A Computationally Efficient Multi-coset Wideband Radar ESM Receiver

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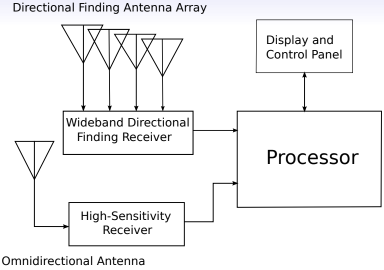
Electronic Support Measures (ESM)



- **Task:** detecting all RF emitters to identify the presence of threats.
- It has a **passive** monitoring system.
- While ESM signals are **very dense**, *e.g.* can be hundreds of thousands of pulses per second, they have **very sparse** TF representations.
- ESM systems can be noise limited, rather than sparsity limited.

Conventional Techniques for ESM Receivers

- **Instantaneous Frequency Measurements:** limited spectral sensitivity.
- **Rapid Frequency Sweeping** ADC's: limited temporal sensitivity.
- **Wideband Analog to Digital Converters**: need multi GHz ADC's.
- **Proposal: Sub-Nyquist Analog to Information Converter**.

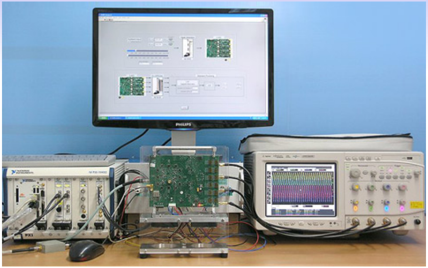
Sub-Nyquist Sampling

- **Why?**
  1. Sampling at the rate of Nyquist is **difficult** or **costly** in some applications, *e.g.* Wideband ADC's and Wideband Digital Receivers.
  2. It is a **waste of resources**, if we sample at a rate, much higher than the information rate.
  3. An **application specific** sampling strategy, *i.e.* exploring signal structures.
- **How?**
  1. Using underlying signal structures, *e.g.* sparsity.
  2. Incorporating non-uniform sampling (random?) in the sensing framework.
  3. Non-linear reconstruction of signals.

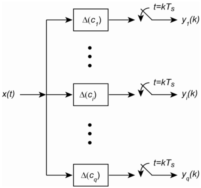
Sub-Nyquist Sampling, cont

- **Challenges?**
  1. *Analog Hardware*: How efficiently can we design the analog part?
  2. *Computational Complexity*: How efficient can we implement the non-linear recovery algorithm?
  3. *Noise Sensitivity*: Sensitivity to the input noise?
  4. *Robustness*: How much the sub-Nyquist algorithm is sensitive to the **signal model mismatch** and **circuit design tolerances**.

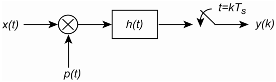
Sub-Nyquist Sampling Techniques



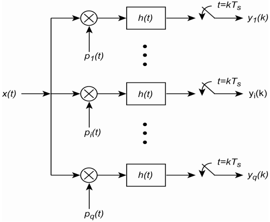
Technion Modulated Wideband Convertor Demonstrator



Multi-coset Sampling
(Feng&Bresler 1996)



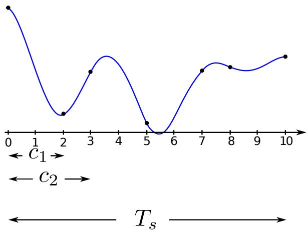
Random Demodulator
(Triopp et al. 2007)

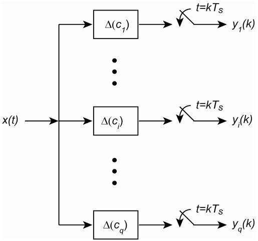


Modulated Wideband Convertor
(Mishali and Eldar 2010)

Multi-coset Sampling Framework

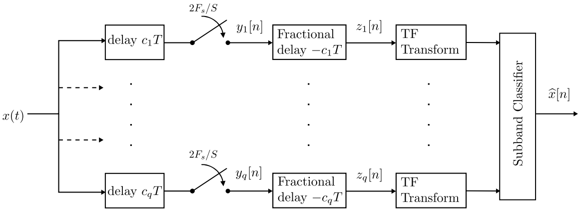
- **Non-uniform** sampling technique [Feng and Bresler, 1996].
- Sparse multiband signal model.
- A **subspace method** for reconstruction by Feng et al.
- A **convex optimisation** problem for reconstruction by [Mishali and Eldar 2009].





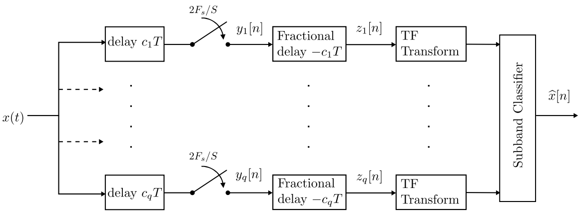
Proposed Sub-Nyquist Sampling Framework

- A Multi-coset sampling strategy.
- Avoiding any complicated operations *e.g.* SVD, ℓ_1 minimisation.
- The signal model has to fit into the ESM.

