646804-BNYQ

Signal Acquisition Modeling and Processing Lab

Technion Israel Institute of Technology

Spectral Coexistence Via Xampling (SpeCX)

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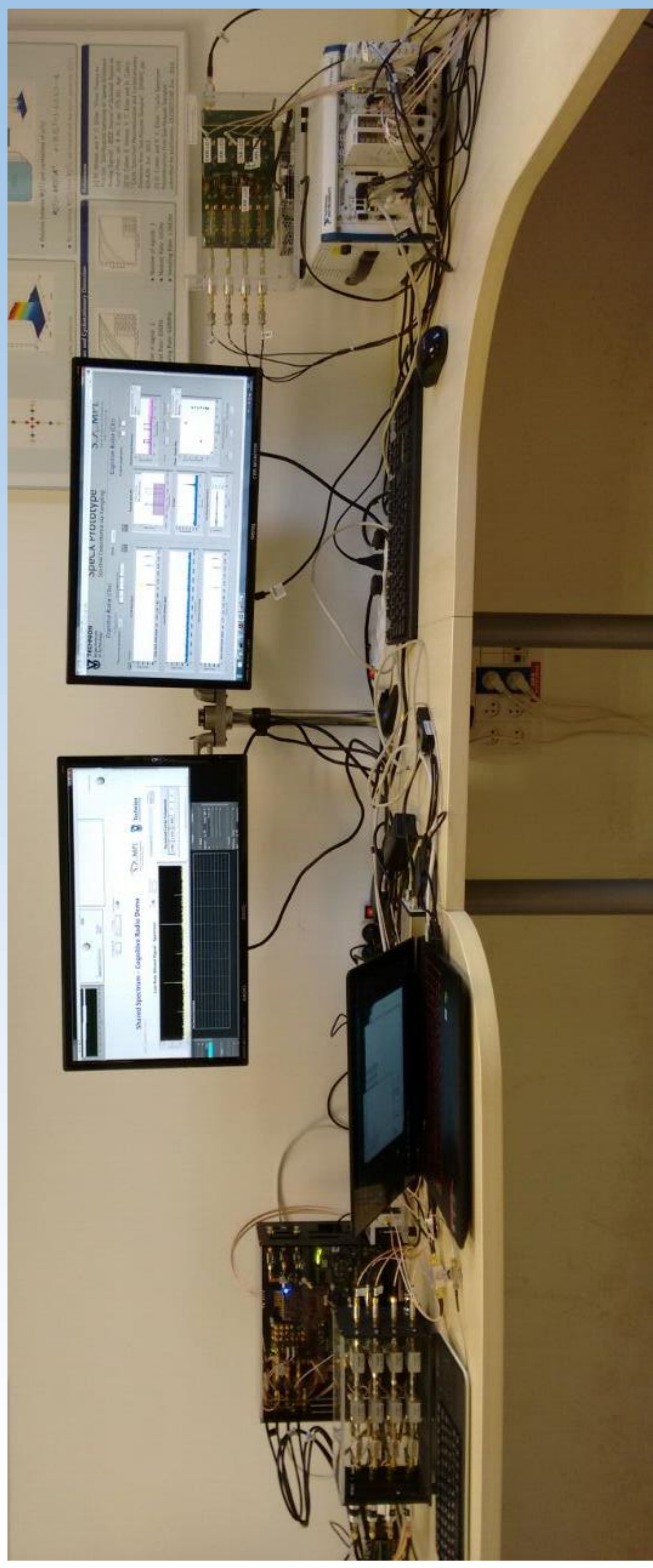

SAMPL – Directed by Yonina C. Eldar
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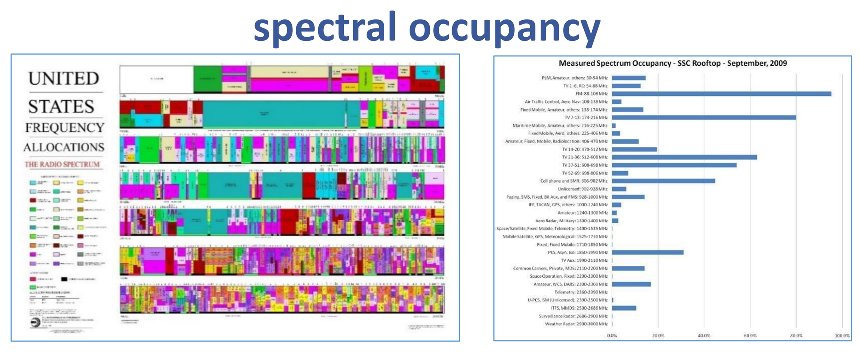
Theoretical Background

Spectral Coexistence

United States frequency allocation and spectral occupancy



- RF spectrum is a scarce resource and becoming increasingly crowded
- Spectral coexistence exploits spectral underutilization by allowing both radar and comm to share the same resource.

