Advanced Radar Signal Processing & Information Extraction

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EPSRC
Engineering and Physical Sciences Research Council

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**Jianlin Cao, **Yixin Chen, **Jamie Corr

** UDRC Affiliated

Acknowledge specific past PhD researchers:

Dr Amin Salleh, Dr Sherif Elgamel and Dr Ahmed Solymon, MTC.

2009-2013: EPSRC- Dstl(MOD) UK University Defence Research Centre (UDRC-I)

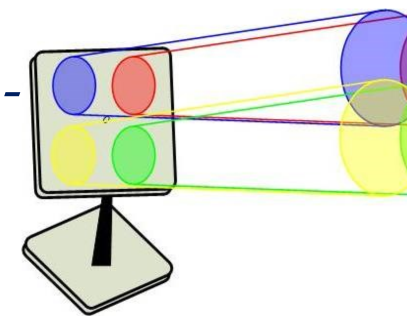
2013-2018: EPSRC-Dstl(MOD) University Defence Research Collaboration (UDRC-II)

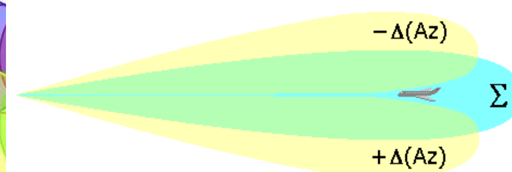
Presentation Overview

- Radar Signal Processing Challenges
- Signal Processing Methods
- Signal Processing Solutions for
    - SAR
    - Monopulse Radar Processors
    - Bistatic SAR Microdoppler Signal Analysis
- Moving Forward within the UDRC II

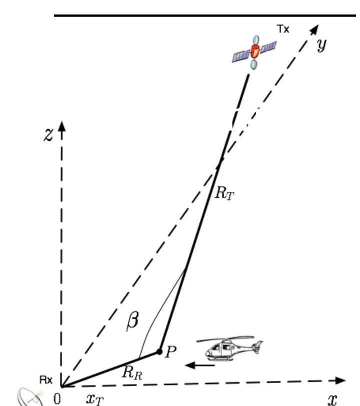
Radar Signal Processing Challenges

SAR Processing:-
High Resolution
SAR, MSAR, BistaticSAR





Monopulse Radar:-
Tgt Tracking
Anti-Jamming
Clutter Rejection

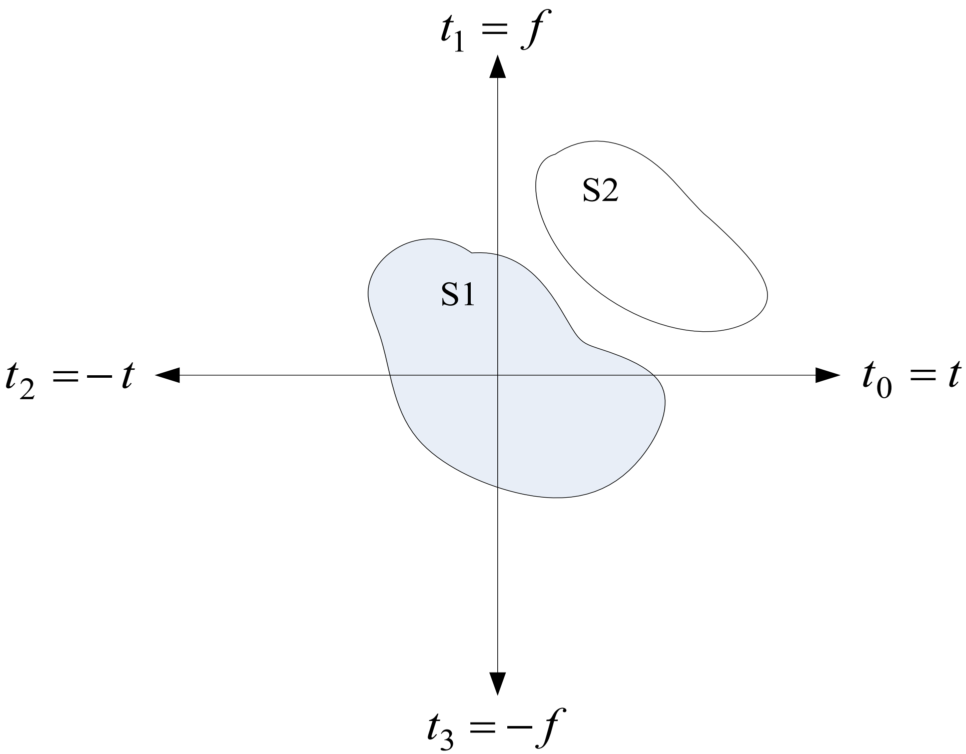


Microdoppler Analysis:-
Tgt Identification

Signal Processing Methods

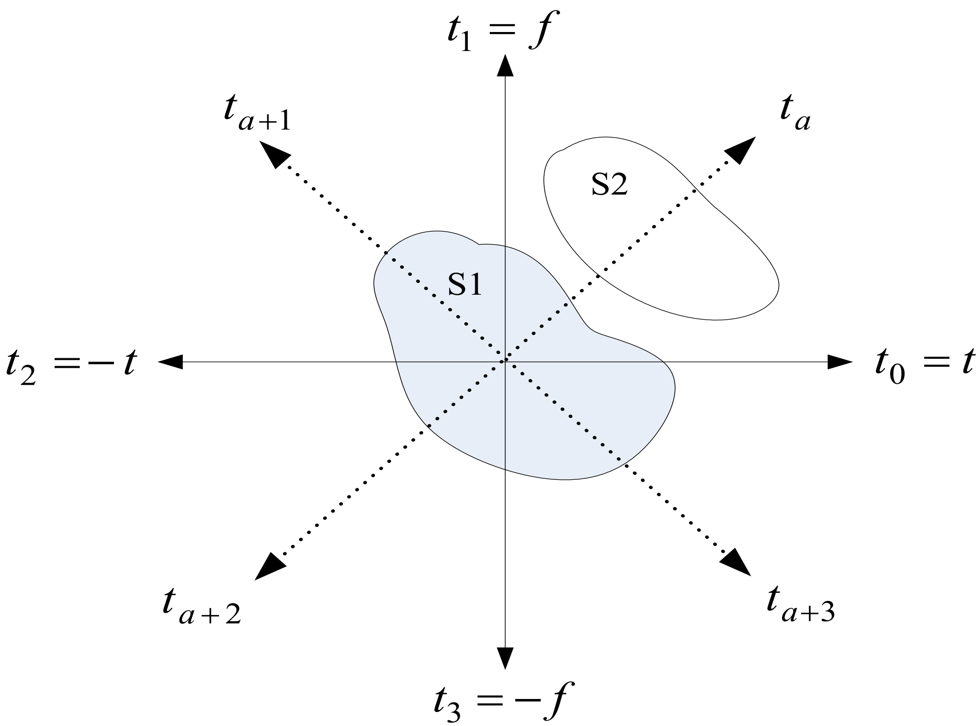
Fractional Fourier Transform (FrFT)	1994-optics
Empirical Mode Decomposition (EMD)	1998-Seismology
Singular Spectrum Analysis (SSA)	1997-Climatology

Fractional Fourier Transform (FrFT)



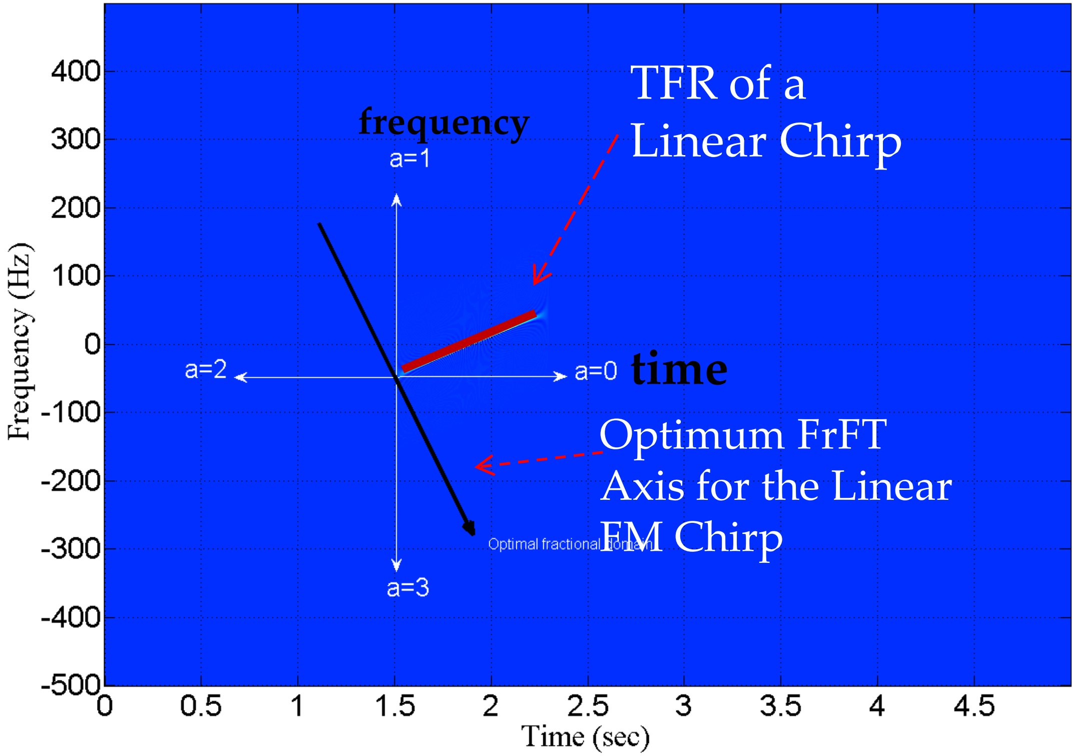
Fractional Fourier Transform (FrFT)

