An Efficient Implementation of the Low-Complexity Multi-Coset Sub-Nyquist Wideband Radar Electronic Surveillance

Mehrdad Yaghoobi, Bernard Mulgrew and Mike E. Davies
Edinburgh Research Partnership in Signal and Image Processing
Institute for Digital Communications,
The University of Edinburgh

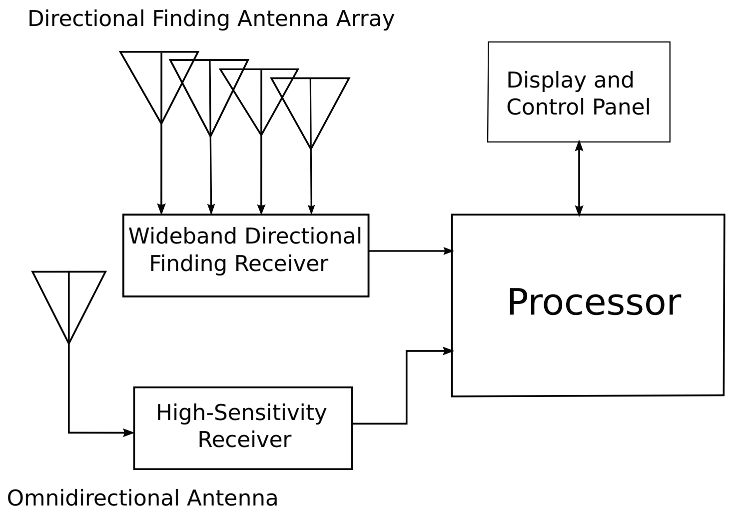
SSPD, Edinburgh, 9 September, 2014

THE UNIVERSITY OF EDINBURGH

UDRC

EPSRC
Engineering and Physical Sciences Research Council

Electronic Surveillance (ES)



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

Conventional Radar ES 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**.

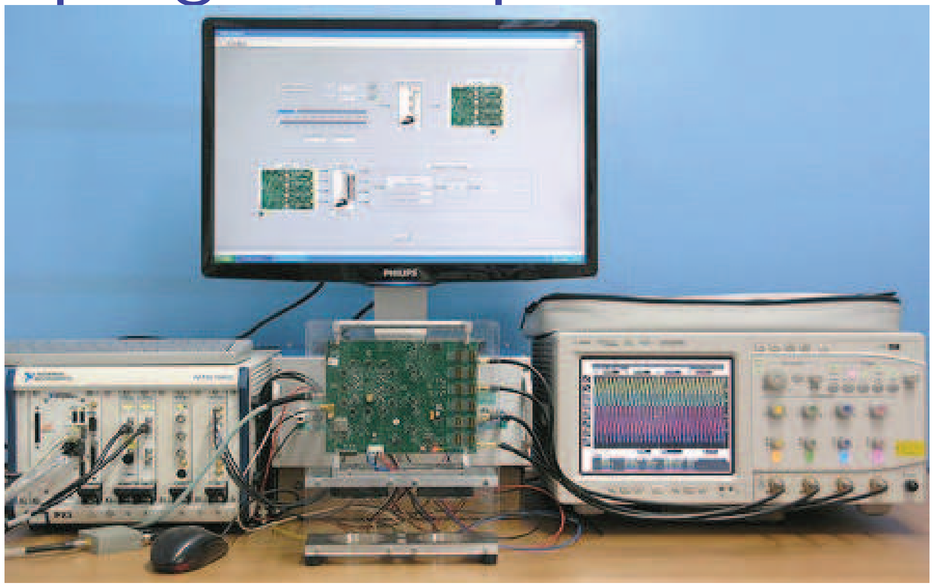
Sub-Nyquist Sampling

- **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.

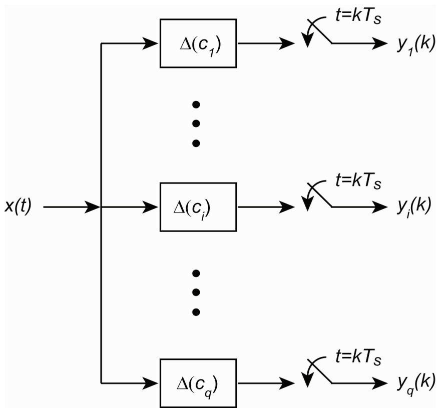
Sub-Nyquist Sampling, cont

- **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**.