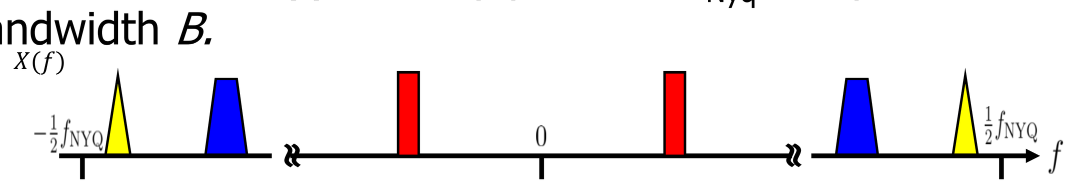
For a wideband signal Nyquist rate is not an option! → *Sub-Nyquist*

Our contributions

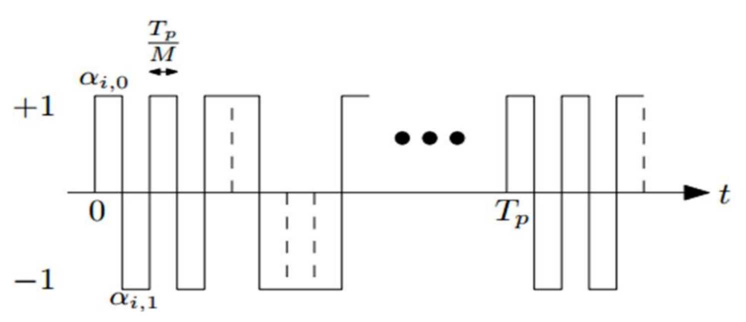
- A spectrum sharing technology enabling interference-free operation of a surveillance radar and communication transmissions over a common spectrum.
- Cognitive radio receiver senses the spectrum using low sampling and processing rates.
- Radar is a cognitive system that employs a Xampling-based receiver and transmits in several narrow bands.
- We merge two systems and adapt them to solve the spectrum sharing problem.

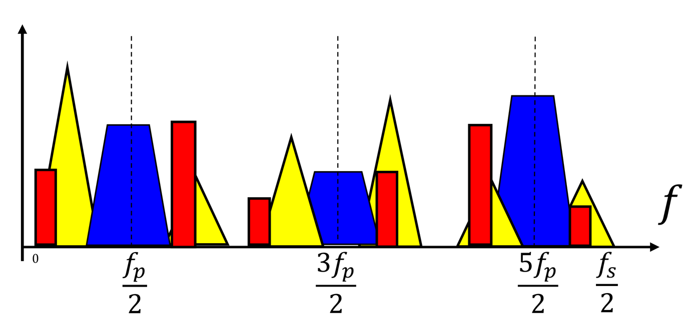
Cognitive Radio (CRo): Signal Model

- Input multiband model – $x(t)$ with Nyquist rate f_{Nyq} composed of $2N_{\text{sig}}$ bands each with max bandwidth B.



- The Modulated Wideband Converter (MWC) serves as an analog front-end: M parallel channels alias the spectrum, so that each band appears in baseband.
- Aliasing is done by mixing with periodic sequences:



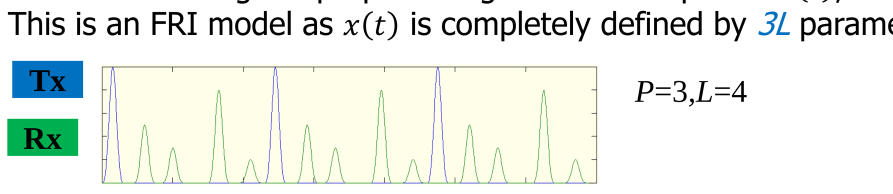


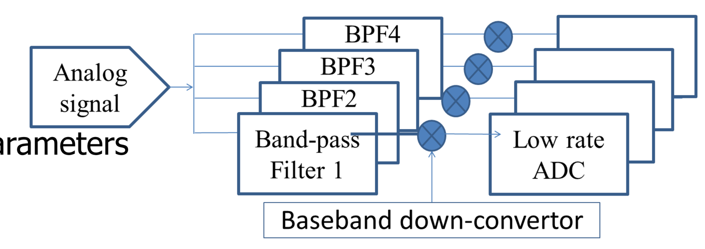
Cognitive Radar (CRr): Signal Model

x(t) → Xampling → Clutter Filtering → Doppler Focusing → Parameter Estimation → Time Delay, Doppler, Amplitude