Almeida L , IEEE Trans SP, 1994



$$X_\theta(t_a) = \int_{-\infty}^{\infty} x(t) K_\theta(t, t_a) dt$$

Fractional Fourier Transform (FrFT)

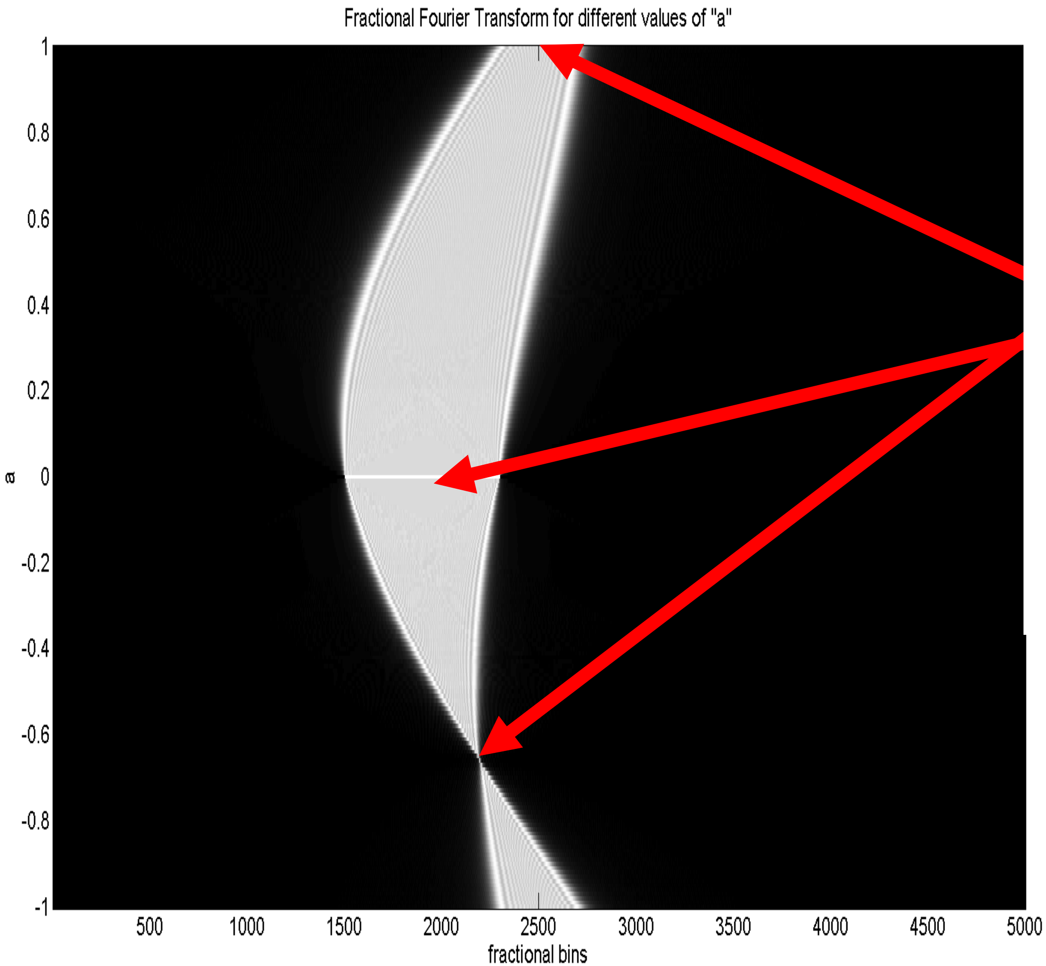


The optimum FrFT order of linear FM chirp

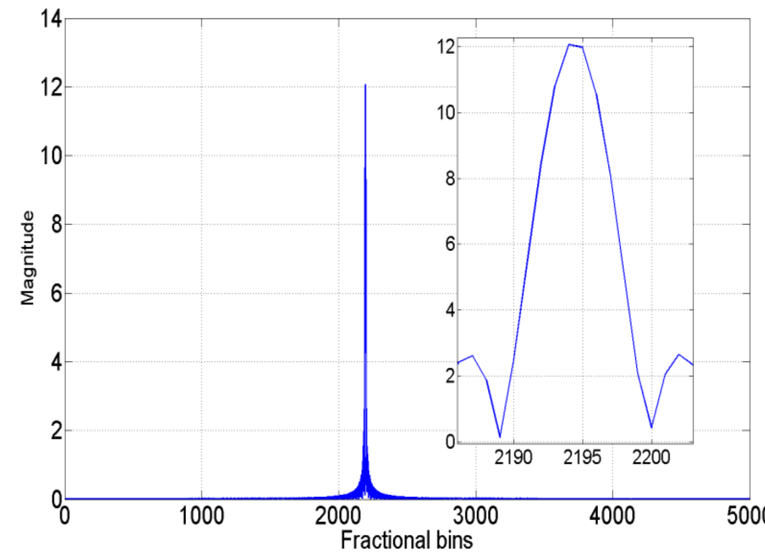
$$a_{opt} = -\frac{2}{\pi}\tan^{-1}\left(\frac{F_s \times T}{(F_{stop} - F_{start}) \times L}\right)$$

Fractional Fourier Transform

For a linear chirp with starting frequency of 5 Hz, ending frequency of 100 Hz, chirp period of 0.8 s, and sampling frequency of 1 kHz; the time window 5 s, and the chirp start at 1.5 s



$a = 0.6588$



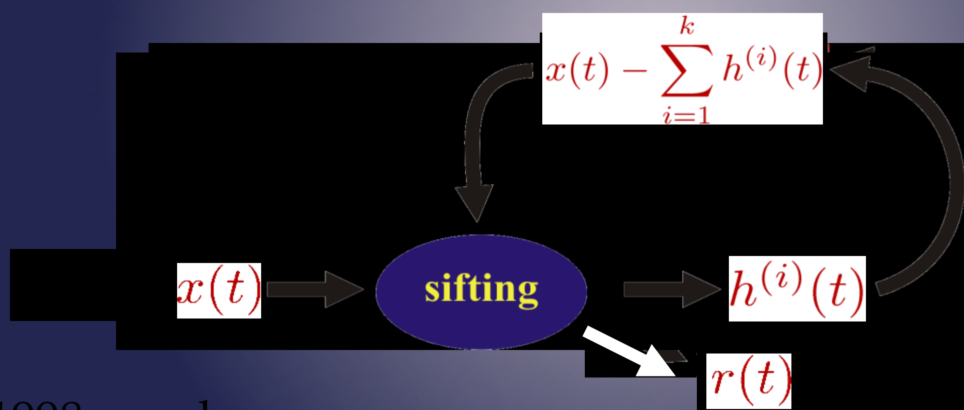
P_p **at Fractional bin 2194**

Empirical mode decomposition (EMD)

•Empirical: EMD lacks theoretical foundations.

•Mode: Intrinsic Mode Functions (IMF's) - Represents the oscillation modes embedded in the data.