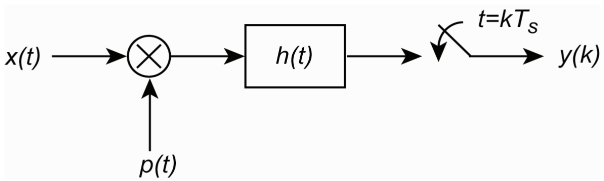
Sub-Nyquist Sampling Techniques



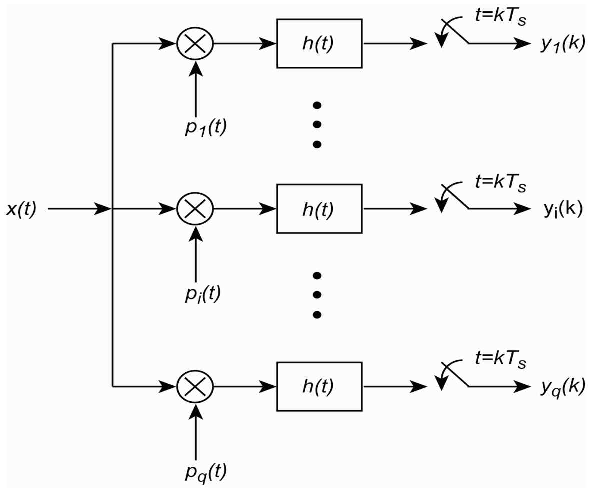
Technion Modulated Wideband Convertor Demonstrator



Multi-coset Sampling
(Feng&Bresler 1996)



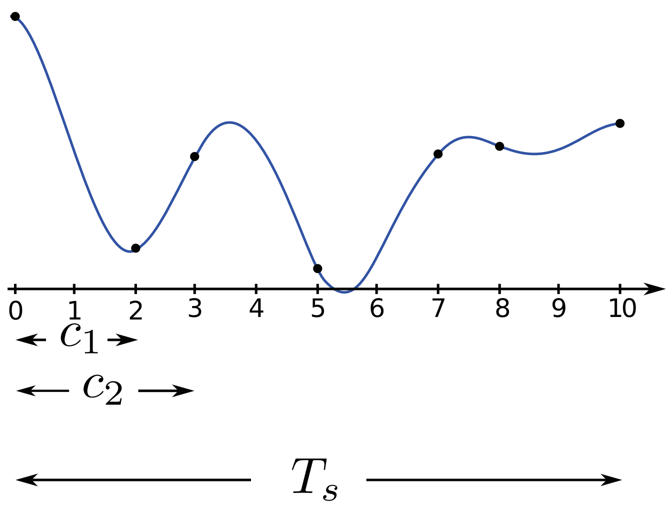
Random Demodulator
(Triopp et al. 2007)

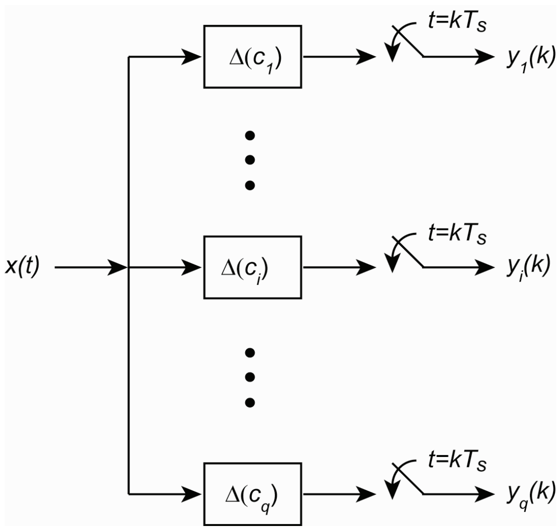


Modulated Wideband Convertor
(Mishali and Eldar 2010)

Multi-coset Sampling Framework

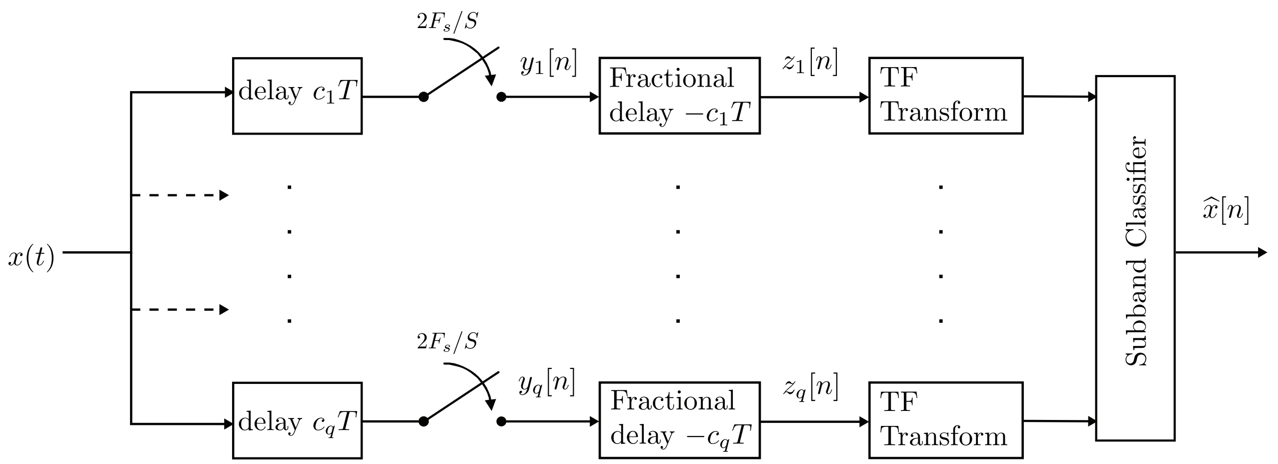
- **Non-uniform** sampling technique [Feng and Bresler, 1996].
- Sparse multiband signal model.
- A **subspace method** for reconstruction by Feng et al.
- A **convex optimisation** problem for reconstruction by [Mishali and Eldar 2009].