- L targets, each defined by 3 degrees of freedom: amplitude α_ℓ, delay τ_ℓ, and Doppler frequency ν_ℓ
- After transmitting P equispaced high-bandwidth pulses $h(t)$, the received signal
- This is an FRI model as $x(t)$ is completely defined by $3L$ parameters

$$x(t)=\sum_{p=0}^{P-1}\sum_{l=0}^{L-1}\alpha_l h(t-\tau_l-p\tau)e^{-j\nu_l p\tau}$$

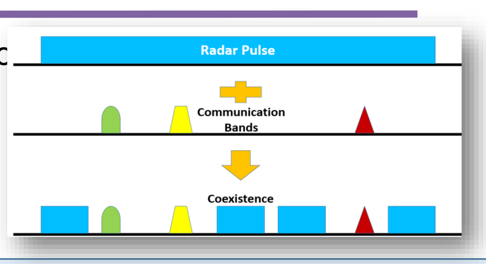




- Xampling acquires signal's Fourier coefficients that contain the required parameters

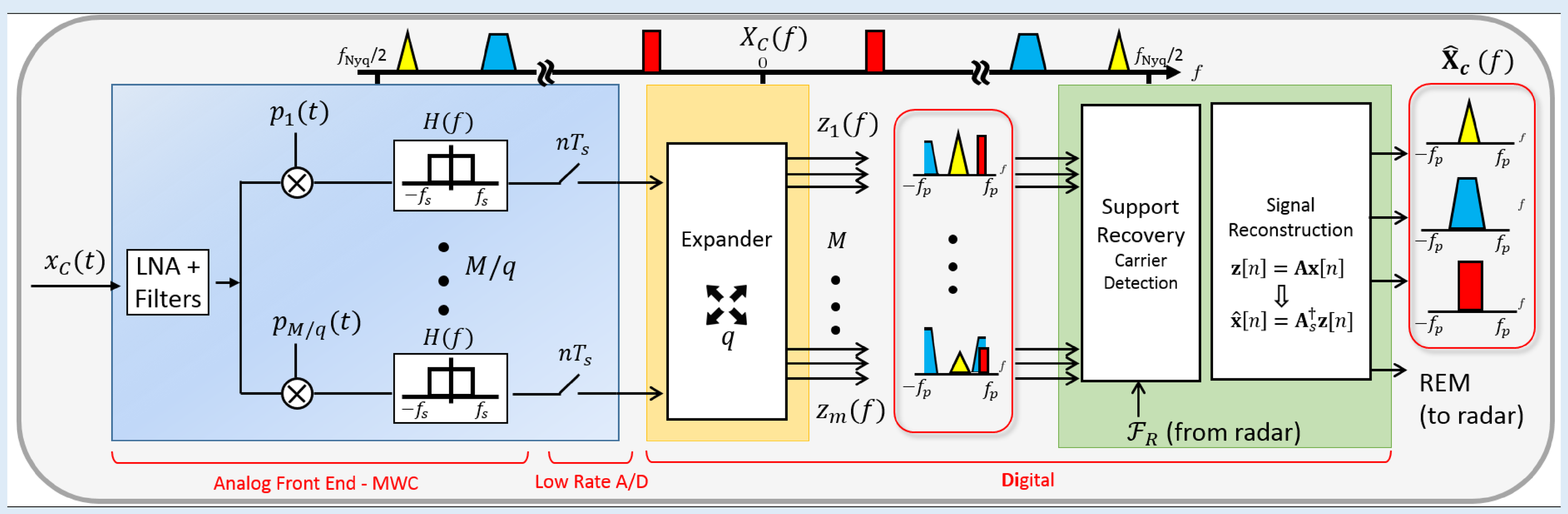
$$c_p[k]=\frac{1}{\tau}\int_0^{\tau}x_p(t)e^{-j2\pi kt/\tau}dt=\frac{1}{\tau}H(2\pi k/\tau)\sum_{\ell=0}^{L-1}\alpha_\ell e^{-j2\pi k\tau_\ell/\tau}e^{-j\nu_\ell p\tau}$$

- In practice, sub-Nyquist radar samples only a few subbands without loss of required info
- Cognitive radar transmits only in subbands sampled by sub-Nyquist receiver
- The unused CRr bands can be used for comm services



CRo and CRr Spectral Coexistence Algorithm

- CRo blind senses multi-band comm signals
- CRo communicates vacant band information to the CRr
- CRr chooses the lowest interference sub-bands for transmission