•Decomposition: $x(t) = \sum_{i=1}^{N} h^{(i)}(t) + r(t)$



*Huang et al, 1998 and

* Rilling et al , IEEE-EURASIP Workshop NSIP, June 2003

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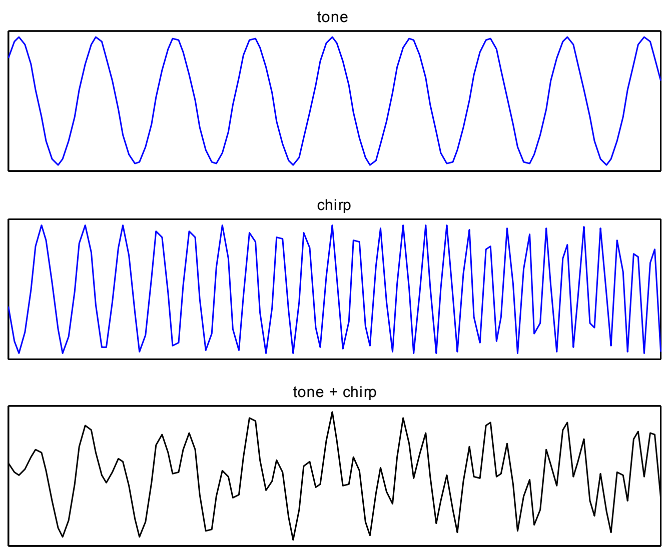
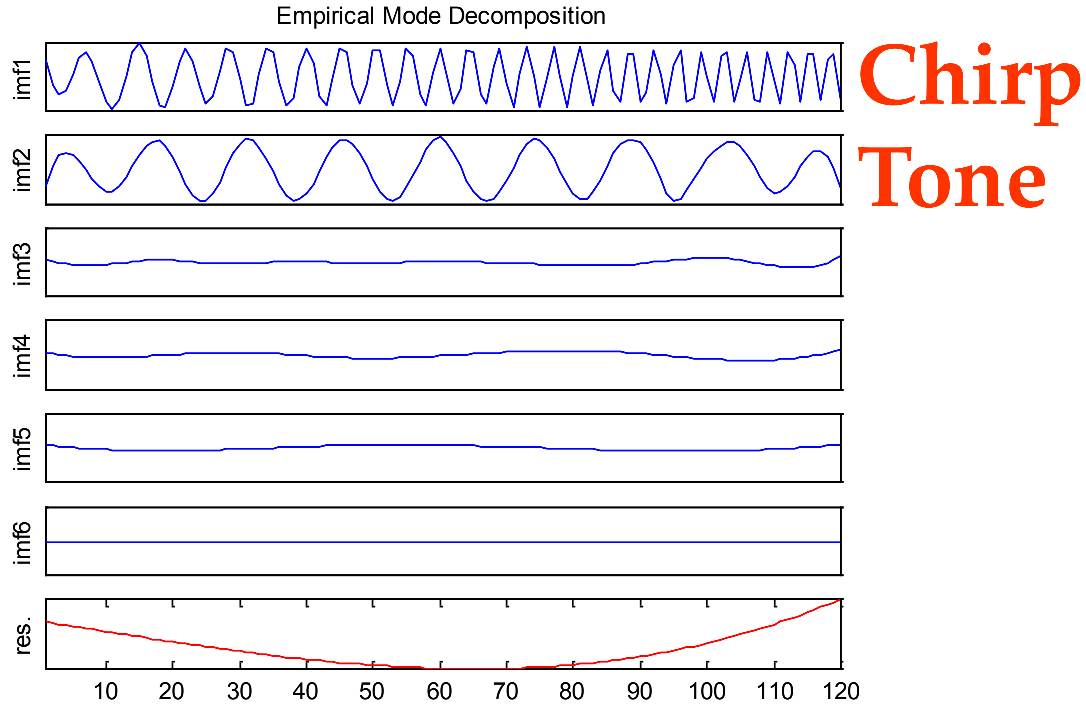
EMD Example

Example: Tone + Chirp





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Methodology: (EMD noise filtering)

Noisy signal

EMD Algorithm

IMF 1
IMF 2
IMF 3
IMF 4
IMF 5
IMF 6

Mostly noise

Estimates the noise level in each IMF using a threshold

$$T_r[i] = C\sqrt{W[i]2\ln(N)}$$

C

IMF 7
IMF 8
IMF 9
IMF 10

Mostly signal

IMF 7
IMF 8
IMF 9
IMF 10

IMF 7
IMF 8
IMF 9
IMF 10

IMF 7 + IMF 8 + IMF 9 + IMF 10

Filtered signal

Singular Spectrum Analysis (SSA)

(Hassani, H, SSA : methodolgy and comparison, 2007)

SSA is the application of SVD/PCA to time series

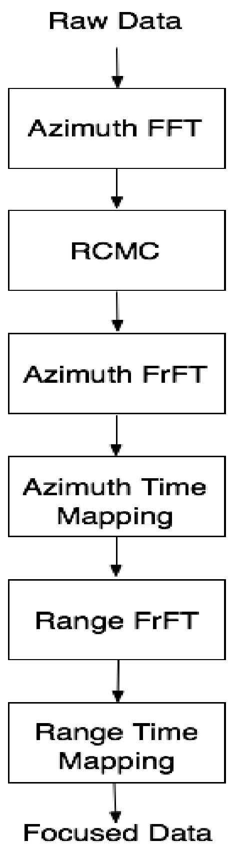
Summary of what it does

- application of PCA to time series which is structured (embedded) into overlapping moving windows of data
- the data vectors are fragments of time series rather than spatial distributions of values at a single time
- the eigenvectors therefore represent characteristic time patterns, rather than characteristic spatial patterns
- used mainly to identify oscillatory features in the time series and in our work for Micro-Doppler Analysis

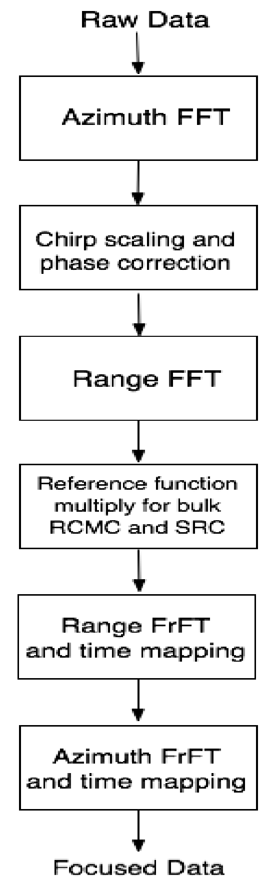
Signal Processing Solutions for

High Resolution SAR Signal Processing

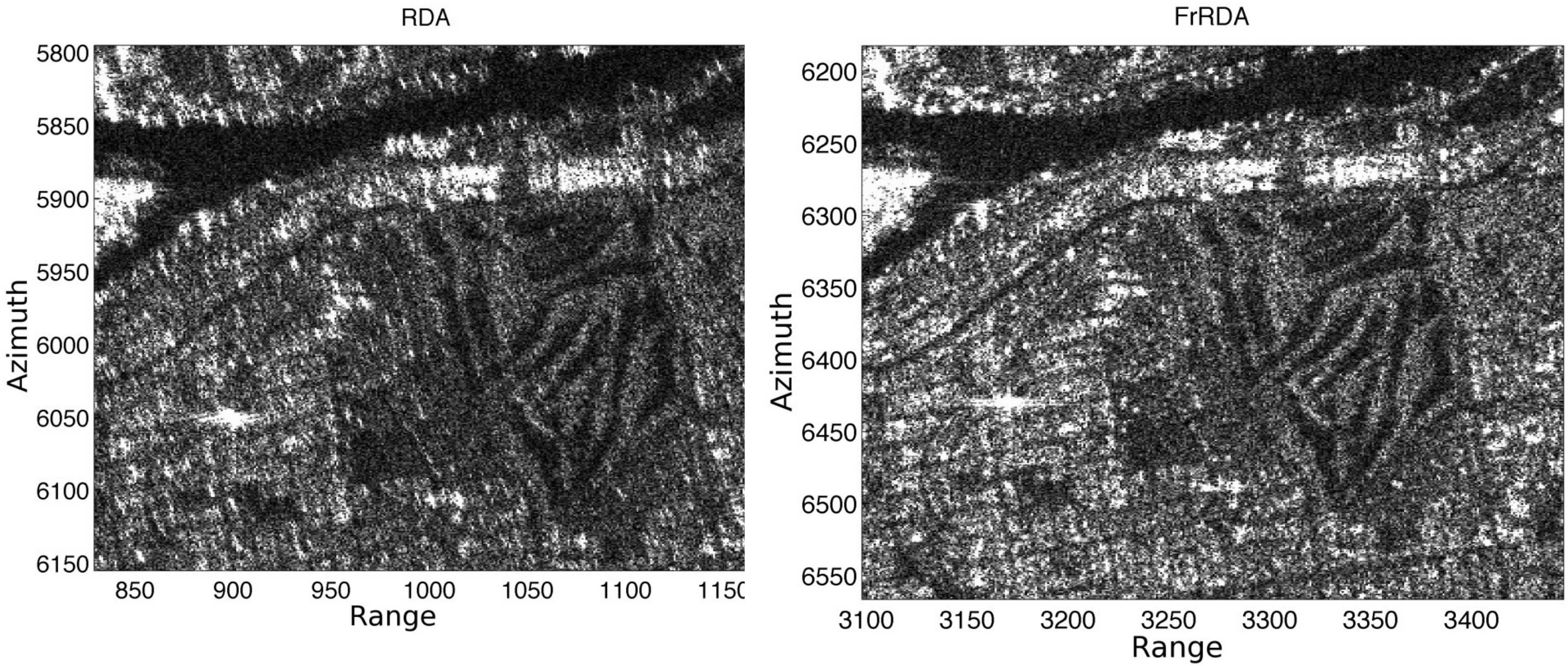
FrFT Range Doppler Algorithm



FrFT Chirp Scaling Algorithm



Golf course area processed with the RDA and the FrRDA.