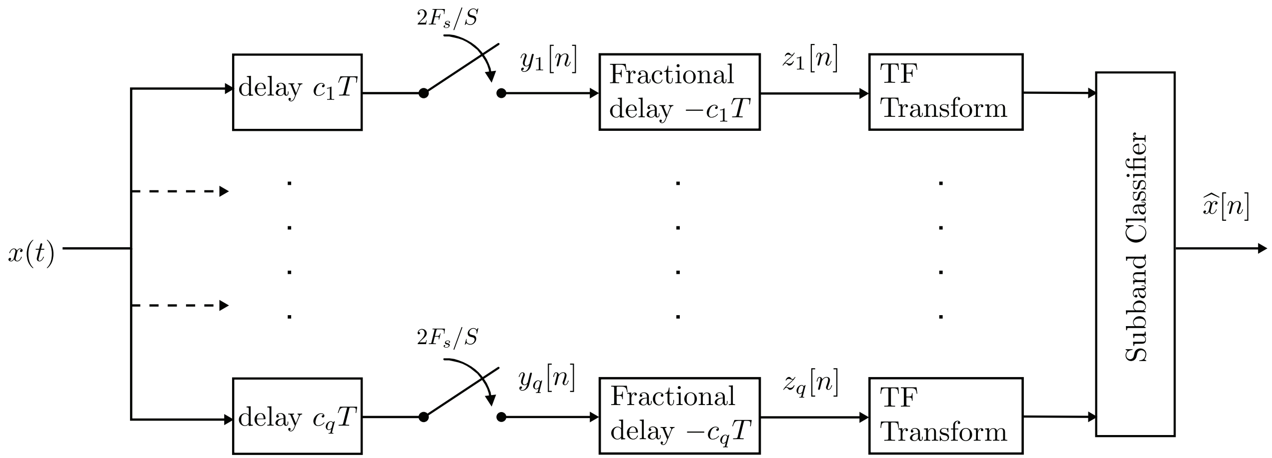
Proposed Sub-Nyquist Sampling Framework

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

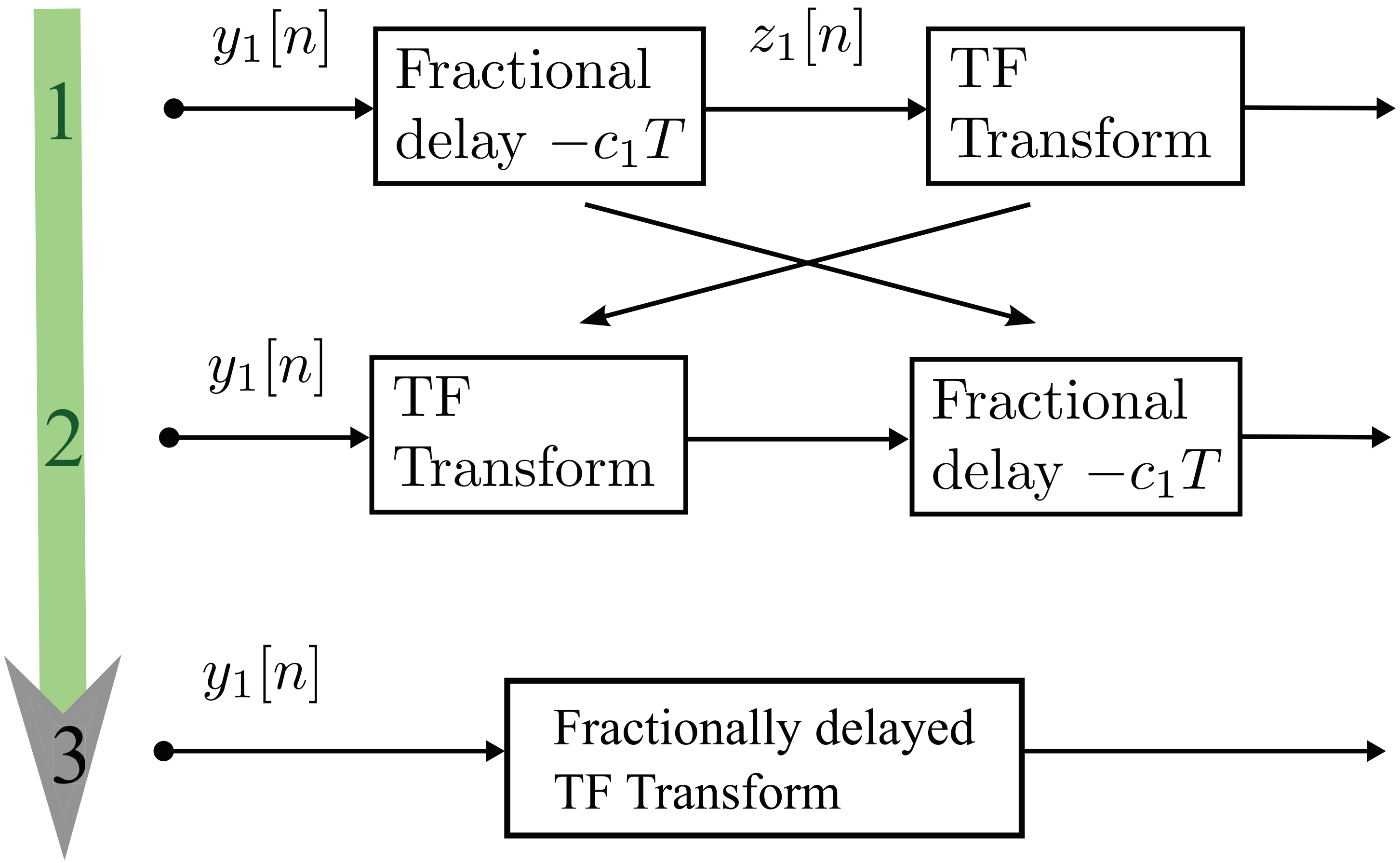


Components of Proposed Framework

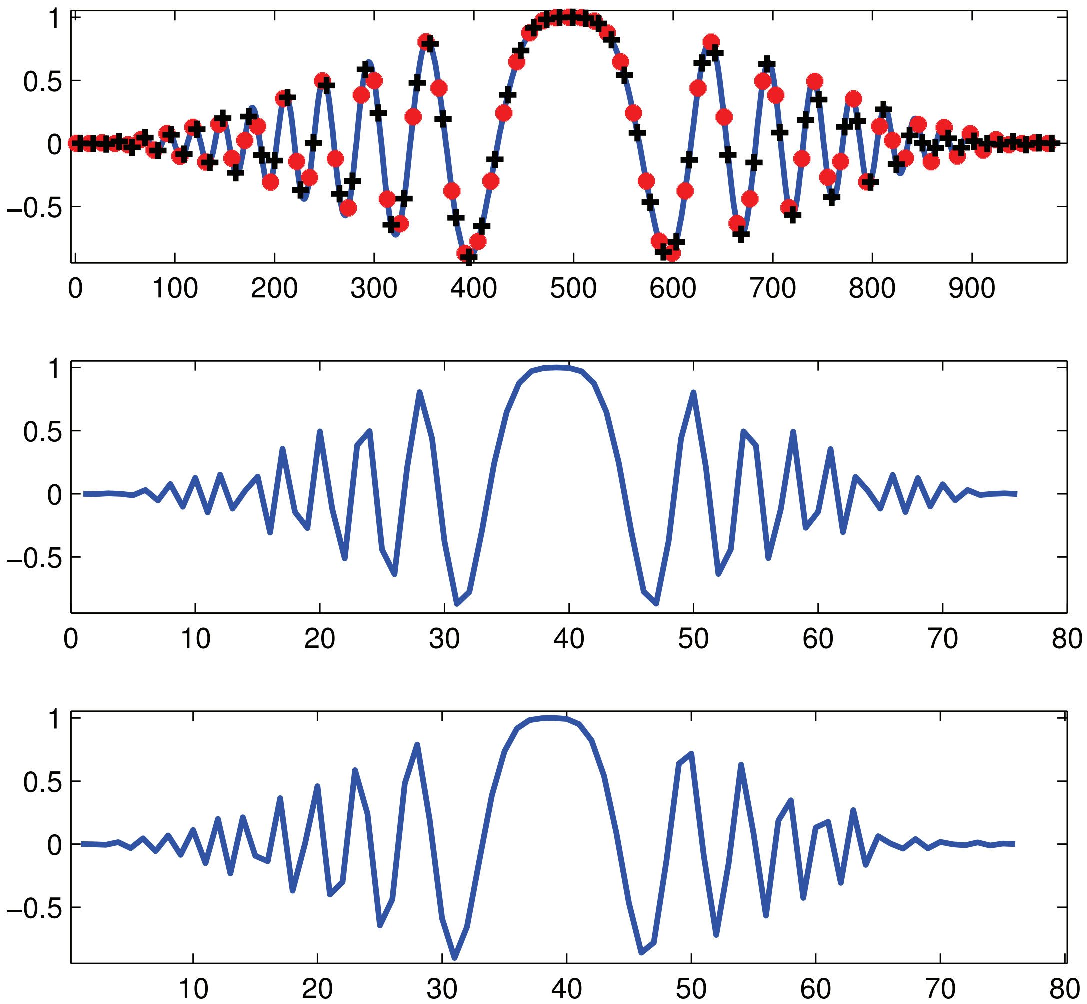
- *A bank of multi-coset channels:* it has distinguished delays.
- *Digital Fractional Delay (DFD) filters.*
- *Time-Frequency transform:* STFT has currently been used.
- *Subband Classifier:* Composed of a linear operator (Harmonic Frame), followed by a simple maximum-absolute value operator.