Spectral Coexistence via Xampling (SpeCX) Prototype

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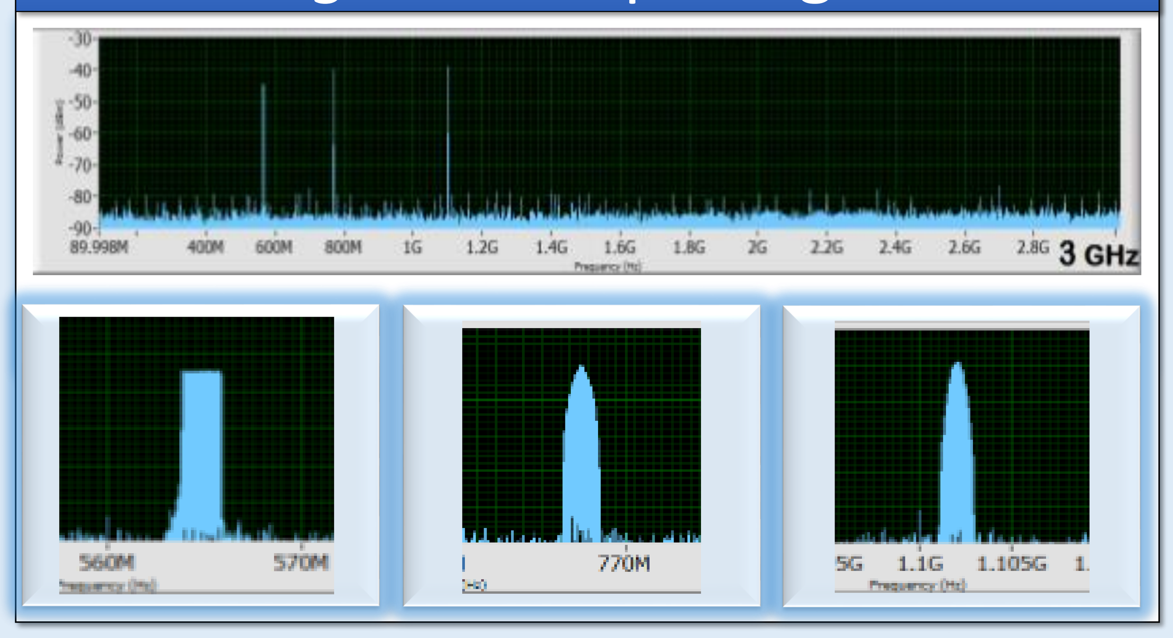
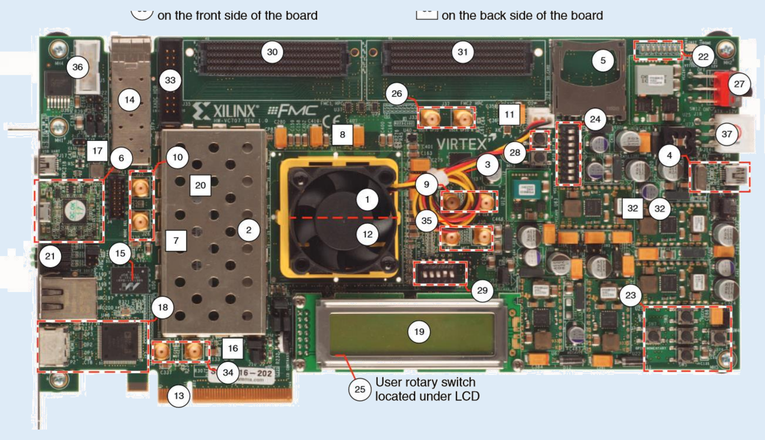
Cognitive Radio (CRo) Prototype