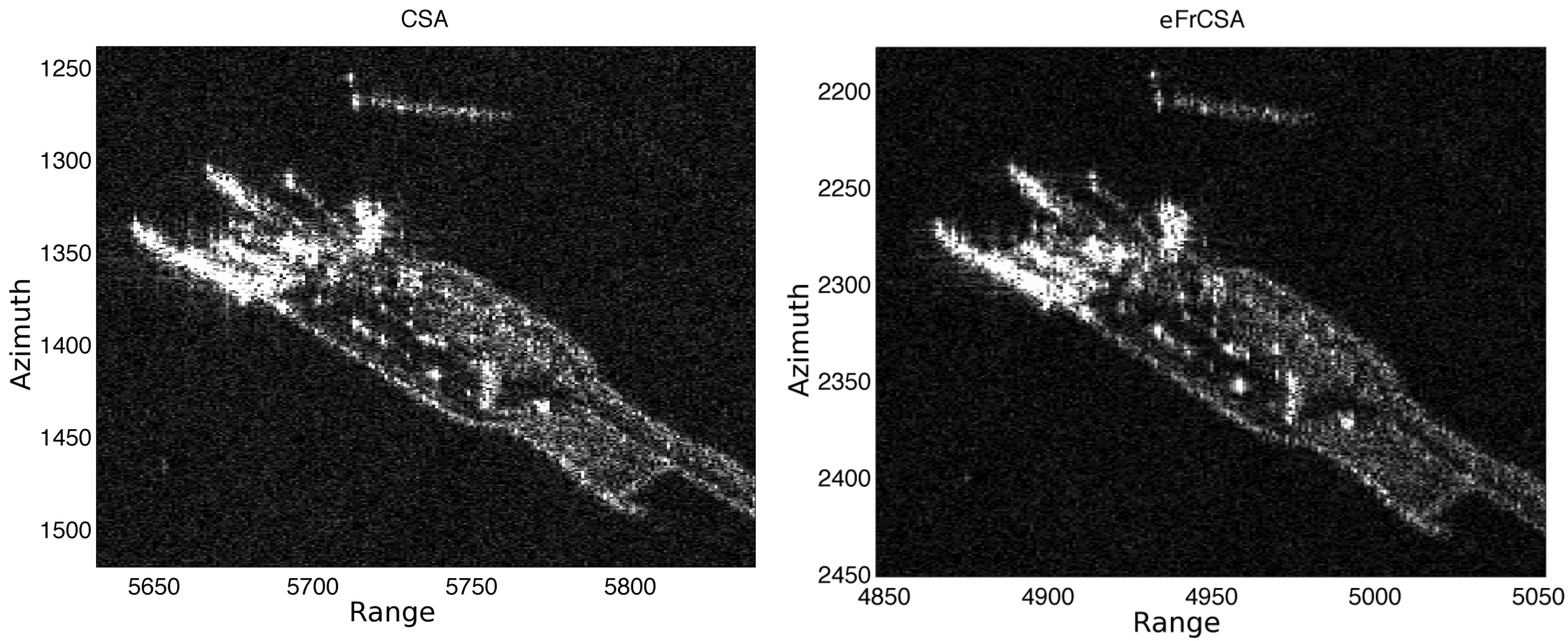


Clemente et al “***Range Doppler SAR processing Using the FrFT***",International Radar Symposium-IRS2010, 2010

Clemente et al ,"***Fractional RDA and Enhanced FrCSA for SAR Imaging***", SSPD-2010, 2010

Clemente et al ,"***Fractional Range Doppler Algorithm for SAR Imaging***", European Radar Conference, Eurad-2010, 2010

Portion of the Vancouver Tsawwassen ferry terminal area processed with the CSA and the eFrCSA.

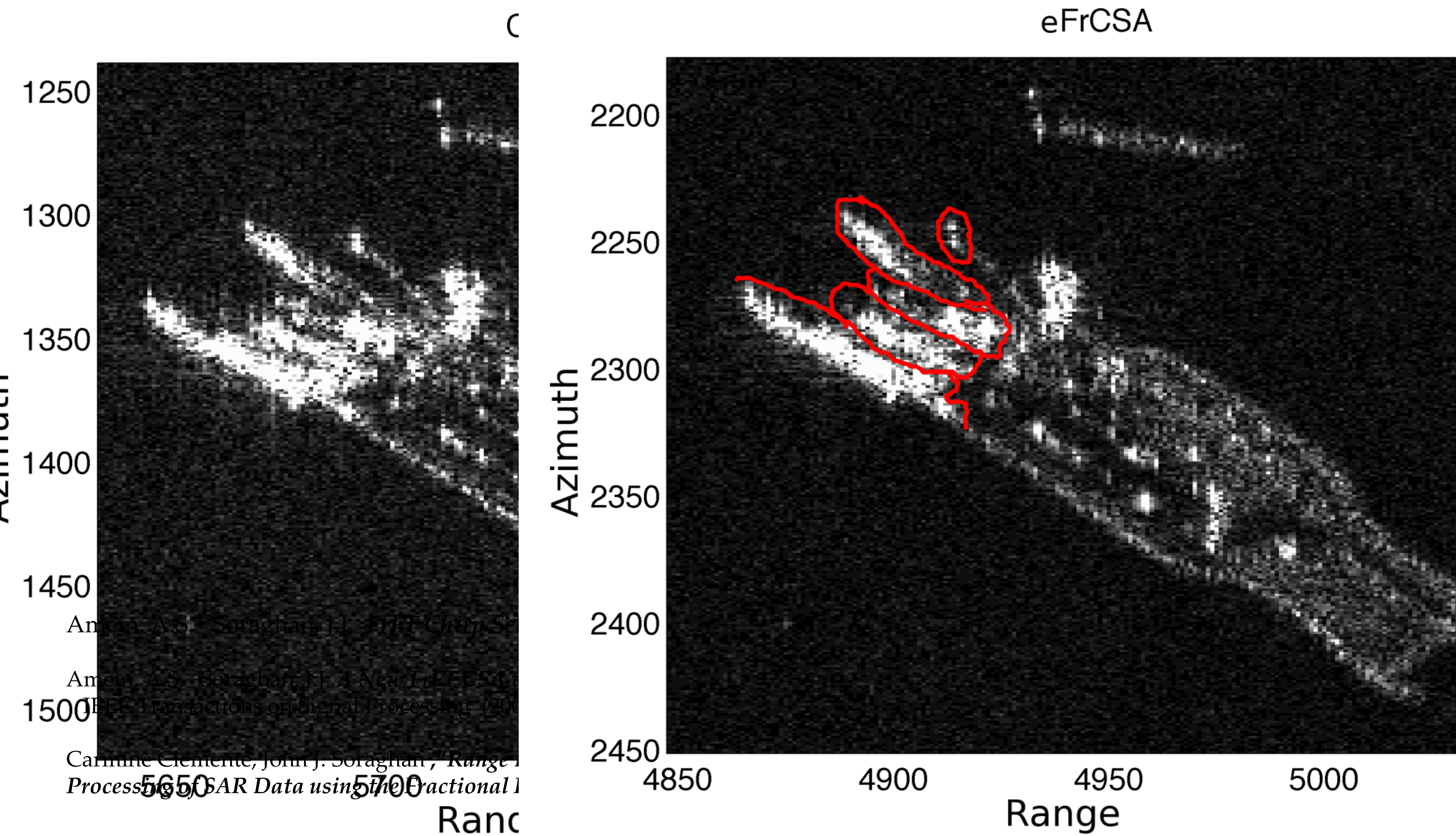


Amein, A.S. Soraghan, J.J. ***FrFT Chirp Scaling Algorithm (FrCSA)*** IEEE TGRS (2006)

Amein, A.S. Soraghan, J.J. ***A New FrFT CSA with Application to High Resolution Radar Imaging*** IEEE Transactions on Signal Processing (2007)

Carmine Clemente, John J. Soraghan **,*"Range Doppler and Chirp Scaling Processing of SAR Data using the Fractional Fourier Transform"*,** IET Signal Processing (2010).

Portion of the Vancouver Tsawwassen ferry terminal area processed with the CSA and the eFrCSA.