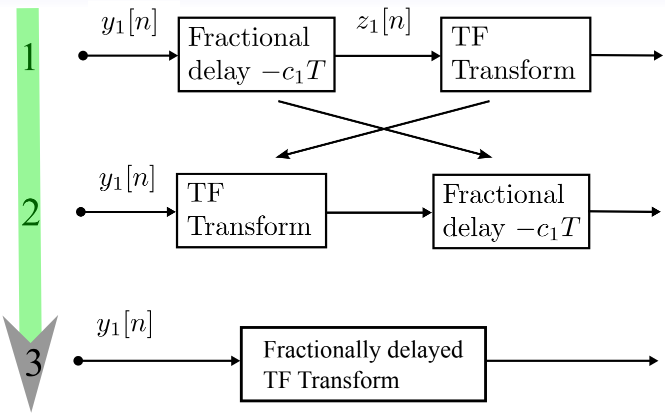


Components of Proposed Framework

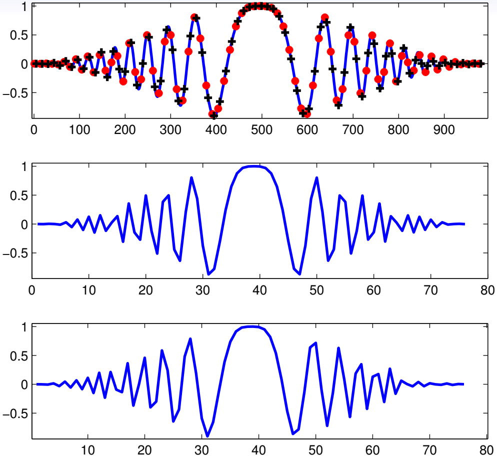
- *A bank of multi-coset channels:* it has distinguished delays.
- *Digital Fractional Delay (DFD) filters*.
- *Time-Frequency transform:* STFT has currently been used.
- *Subband Classifier:* Composed of a linear operator (Harmonic Frame), followed by a simple maximum-absolute value operator.



Digital Fractional Delay Implementation

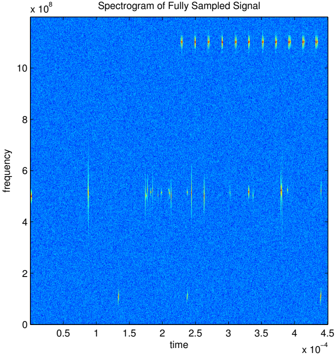


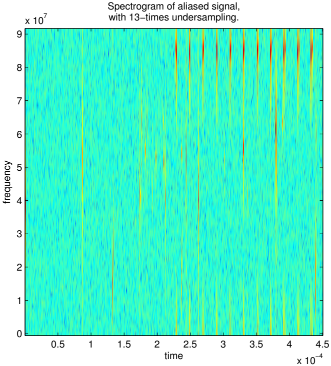
Discretisation of Time-Frequency Kernel



Assumptions and Properties

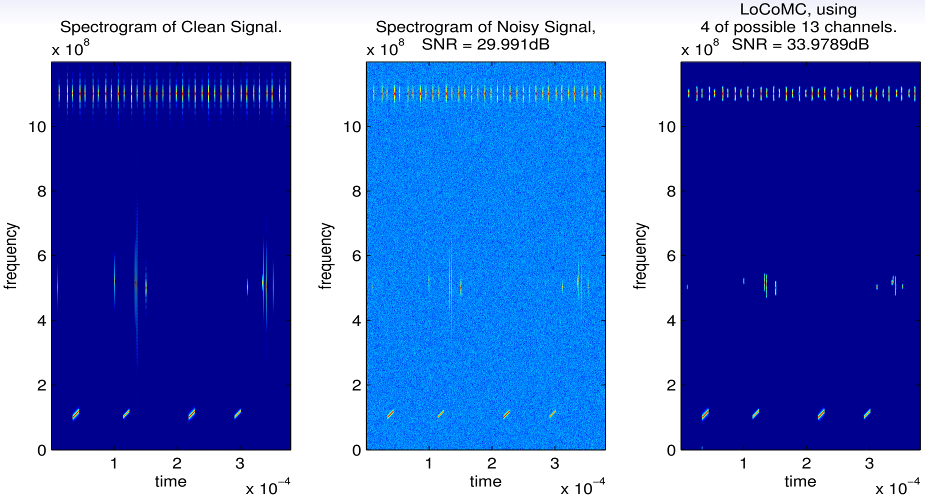
- **Approximate Disjoint Aliased Support:** different to sparsity.