High Rate Input Signal



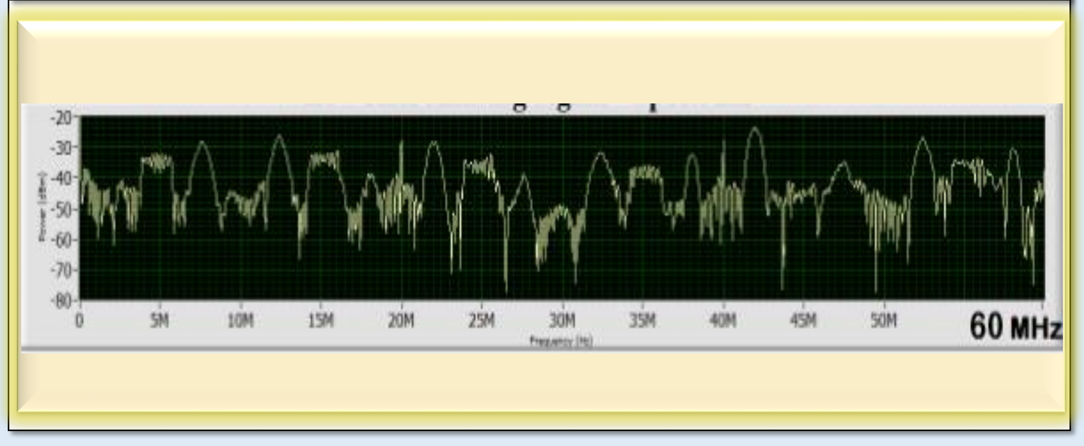
FPGA Series Generator

$p_i(t)$



XILINX FPGA – VC707

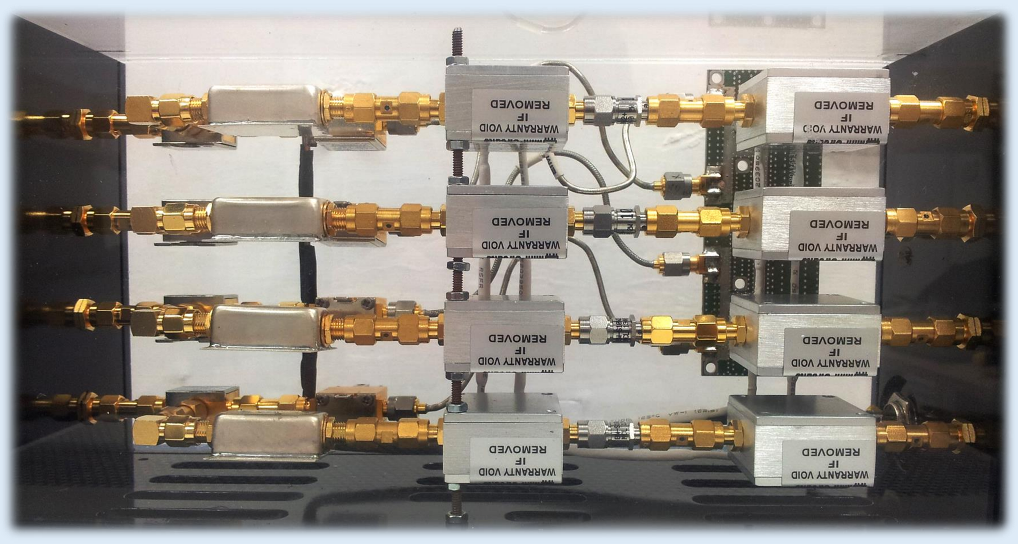
Low Rate Aliased Signal



Signal Generator

NI© USRP-2942R RF Generator

$x(t)$



The MWC Card

NI© PXIe-1065 with DC Coupled 4-Channel ADC

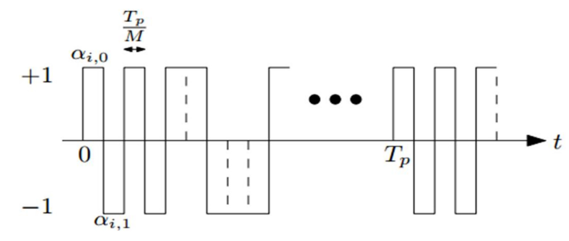
$y_i[n]$

Signal ADC + DSP

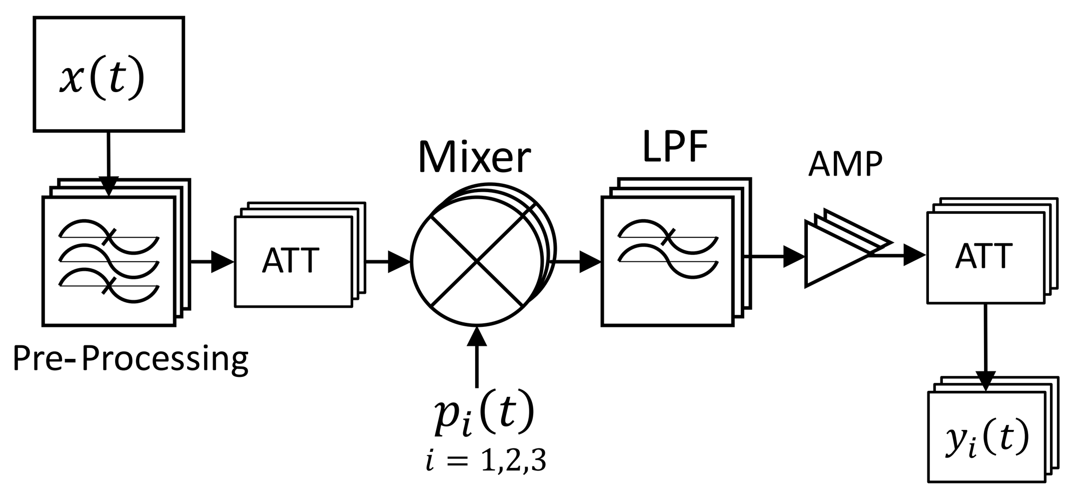
Mixing Series

- The mixing series are generated at high rate and alias the signal's bands to baseband.
- Alternate between ±1 at rate 6.1GHz.