Amein, A.S., Soraghan, J.J. *FrFT Chirp Sc*

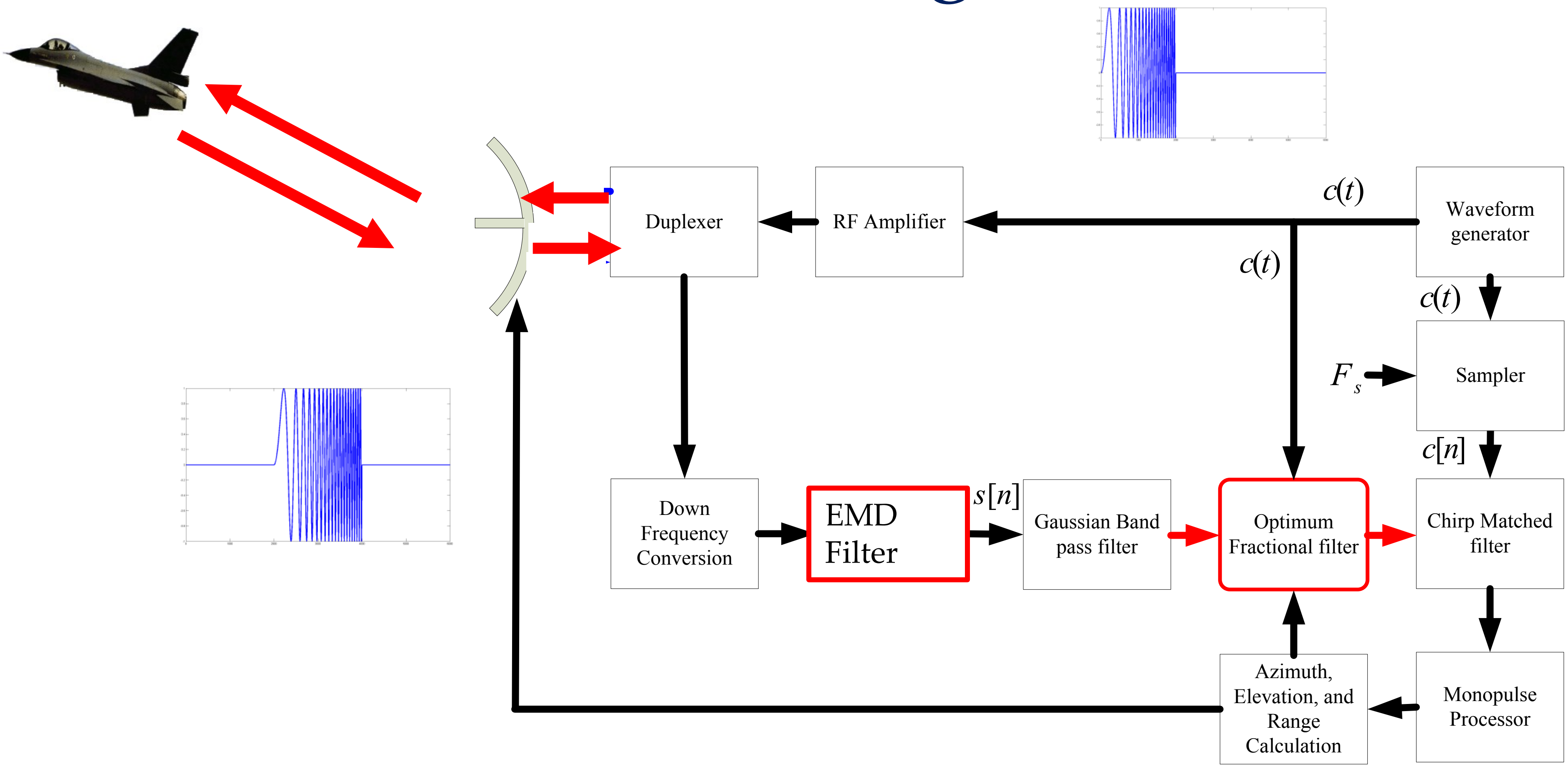
Amein, A.S., Soraghan, J.J. *A New FrFT CSA* … IEEE Transactions on Signal Processing (200…

Carmine Clemente, John J. Soraghan, "*Range* … *Processing of SAR Data using the Fractional F*…

Signal Processing Solutions for

Target Tracking & Anti-Jamming

FrFT/EMD Monopulse Radar Tracking

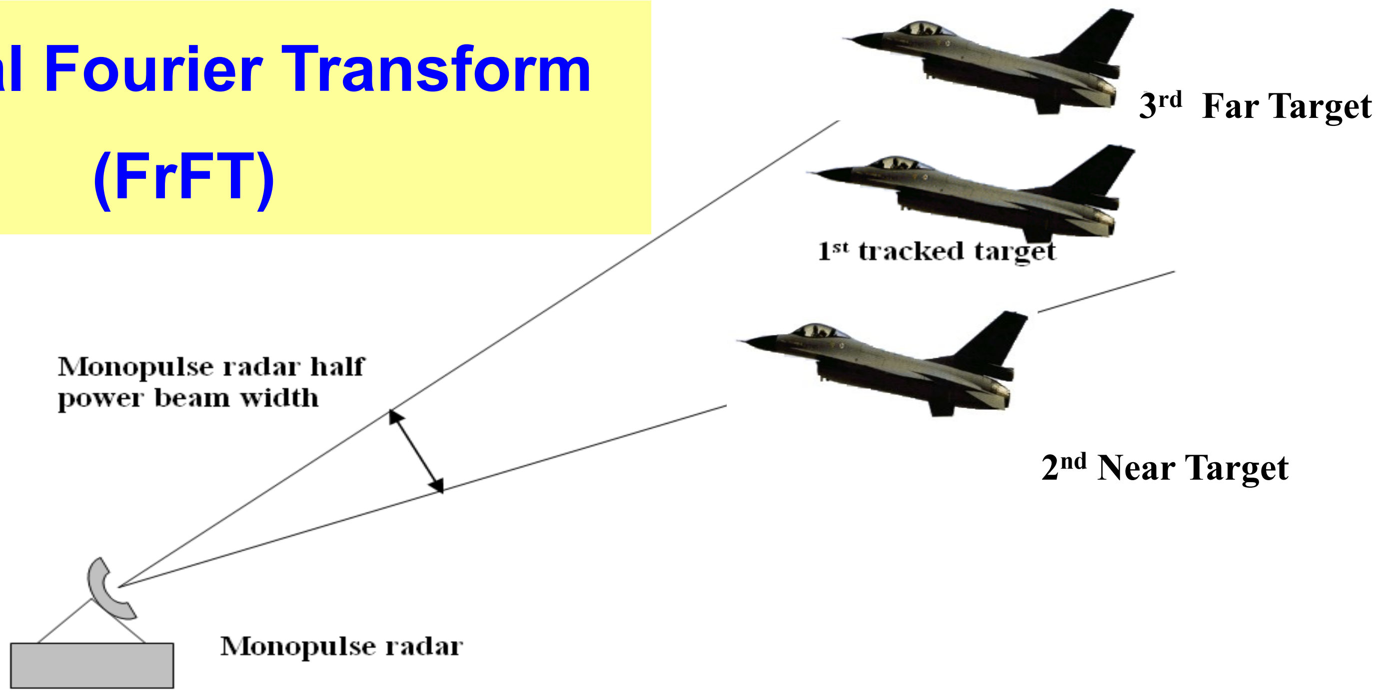


[A] Tracking

Solve the problem of interference due to more than one target appearing in the monopulse radar half power beam width

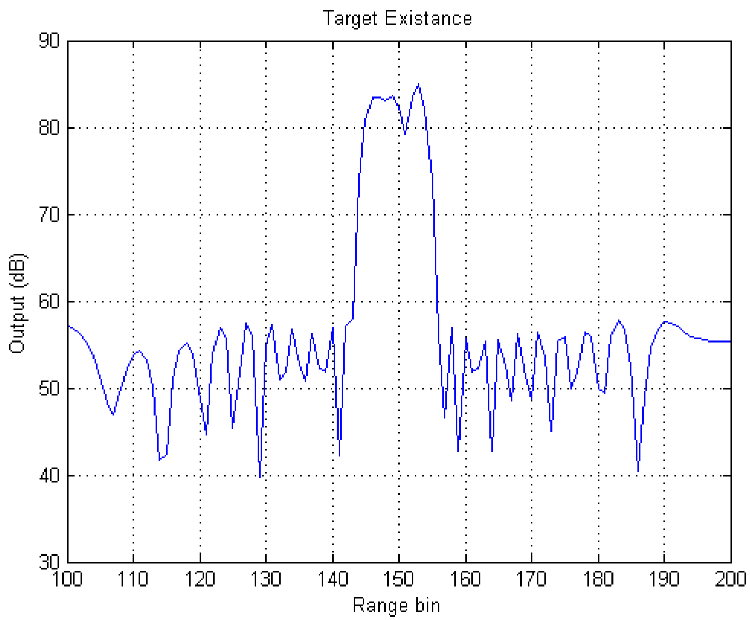
three targets scenario for Monopulse radar

Fractional Fourier Transform (FrFT)