Digital Fractional Delay Implementation

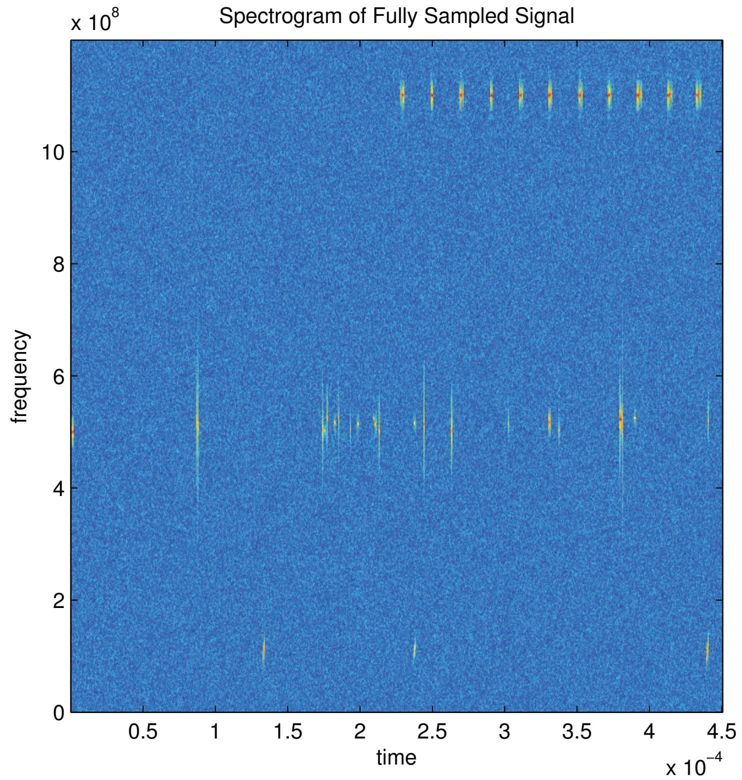


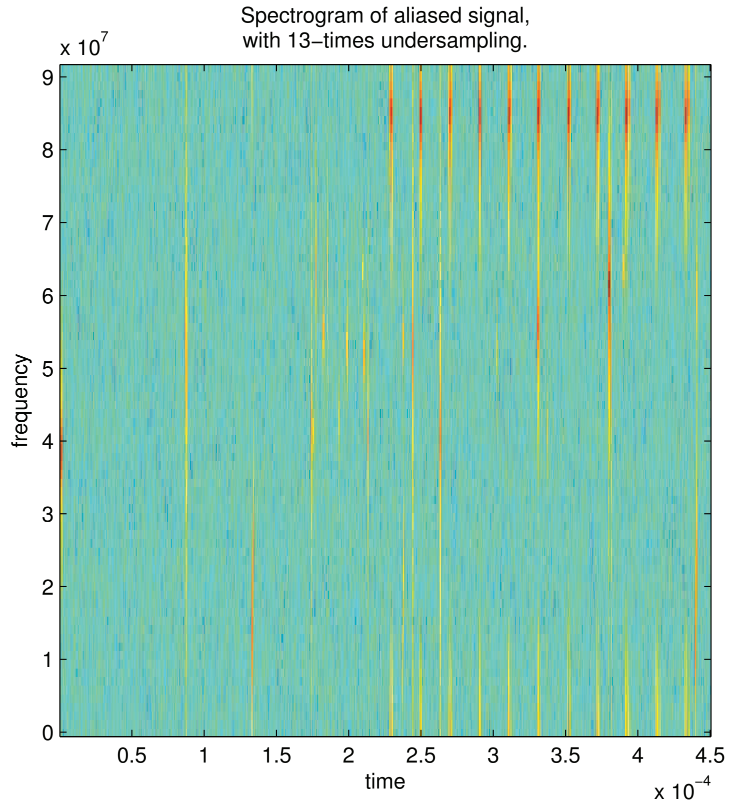
Discretisation of Time-Frequency Kernel



Assumptions and Properties

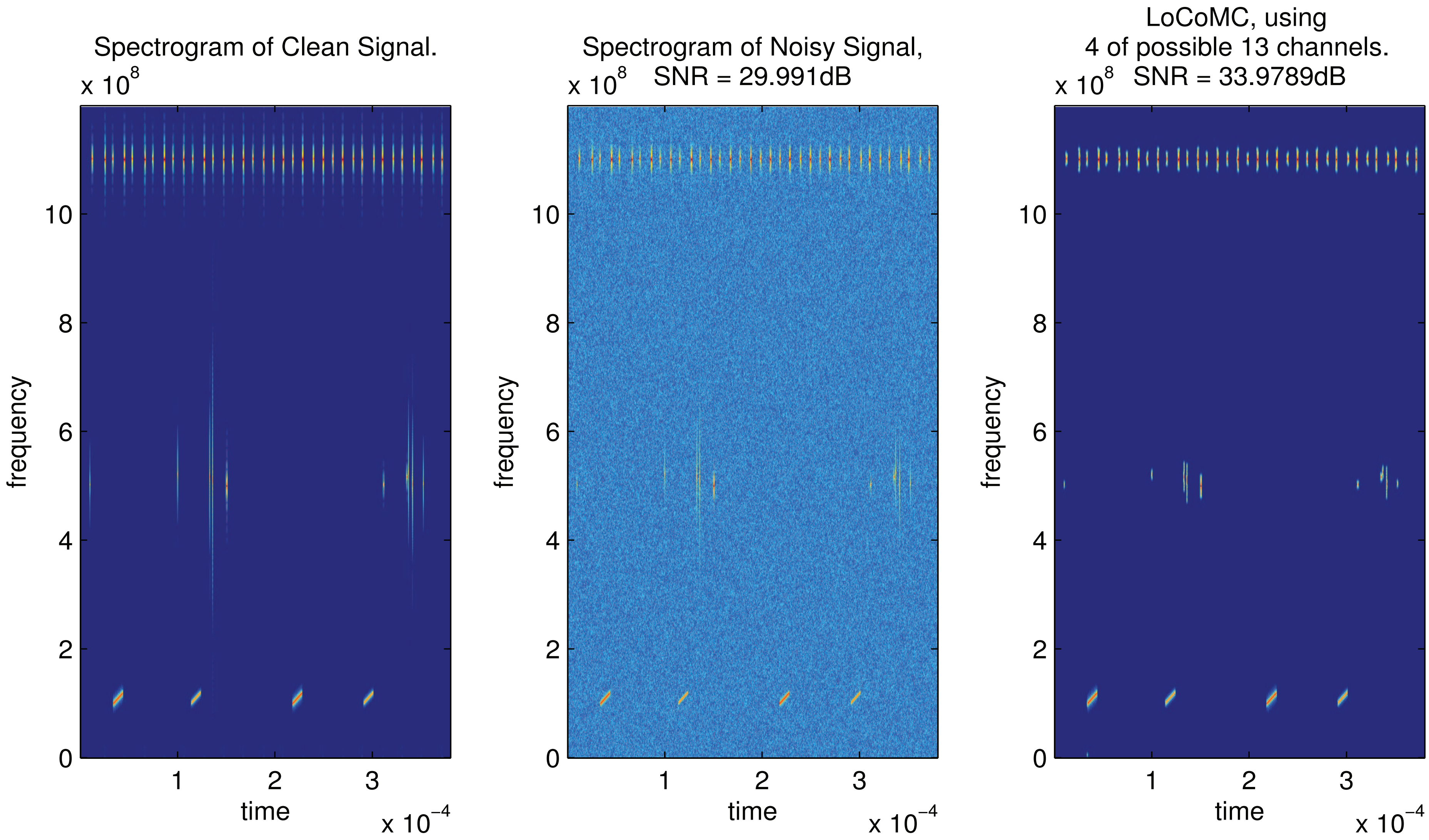
- **Approximate Disjoint Aliased Support:** different to sparsity.