- Generated using XINLINX VC707 FPGA

$p_i(t)$
$i = 1,2,3$



Analog Design

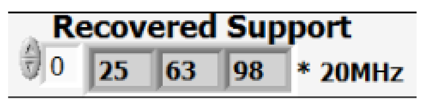


Digital Support & Signal Recovery

- The transfer matrix **A** is produced by the calibration procedure.
- The Orthogonal Matching Pursuit (OMP) algorithm is used to detect the transmitted signal carriers.
- the signal slices are then reconstructed by inverting the matrix A reduced to the recovered support:

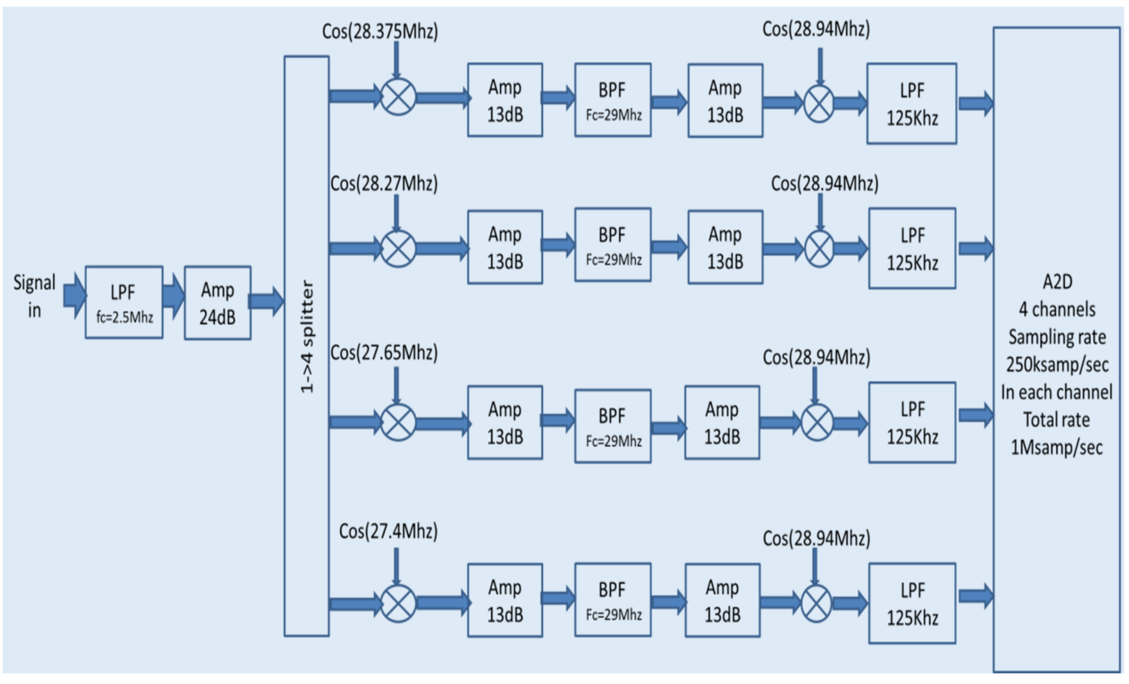
$$\mathbf{y}[n] = \mathbf{A}\mathbf{z}_S[n] \implies \boxed{\hat{z}_S(f) = \mathbf{A}_S^{\dagger}\mathbf{y}(f)}$$