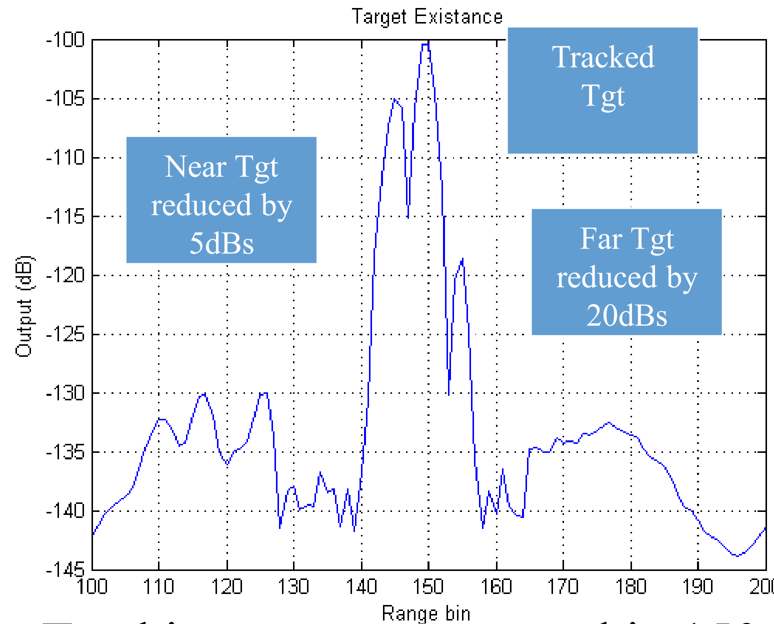
S. A. Elgamel and J. J. Soraghan, "*Enhanced monopulse tracking radar using optimum Fractional Fourier Transform*," IET Journal of Radar, Sonar & Navigation, July 2010.

Results from the Fractional Fourier Transform based Monopulse Radar System



Tracking a target at range bin 150 using convenional Spatial Adaptive Monopulse Radar

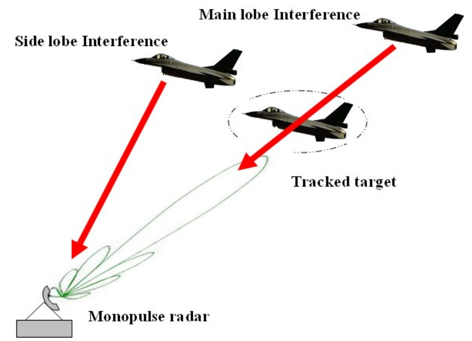
➔ Poor Tracking Result



Tracking a target at range bin 150 using the new Fractional Fourier Transform Based Monopulse Radar

➔ Tracking of main target maintained

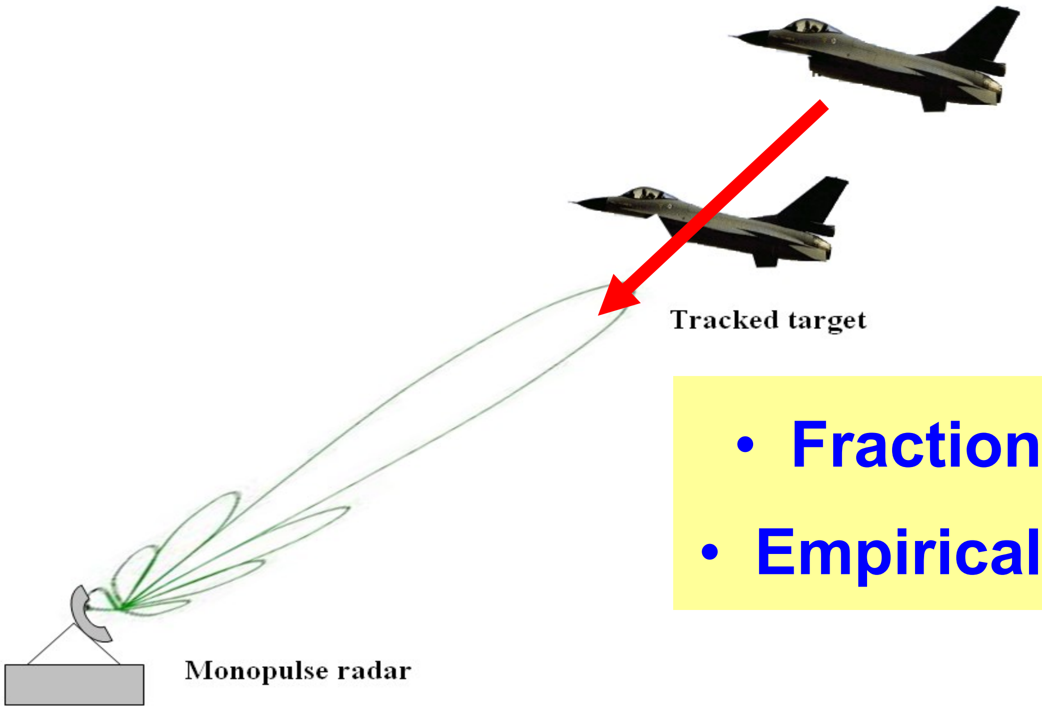
Results :(High power interference)



OINR in db for Monopulse Processors

Monopulse processor	Main lobe interference		Side lobe interference	
Conventional processor				
(a) No filtering	14.31	↑ **15 dB**	-3.3	↑ **9.6 dB**
(b) FrFT filtering	-1.33		-12.99	
Spatial processor				
(a) No filtering	-19.69	↑ **3.6 dB**	-77.18	↑ **9.5 dB**
(b) FrFT filtering	-23.3		-86.75	

[B] High Power Jamming Interference



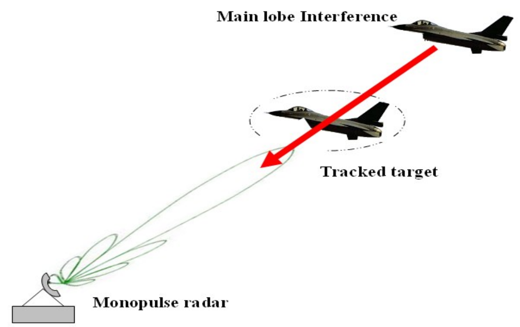
- **Fractional Fourier Transform**
- **Empirical Mode decomposition**

Interference scenarios for Monopulse radar.

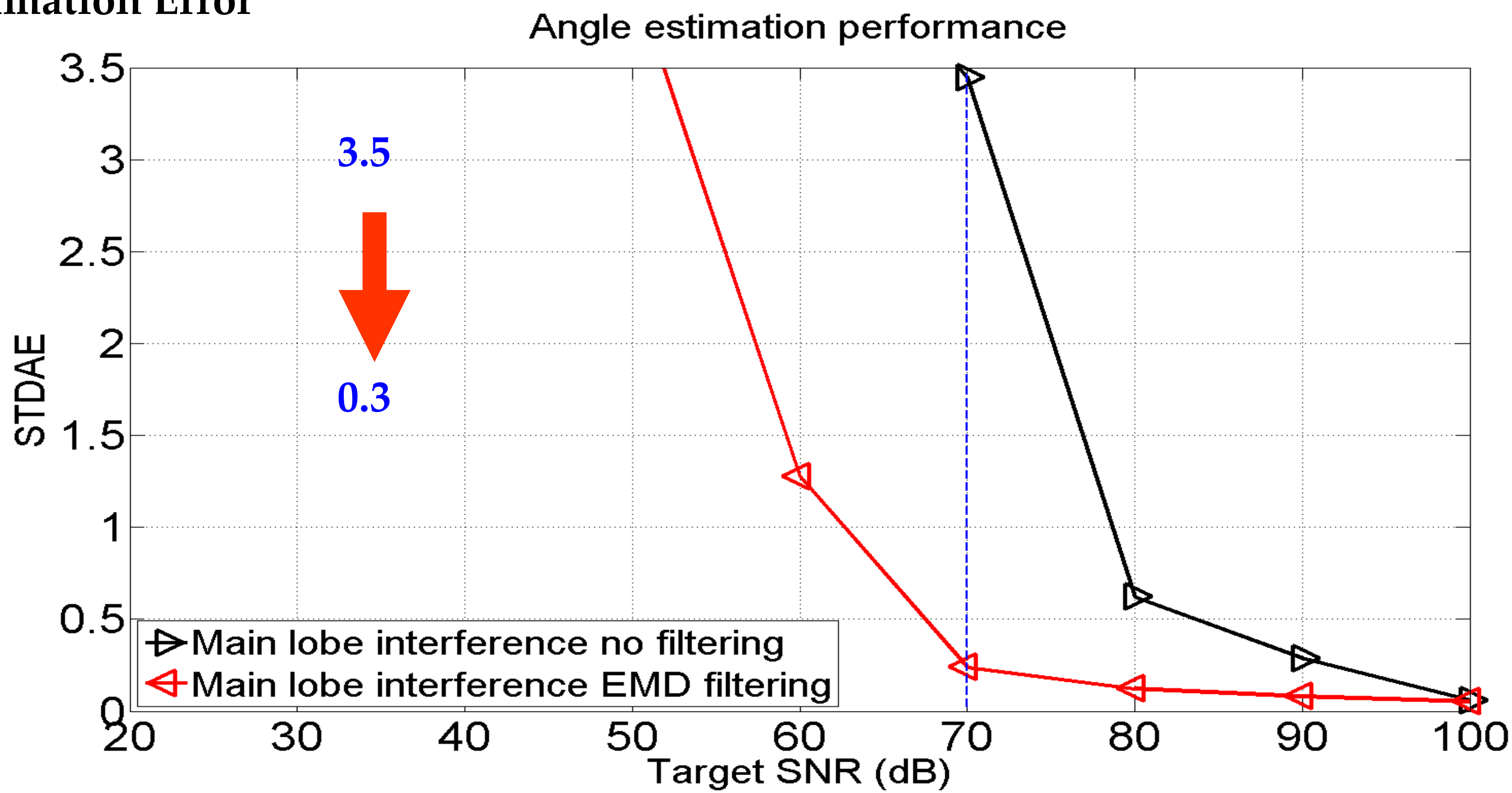
Elgamel & Soraghan, "***Empirical mode decomposition-based monopulse processor for enhanced radar tracking in the presence of high-power interference***" IET Radar, Sonar & Navigation, August 2011

