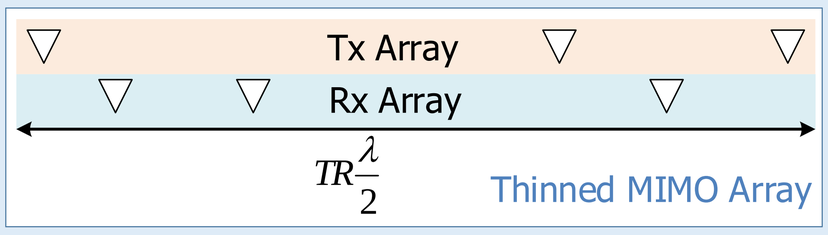

MIMO transmits orthogonal waveforms and processes linear combination of echoes received due to each waveform



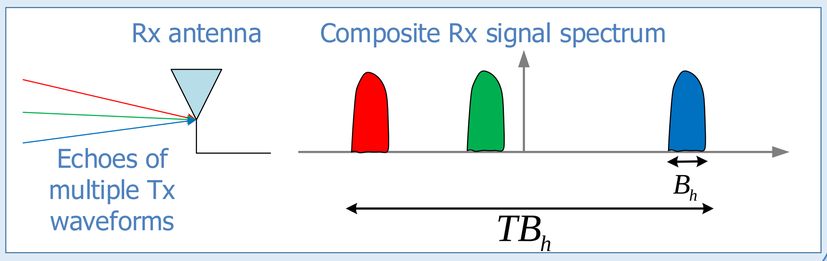

MIMO array with fewer elements has same spatial resolution as a virtual array with more elements

## Sub-Nyquist Collocated MIMO Radar

**Spatial Sub-Nyquist**
Thinned random array that preserves the azimuthal resolution as a virtual ULA




**Temporal Sub-Nyquist**
Reduced sampling rate at each receiver that preserves the range resolution as with bandwidth $TB_h$




## Signal Model and Xampling

- Received signal for $P$ pulses at the $q$th 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 azimuth; Target time delay; Element location factor

- Fourier coefficients of the $m$th transmitter channel at the $q$th receiver:

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

Operating frequency; Target reflectivity

- Xampling retrieves the Fourier coefficients from low rate samples

## Recovery algorithm: Matrix OMP with Doppler Focusing

- Doppler focusing for a specific frequency $\nu$

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

- Goal: Recover delay, azimuth, Doppler and reflectivity from $\phi_{m,q}^{\nu}[k]$
- Matrix form: $\boldsymbol{\Psi}^p = \boldsymbol{A}^H \boldsymbol{R}^p \boldsymbol{B}$

Sparse reflectivity matrix; non-zero values at target location; Range dictionary; Azimuth dictionary

- Use OMP for simultaneous sparse 3D recovery with focusing

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# Cognitive Sub-Nyquist MIMO Radar Prototype

## Technical Features

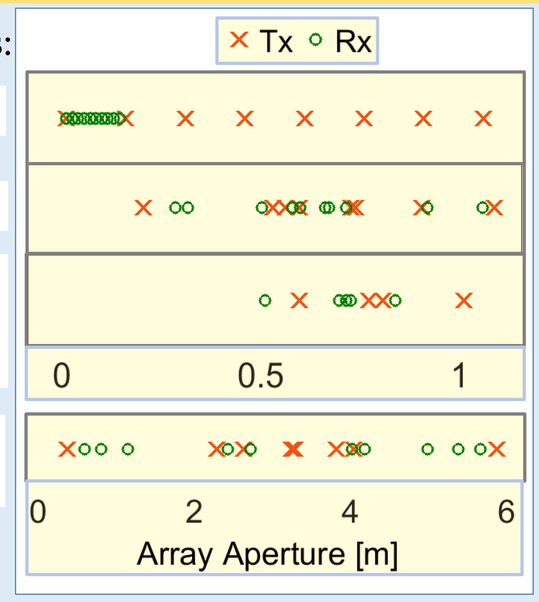
- Prototype array configurations:

Mode 1: Filled uniform array, 8x10

Mode 2: Filled random array, 8x10

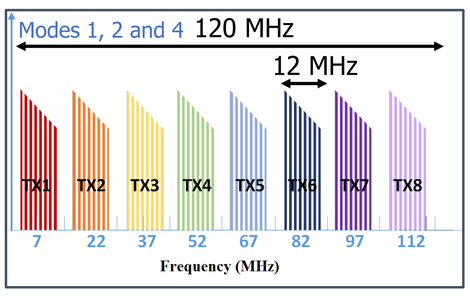
Mode 3: Thinned random array, 4x5 (~Virtual 8x10 ULA)
Spatial sub-Nyquist mode

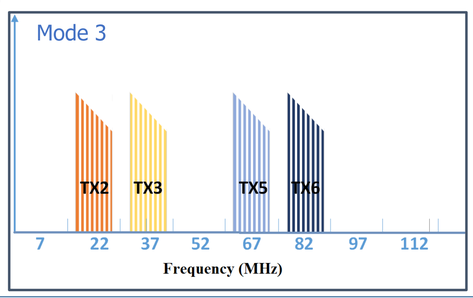
Mode 4: Thinned random array, 8x10 (~ Virtual 20x20 ULA)




- Cognitive transmission of eight 375 kHz bands within each 12 MHz Tx BW (3 MHz guardband)

Transmit spectrum




- Sub-Nyquist processing of subsampled 12 MHz spectrum

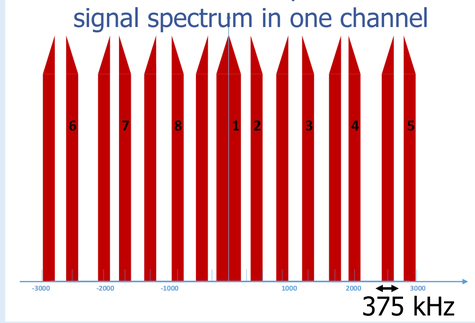
Total BW, 8 Tx channels: 120 MHz

Cognitive BW, 1 Tx channel:
3 MHz (= 8 x 375 kHz)

Cognitive BW, 4 Tx channels:
12 MHz (= 4 x 8 x 375 kHz)

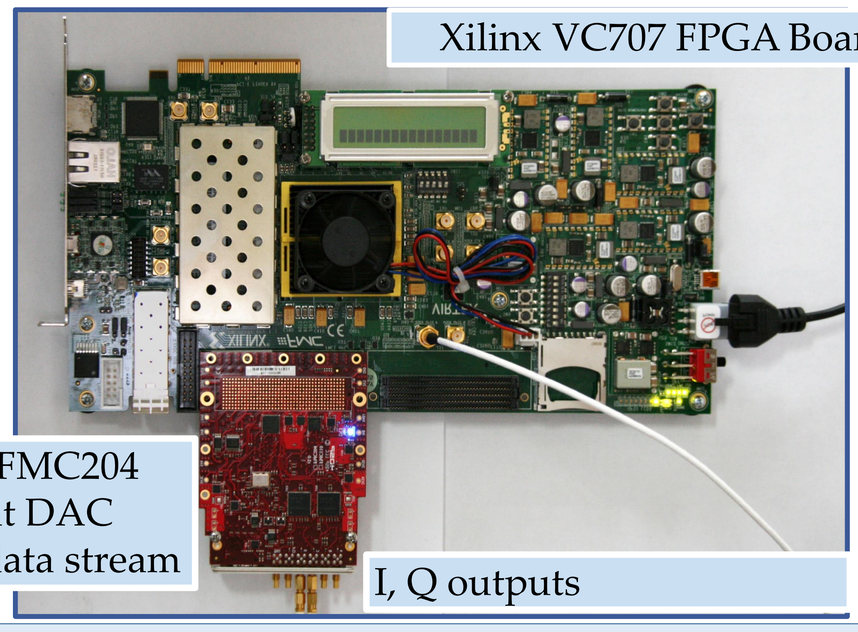
Reduction Factor: 10% (12 of 120 MHz)

Illustration: Subsampled received signal spectrum in one channel



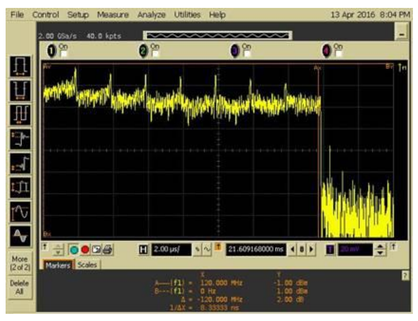

## Waveform Generator

- Virtex-7 XCVX486T FPGA based digital waveform generator serializes all receivers separately into I and Q analog channels