- Support recovery and reconstruction occurs in real time



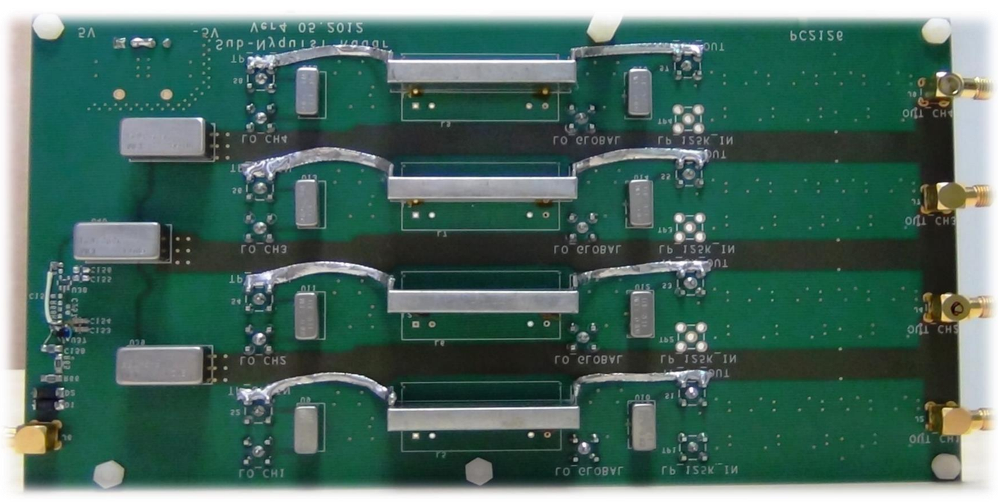
Cognitive Radar (CRr) Prototype

System Design



Multi-channel design for 4 transmit subbands

Pulse Analog Xampler



Features:

- Input signal BW< 150MHz
- Crystal filter BW 70KHz
- Modular and flexible design Dynamic range 65dB

Supporting Hardware – NI System

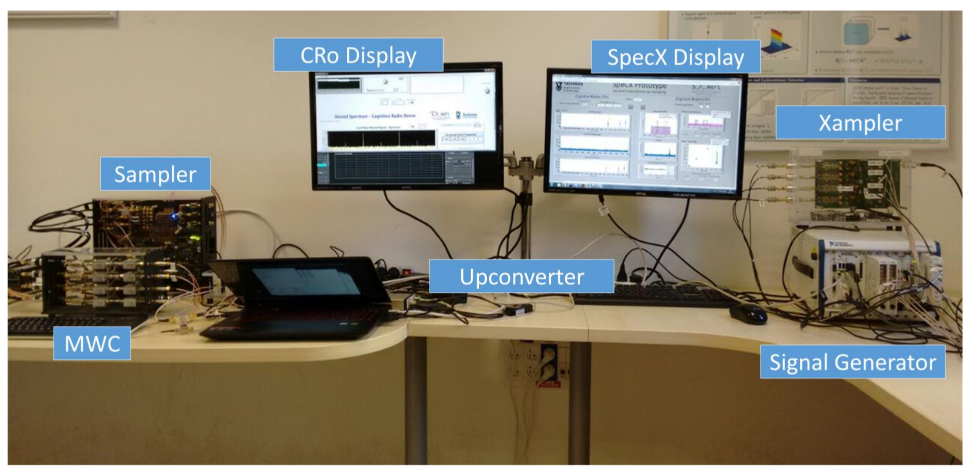
NI 8133 I7 controller Runs AWR | NI 5451 Arbitrary Waveform Generator | NI 5690 RF amplifier | NI 6123 4 channels ADC, 250 KSps | NI 4130 Power supply to Pulse Xampler

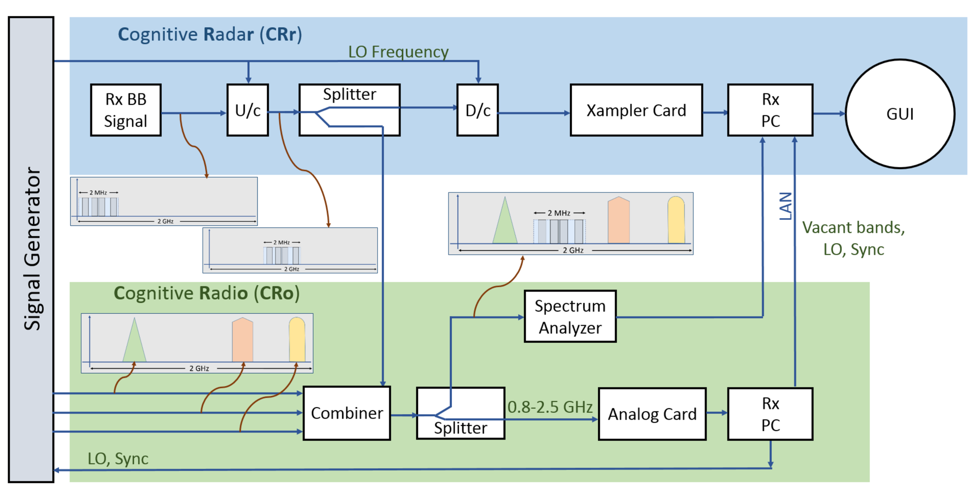
System Challenges:

- Start all devices at the same time with skew less then 1 ns
- Good synchronization- Low clock jitter and small clock drifts between devices

SpeCX Prototype and Measurement Results

Prototype

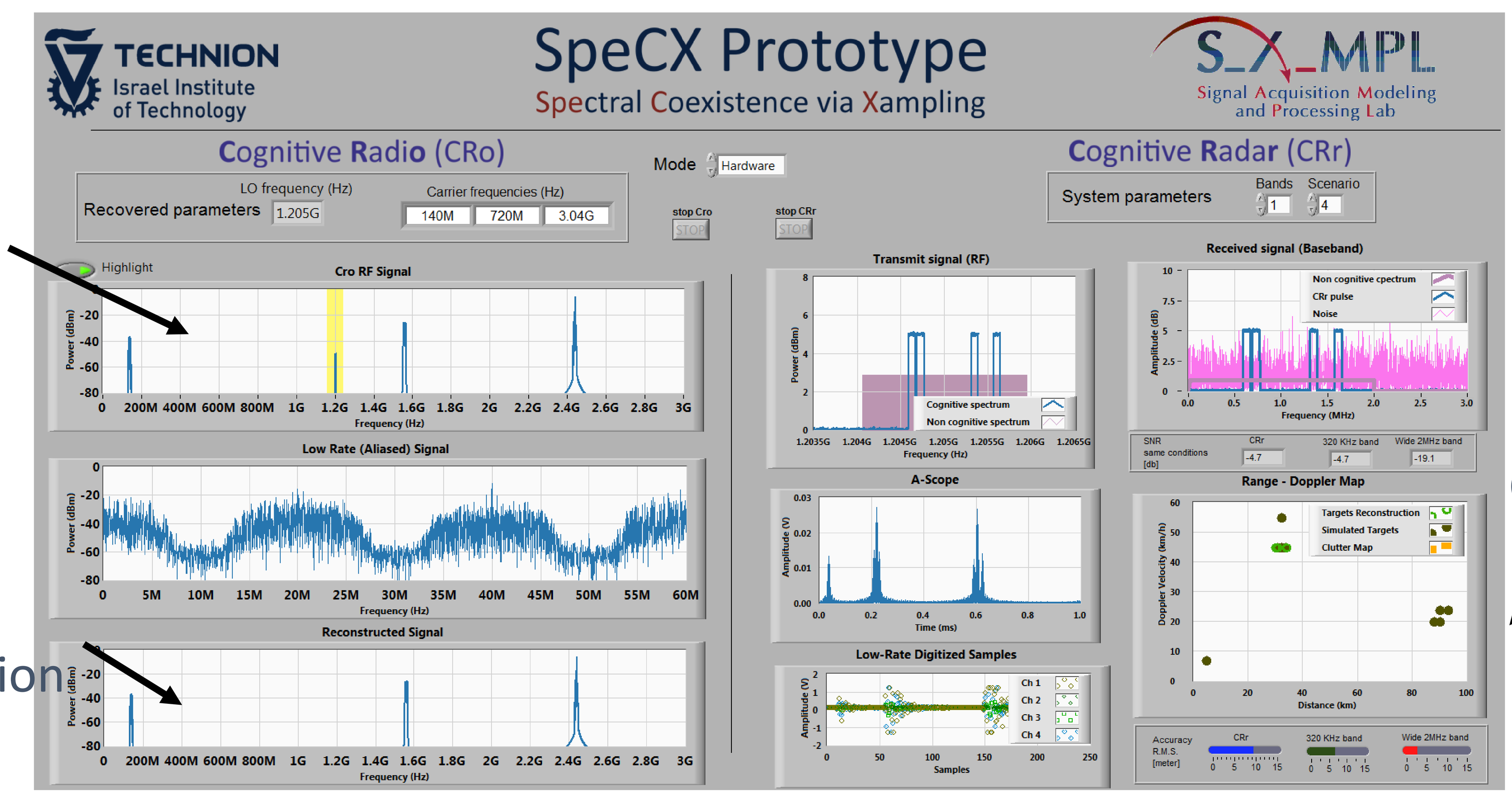




Measurement Results

CRo+CRr Input Signal

CRo Reconstruction



CRr Detections