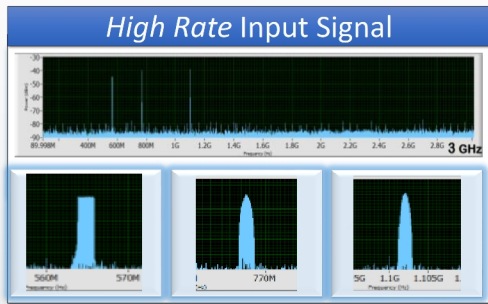


# Sub-Nyquist Cognitive Radio System

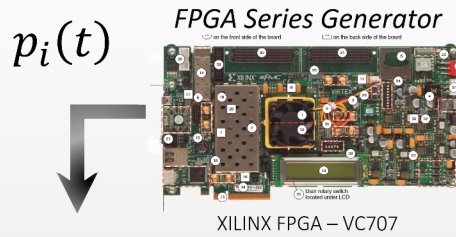
Etgar Israeli, Shahar Tsiper, Deborah Cohen, Eli Shoshan, Rolf Hilgendorf, Yonina C. Eldar



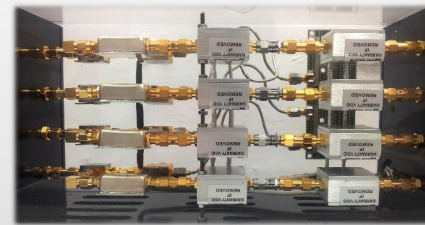
Signal Generator



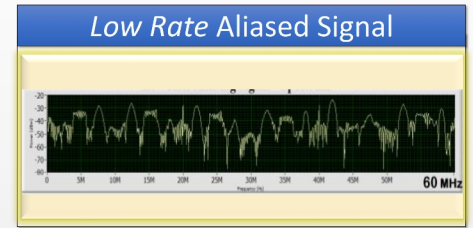
NI® USRP-2942R RF Generator



XILINX FPGA – VC707



The MWC Card



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

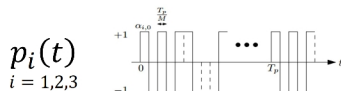


$y_i[n]$

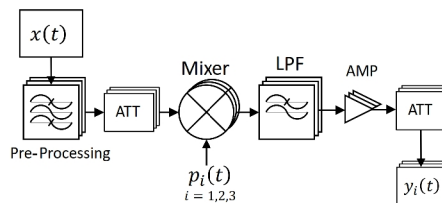
Signal ADC + DSP

## Mixing Series

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



## Analog Design



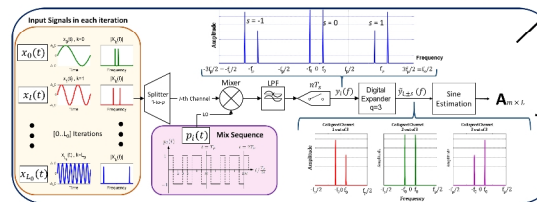
## Digital Support & Signal Recovery

- The transfer matrix  $\mathbf{A}$  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  $\mathbf{A}$  reduced to the recovered support:
- $$\mathbf{y}[n] = \mathbf{A}\mathbf{z}[n] \Rightarrow \hat{\mathbf{z}}_s(f) = \mathbf{A}_s^\dagger \mathbf{y}(f)$$
- Support recovery and reconstruction occurs in real time

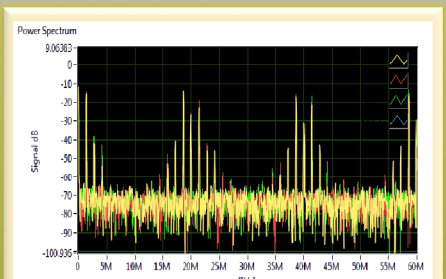


## The Calibration Process

- The calibration process estimates the transfer function of the system, the matrix  $\mathbf{A}$ .
- In the  $l$ -th step, a sine wave is injected to the system:
 
$$x_l(t) = \beta_0 \sin(2\pi(f_p l + f_0)t)$$
- To recover the skewed coefficients of the expander we use linear combinations of the output samples.
- An estimation technique recovers the coefficients of the transfer matrix  $\mathbf{A}$ .
- Least Squares (Trust Region method) minimizes the error according to:
 
$$[\hat{\beta}_0, \hat{\varphi}_0] = \arg \min_{\beta', \varphi'} \|\tilde{\Psi}_n - \beta' \sin(2\pi f_0 n + \varphi')\|^2$$

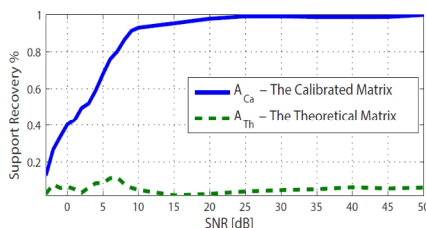


The autonomous calibration process flow chart.

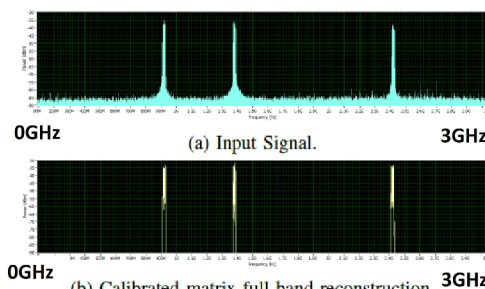


The Modulation of an input signal with  $T_p$  periodic series  $p_i(t)$  at the mixer's LO input, adds additional redundant harmonics to the output mixed signal  $y[n]$ . When inserting sinusoid waves at rate  $k f_p + f_0$ , additional harmonics are present at  $f = m_1 f_p \pm m_2 f_0, m_1, m_2 \in \mathbb{Z}$

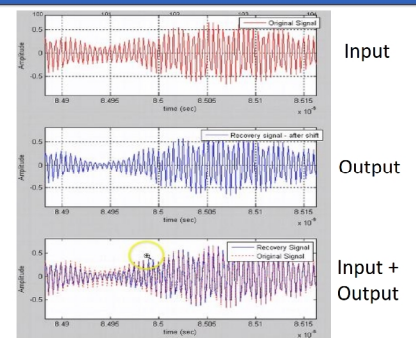
## Results



Hardware reconstruction success percentage of the calibrated matrix  $\mathbf{A}_{calibrated}$  vs. the theoretical  $\mathbf{A}_{Theory}$ .



Correct support detection of the input signal, and full reconstruction, in frequency domain.



Full reconstruction in time domain

## References

- Mishali, M., & Eldar, Y. C. (2010). From theory to practice: Sub-Nyquist sampling of sparse wideband analog signals. *Selected Topics in Signal Processing, IEEE Journal of*, 4(2), 375-391.
- Cordeiro, Carlos, et al. "IEEE 802.22: the first worldwide wireless standard based on cognitive radios." *New Frontiers in Dynamic Spectrum Access Networks, 2005. DySPAN 2005. 2005 First IEEE International Symposium on*. IEEE, 2005.

## Contact Us

- |               |                          |            |
|---------------|--------------------------|------------|
| Etgar Israeli | setgar@t2.technion.ac.il | (Technion) |
| Shahar Tsiper | tsiper@technion.ac.il    | (Technion) |
| Yonina Eldar  | yonina@ee.technion.ac.il | (Technion) |