- Transmitter outputs

120 MHz spectrum of all 8 transmitters

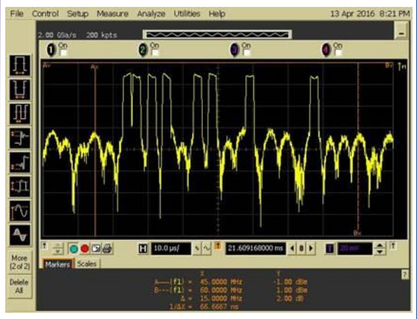


3 MHz guardband between adjacent channels

Pulse from one transmitter

Transmit signals differ in carrier frequencies

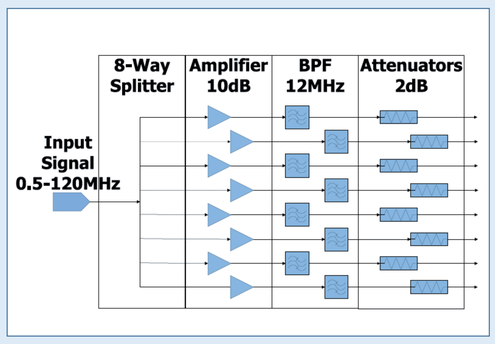
Spectrum of one transmit signal



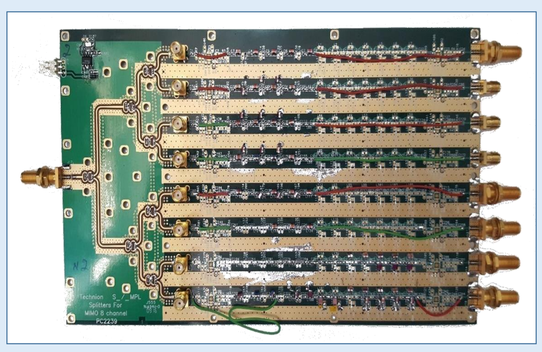
Only eight 375 kHz slices are transmitted