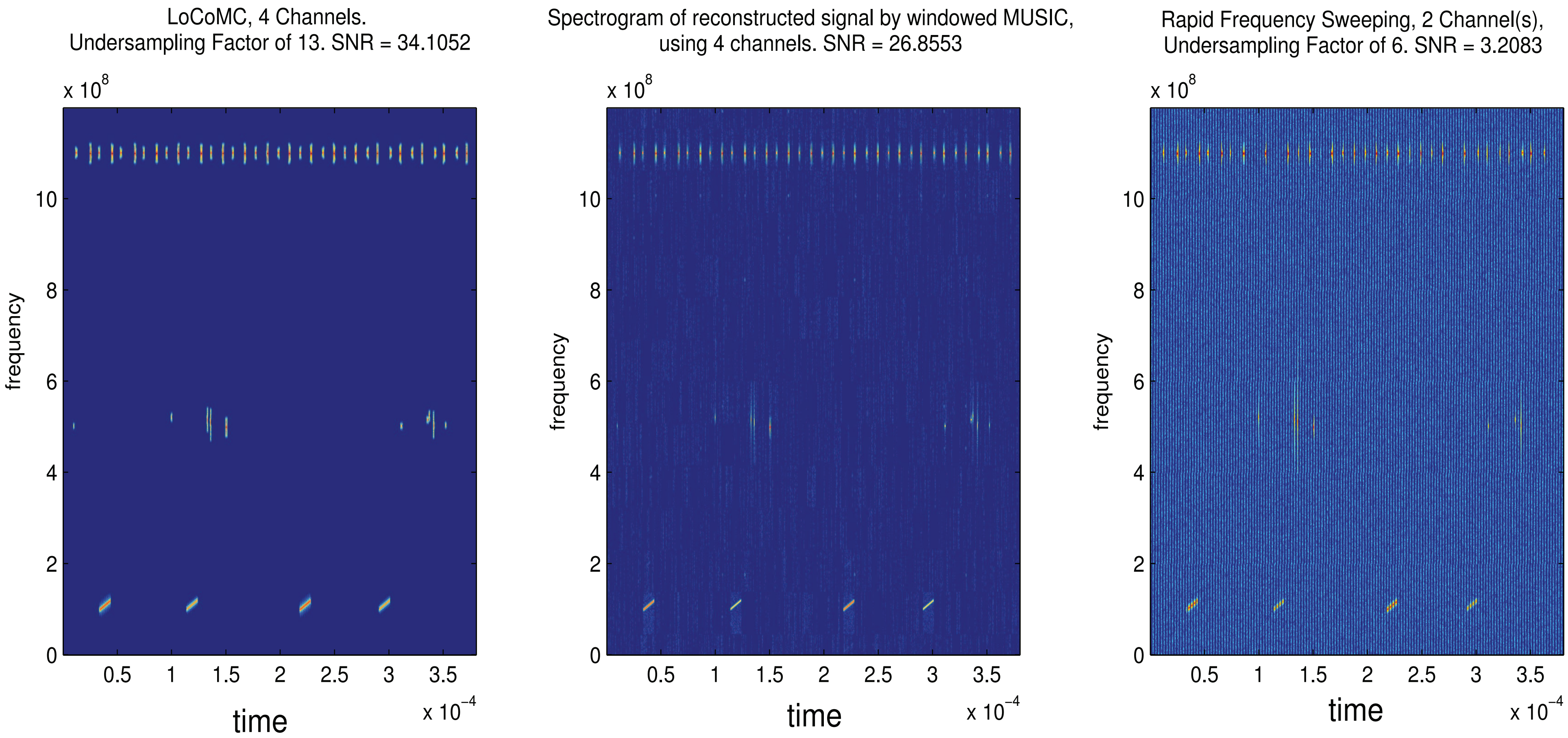


- **No random sampling:** optimal delay parameters from a Harmonic Equiangular Tight Frame (HETF).
- **No DFD filter:** absorption into TF transform.