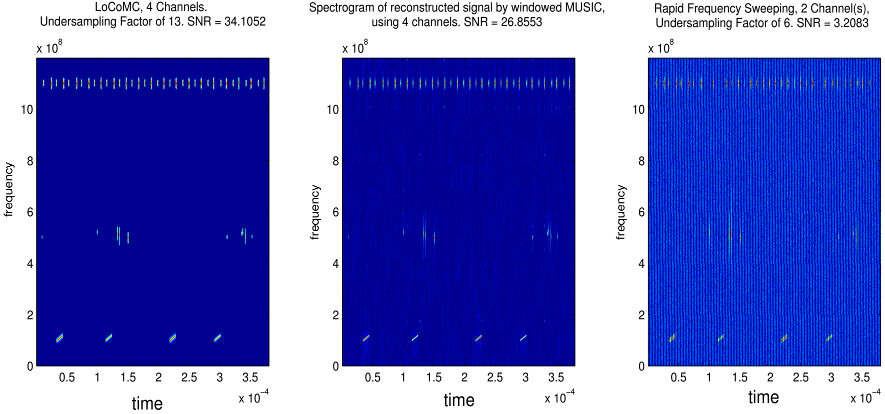


- **No random sampling:** optimal delay parameters from a Harmonic Equiangular Tight Frame (HETF).
- **No DFD filter:** absorption into TF transform.

Evaluation with Radar ESM signals

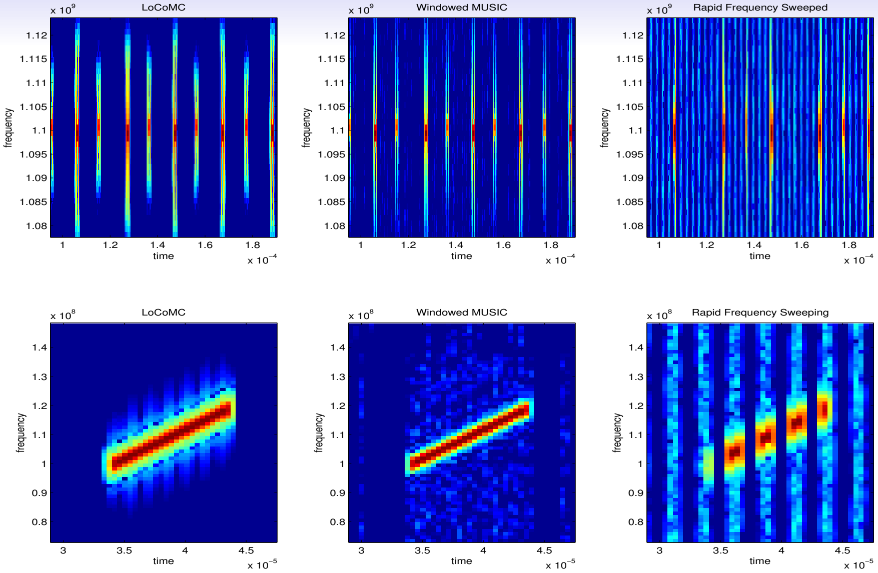


Comparison with Other Methods



- Two overlapping ADC's with 1/6 of Nyquist sampling rate for RFS method.

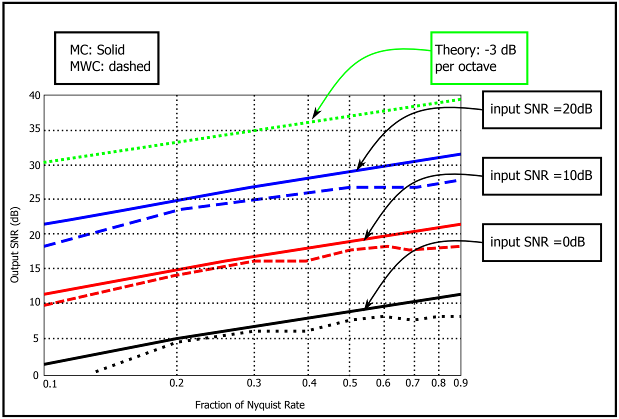
Comparison with Rapid Frequency Sweeping



LoCoMC at a Glance:

- **Pros:**
  - **Non-iterative**: it may be pipelined.
  - Can use only **a few** Multi-coset channels, *e.g.* as few as $q = 2$.
  - Uses a different signal model, *i.e.* **ADAS**, which matches well to some classes of signals, *e.g.* ESM.
  - **Large Dynamic Range**, *e.g.* 70 dB, which makes it suitable for the low probability of intercept signals.
  - **Continuously monitoring** wideband RF signals, in a contrast with the rapid frequency sweeping technique.
- **Cons:**
  - **Noise folding:** 3 dB processing gain loose per octave. A characteristic of sub-Nyquist sampling techniques.
  - Needs a **Fast** "sampler". The "holder/tracker" can be slow.

Noise Folding in Sub-Nyquist Sampling



Conclusion and Future Work

- **Conclusion:**
  - A low SWAP algorithm for radar ESM receiver.
  - Exploring parsimonious structure of ESM signals.
  - When ESM signals are ADAS, the signal recovery is guaranteed.
  - Outperforms the MUSIC recovery algorithm in the given ESM signals.
- **Future work:**
  - An optimal TF transform to maximise coherent processing gain.
  - Sensitivity and robustness analysis.
  - Pulse descriptor word extraction.
  - Designing Hardware Demonstrator.

Thanks for your attention.