## Analog Pre-Processor (APP) Board

APP filters the receiver data into eight channels



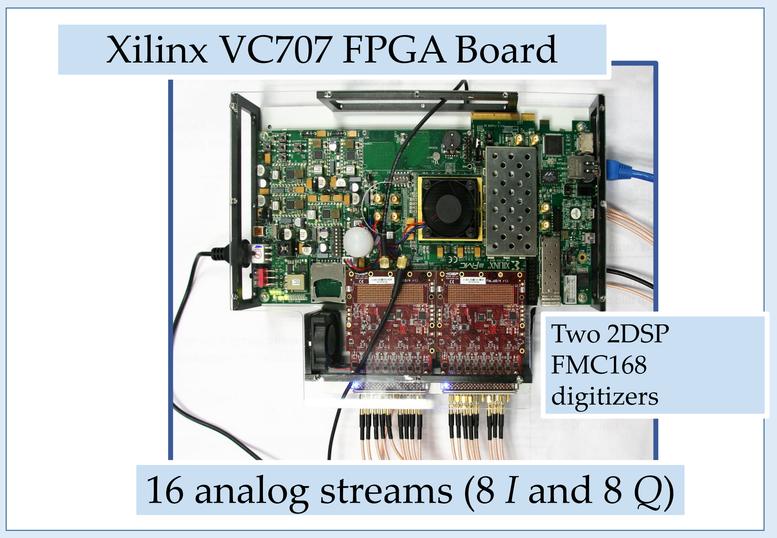

Dual back-to-back APPs in a single chassis



BPFs have ~30 dB stopband attenuation to mitigate subsampling noise

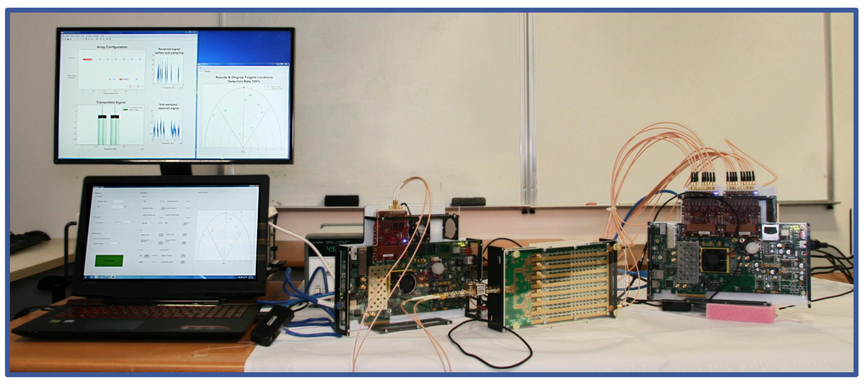
## Digital Receiver

- Two 16-bit eight-channel digitizers for I and Q streams
- Sub-Nyquist sampling rate: 7.5 MHz/channel
- Signal BW with guard-bands: 30 MHz/channel




16 analog streams (8 *I* and 8 *Q*)

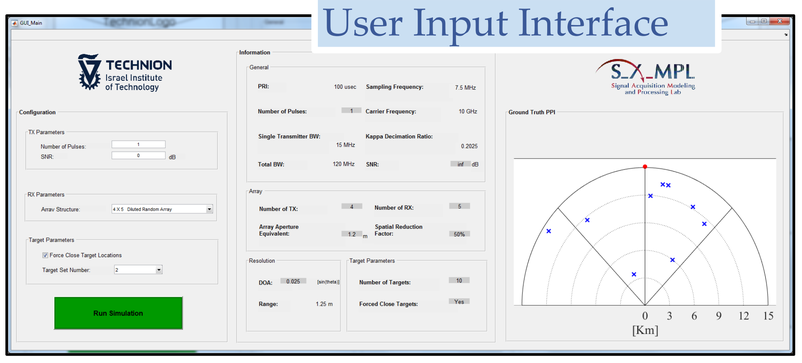
## User Interface and Measurement Results (Mode 3, 4x5 Array)



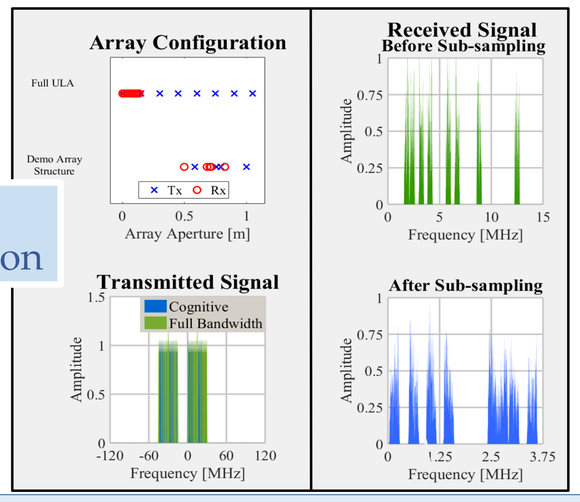
Prototype with user control and measurement output

- Selectable scenarios, including closely-spaced targets
- Mode 3: 4x5 sub-Nyquist array resolution performance same as the virtual ULA (Mode 1)
- Mode 4: 8x10 sub-Nyquist array shows higher resolution performance than other modes

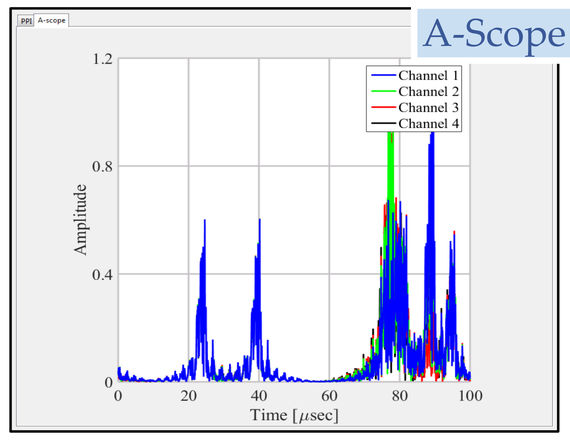
User Input Interface




Signal Information




A-Scope




PPI