Elgamel, S.A.; Soraghan, J.J.; ***Using EMD-FrFT Filtering to Mitigate Very High Power Interference in Chirp Tracking Radars,*** IEEE Signal Processing Letters. Volume: 18 , 2011 , Page(s): 263 - 266

Results :(High power interference)



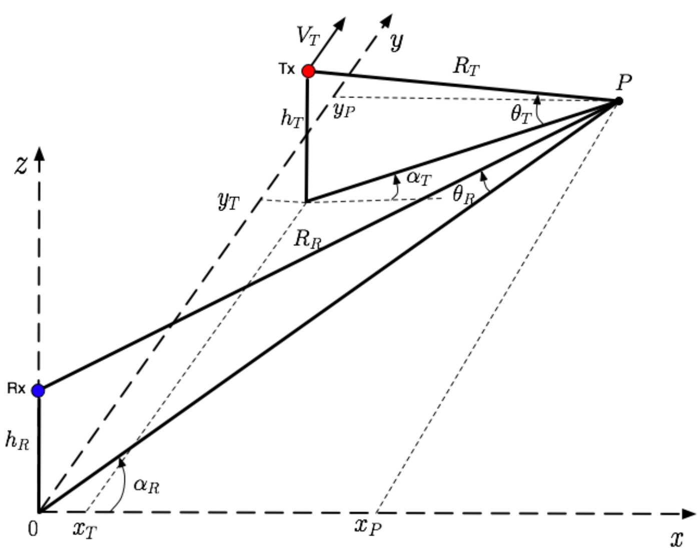
STDAE : **Std Dev Angle Estimation Error**

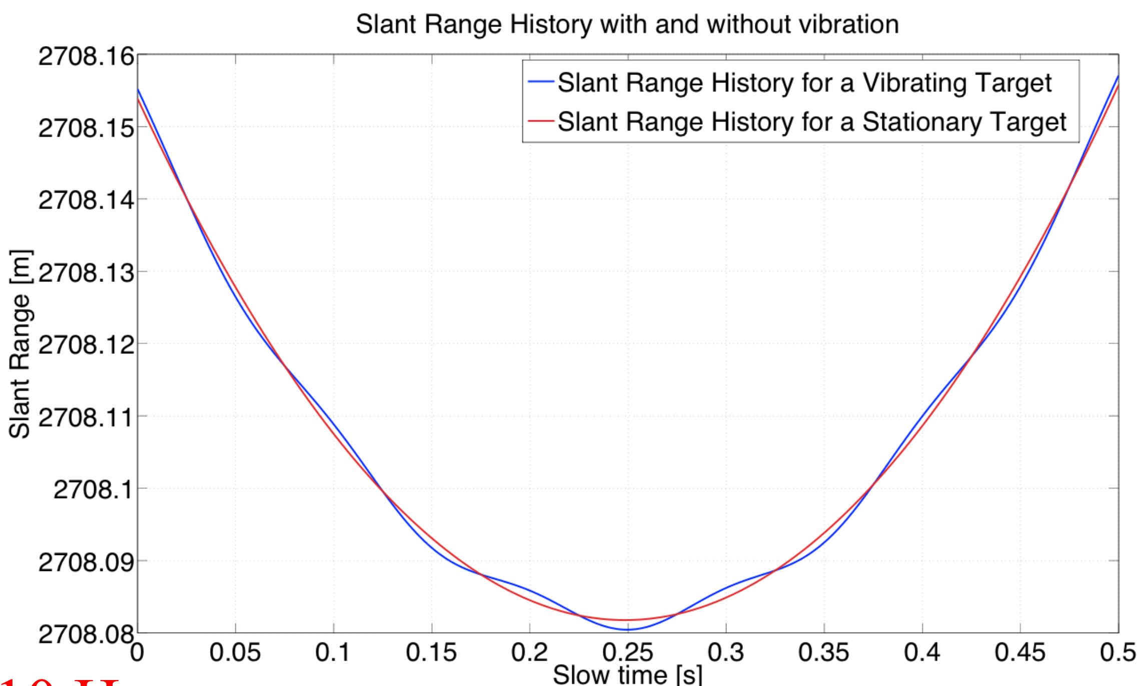


STDAE for Spatial adaptive processor configuration

Microdoppler Signature Extraction from BiSAR

Bistatic SAR Geometry





A small 1 mm amplitude at 10 Hz introduces a visible effect on the bistatic slant range function

Clemente et al ,"***Vibrating Target Micro-Doppler Signature in Bistatic SAR with a Fixed Receiver***", IEEE Trans on Geoscience and Remote Sensing, August 2012

Clemente et al ,"***Approximation of the Bistatic Slant Range Using Chebyshev Polynomials***", IEEE Trans Geoscience and Remote Sensing Letters, July 2012

Helicopters

Table: Simulated helicopters and rotor blades features.

Model	# of blades	Blade length [m]	Blade width [m]
AW-109 Agusta	4	5.5	0.6
AH-64 Apache	4	7.3	0.6
UH-60 Black Hawk	4	8.18	0.6
MD 500E Defender	5	4	0.6

Table: Tip velocity, expected maximum micro-Doppler shift and RCS

Model	Tip Velocity [m/s]	Maximum m-D shift [Hz]	RCS [dBsm]
AW-109 Agusta	241.90	112.24	25.76
AH-64 Apache	220.16	102.13	28.2
UH-60 Black Hawk	221.00	102.52	29.2
MD 500E Defender	206.08	95.60	22.9

Helicopters

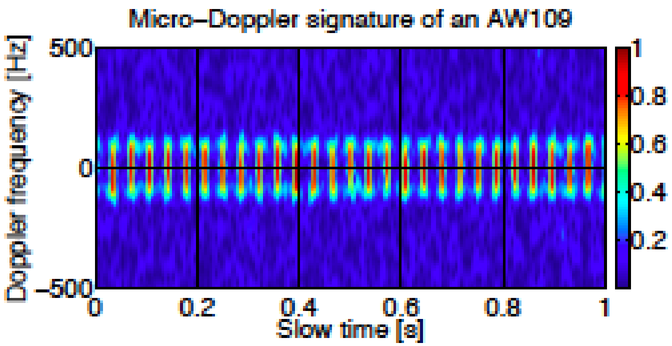


Figure: AW109.

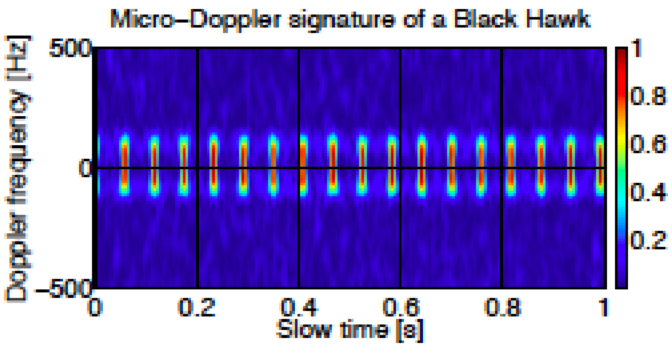


Figure: Black Hawk.

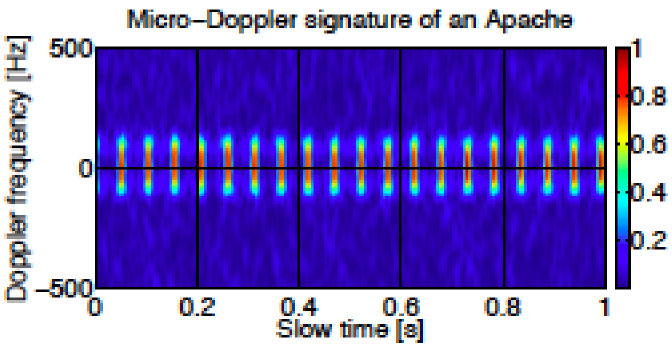


Figure: Apache.