Evaluation with Radar ES signals

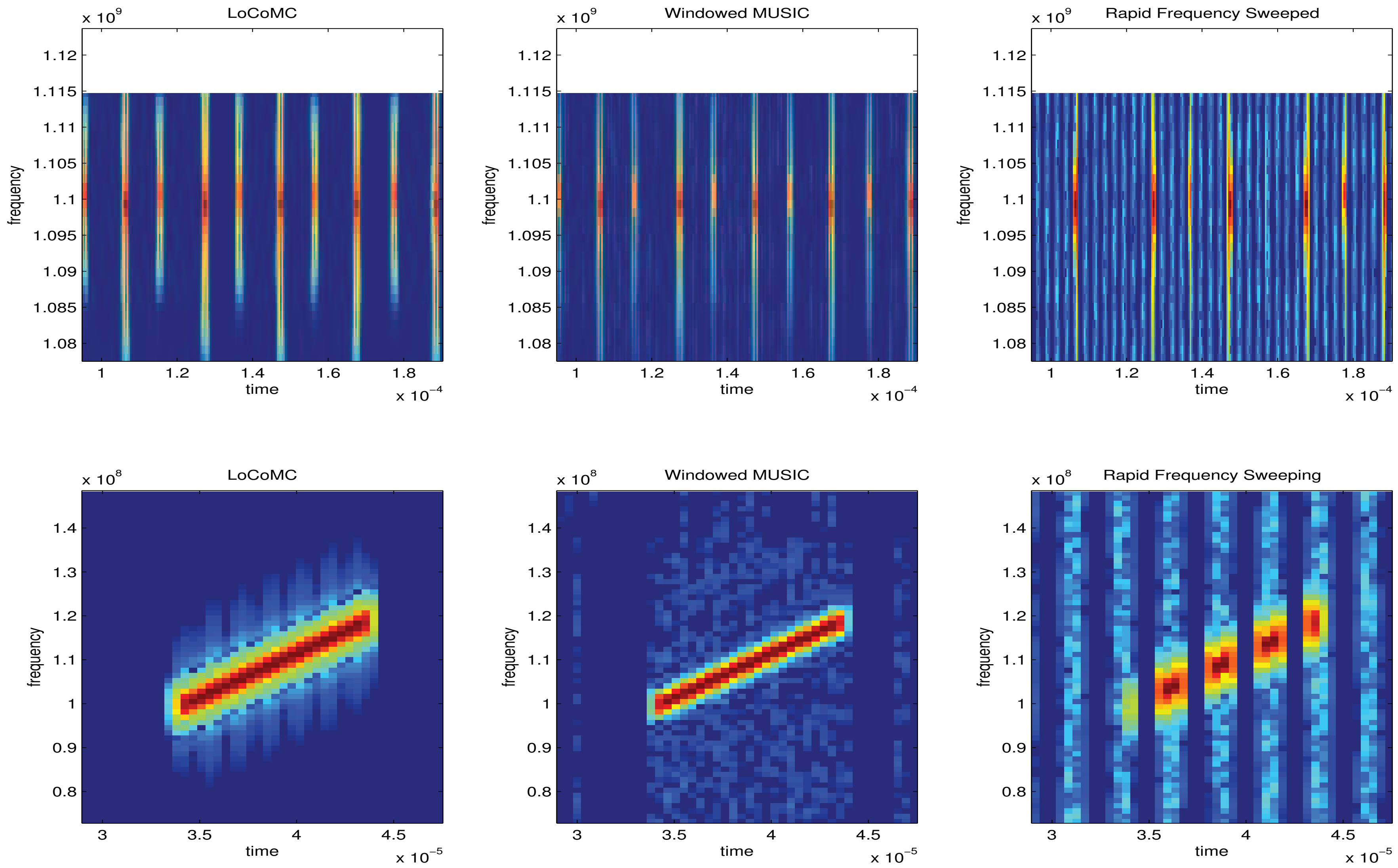


Comparison with Other Methods



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

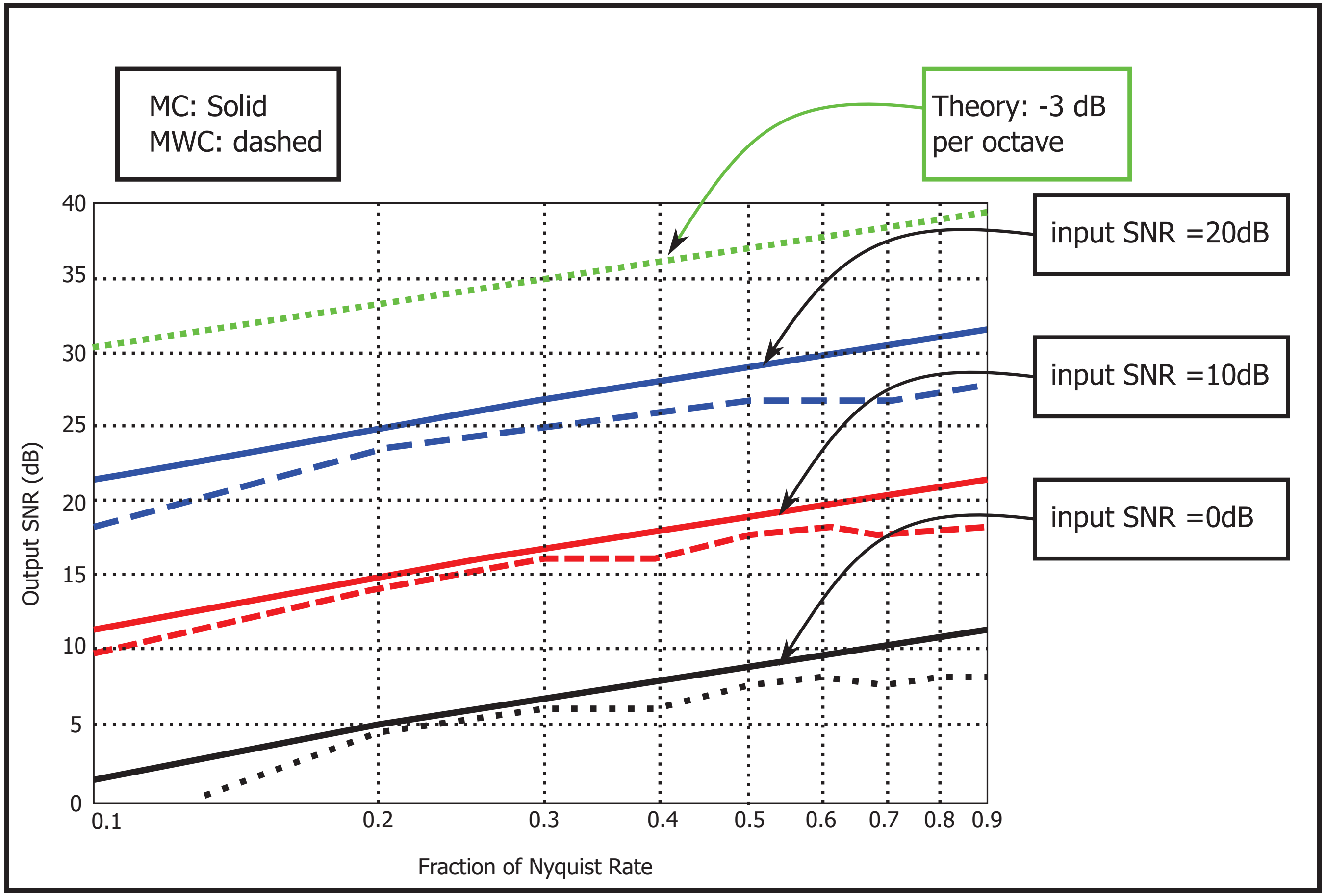
Comparison with Rapid Frequency Sweeping



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.* Radar ES.
  - **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:**
  - Needs a **Fast** "sampler". The "holder/tracker" can be slow.
  - **Noise folding:** 3 dB processing gain loose per octave. A characteristic of sub-Nyquist sampling techniques.

Noise Folding in Sub-Nyquist Sampling



Conclusion and Future Work

- **Conclusion:**
  - A low SWAP algorithm for Radar ES receiver.
  - Exploring parsimonious structure of ES signals.
  - When ES signals are ADAS, the signal recovery is guaranteed.
  - Outperforms the MUSIC recovery algorithm in the given ES signals.
- **Future work:**
  - CFAR analysis for parameter selection.
  - Pulse descriptor word extraction.
  - Sensitivity and robustness analysis.

We gratefully acknowledge the support from:

UDRC

EPSRC
Engineering and Physical Sciences
Research Council

THALES

Thanks for your attention.