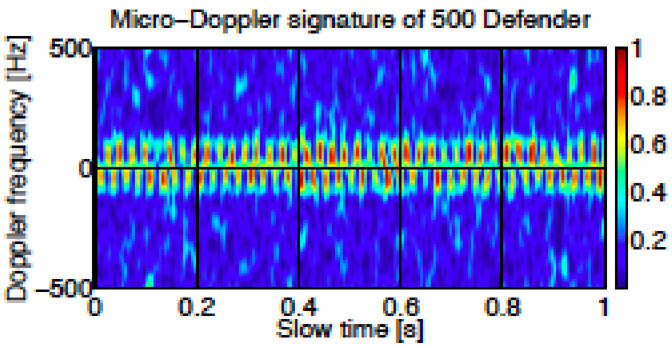


Figure: Defender.

Micro-Doppler Signal Extraction in clutter

- Strong Clutter can mask micro-Doppler signatures
  - In SAR the surrounding scene produces strong clutter
  - The fuselage of a helicopter and the direct signal will produce strong signals to the receiver
- Singular Spectrum Analysis **(SSA)** based methods have been developed and applied in low SCR micro-Doppler

Carmine Clemente, John J. Soraghan,"***Vibrating Micro-Doppler signature extraction from SAR data using Singular Value Decomposition***",EUSAR2012, European Conference on Synthetic Aperture Radar, 2012

Extraction from clutter

SSA applied to extract helicopter rotor blades signatures with a Signal-to-Clutter and Interference Ratio less than -90 dB.

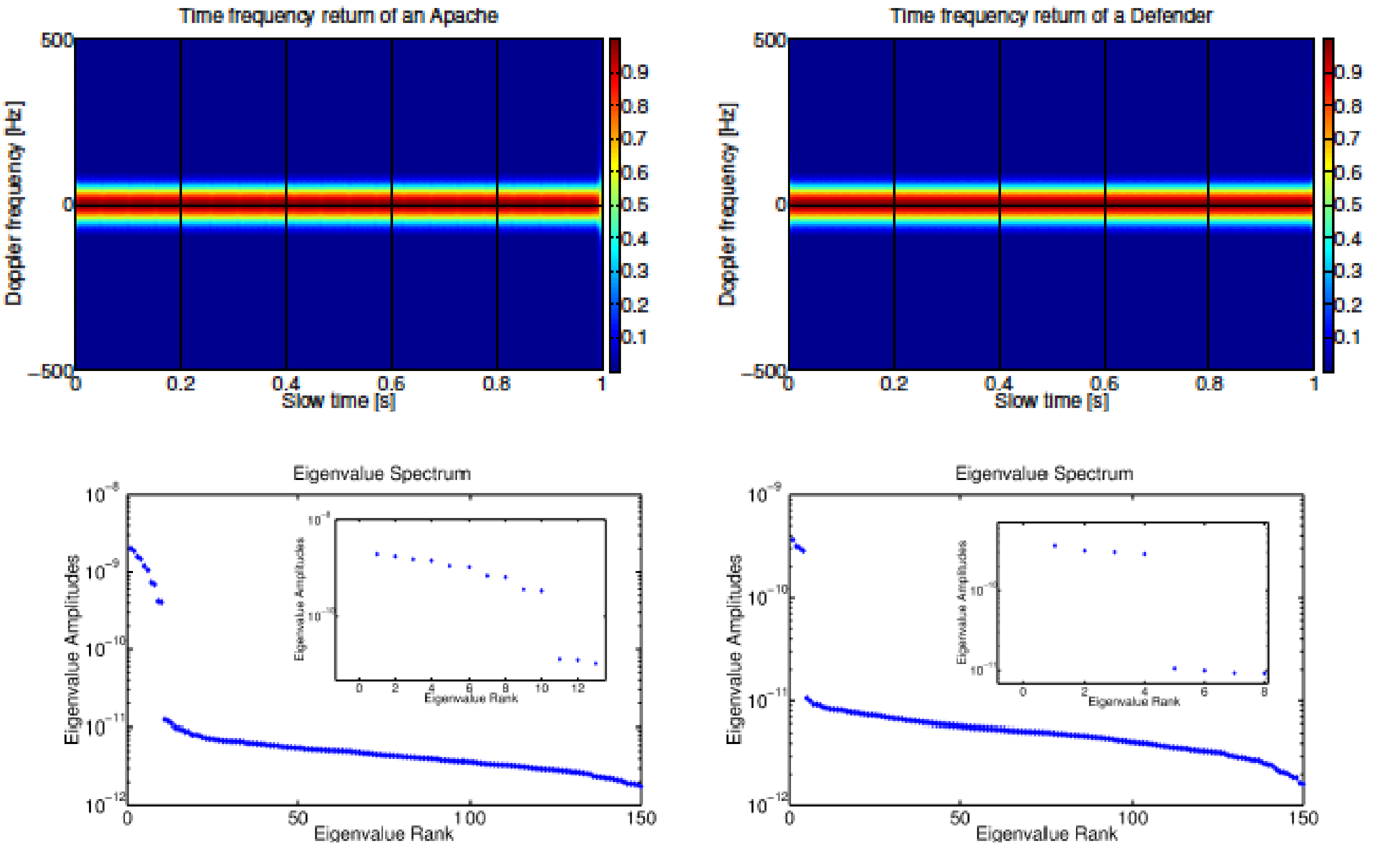


Figure: Results for an Apache and a Defender

Extraction from clutter

We applied the technique to the helicopter rotor blades signatures with a Signal to Clutter and Interference Ratio less than -90 dB.

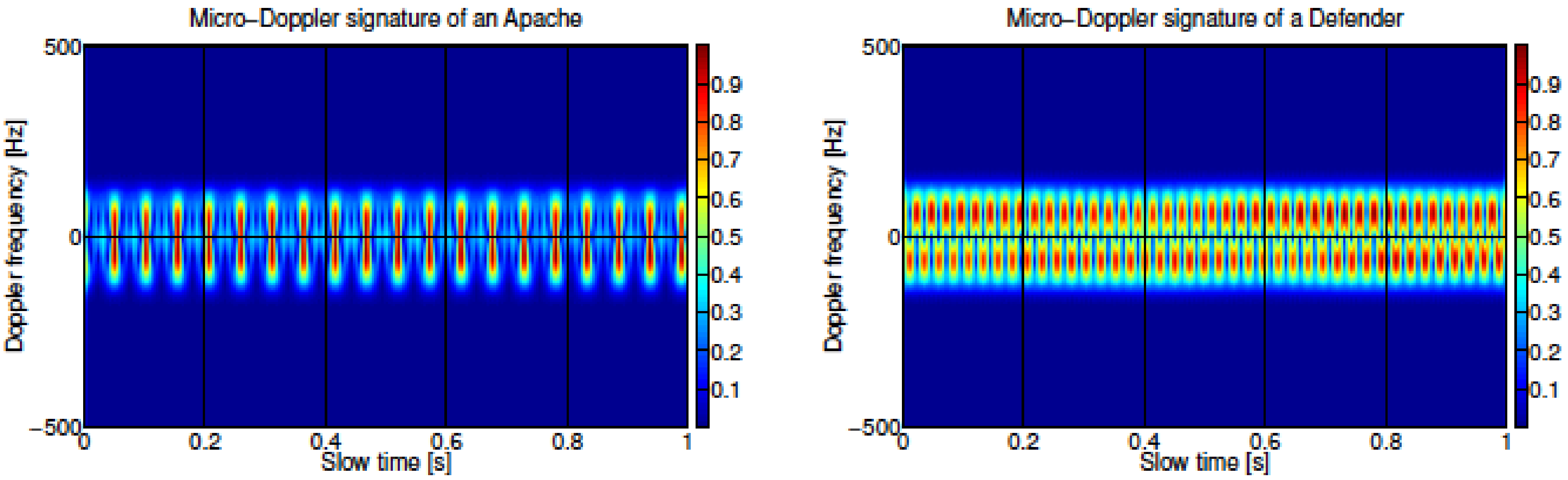


Figure: Results for an Apache and a Defender

Carmine Clemente, John J. Soraghan, "***Passive Bistatic Radar for Helicopters Classication: a Feasibility Study***", IEEE Radar Conference 2012, Radarconf2012, May 7-11, Atlanta, USA

Moving Forward within the UDRC

- MIMO & Distributed Sensing Systems
  - Waveform Design
  - Micro-Doppler for ATR

- FrFT/EMD/LBP based Solutions for Sonar

Questions ?