Partially Adaptive STAP

ILIAS S. KONSOULAS, MSc, CEng, PMP, MIET

HELLENIC AIR FORCE

ekonsoul@yahoo.com

Taxonomy of Partially STAP Algorithms

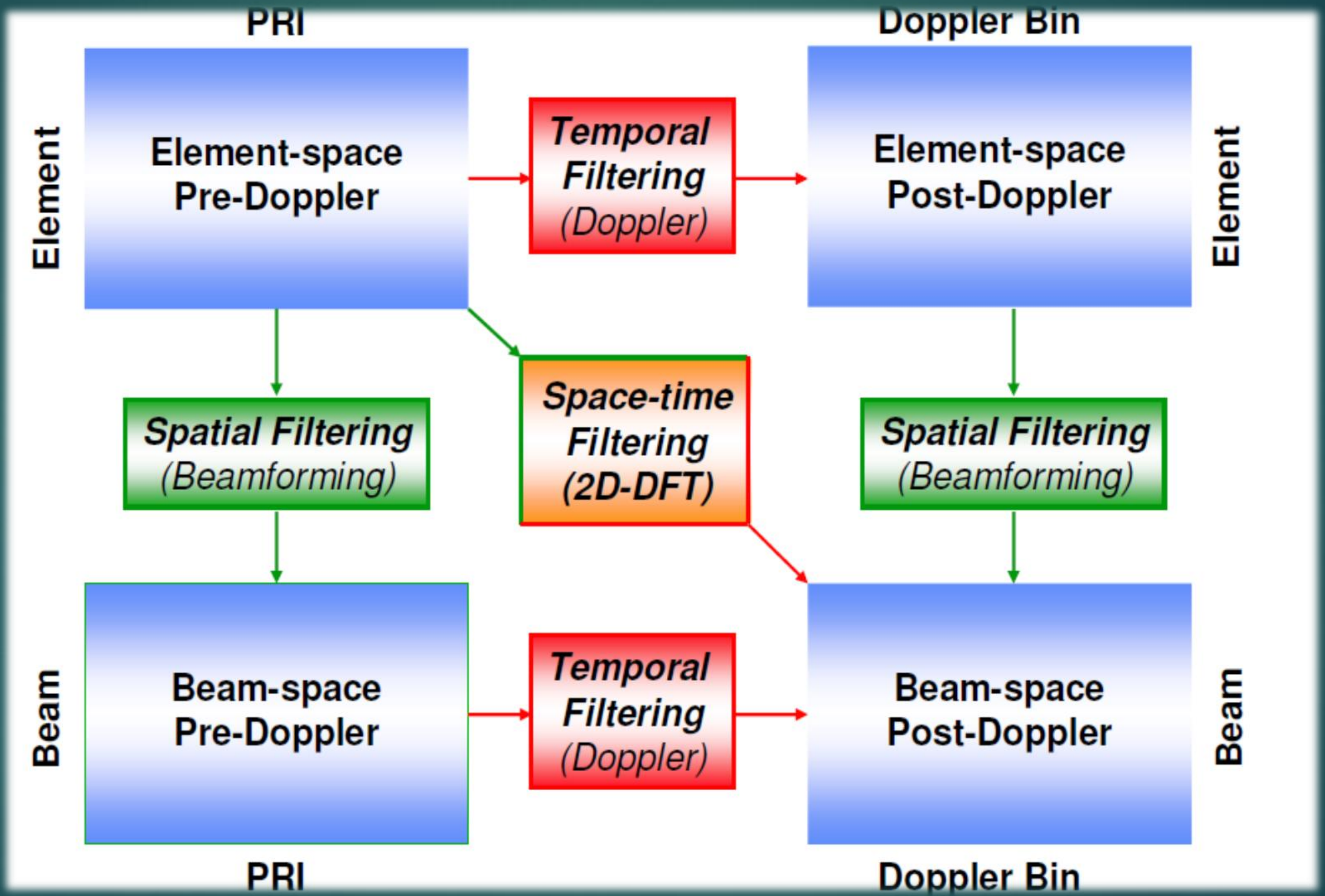
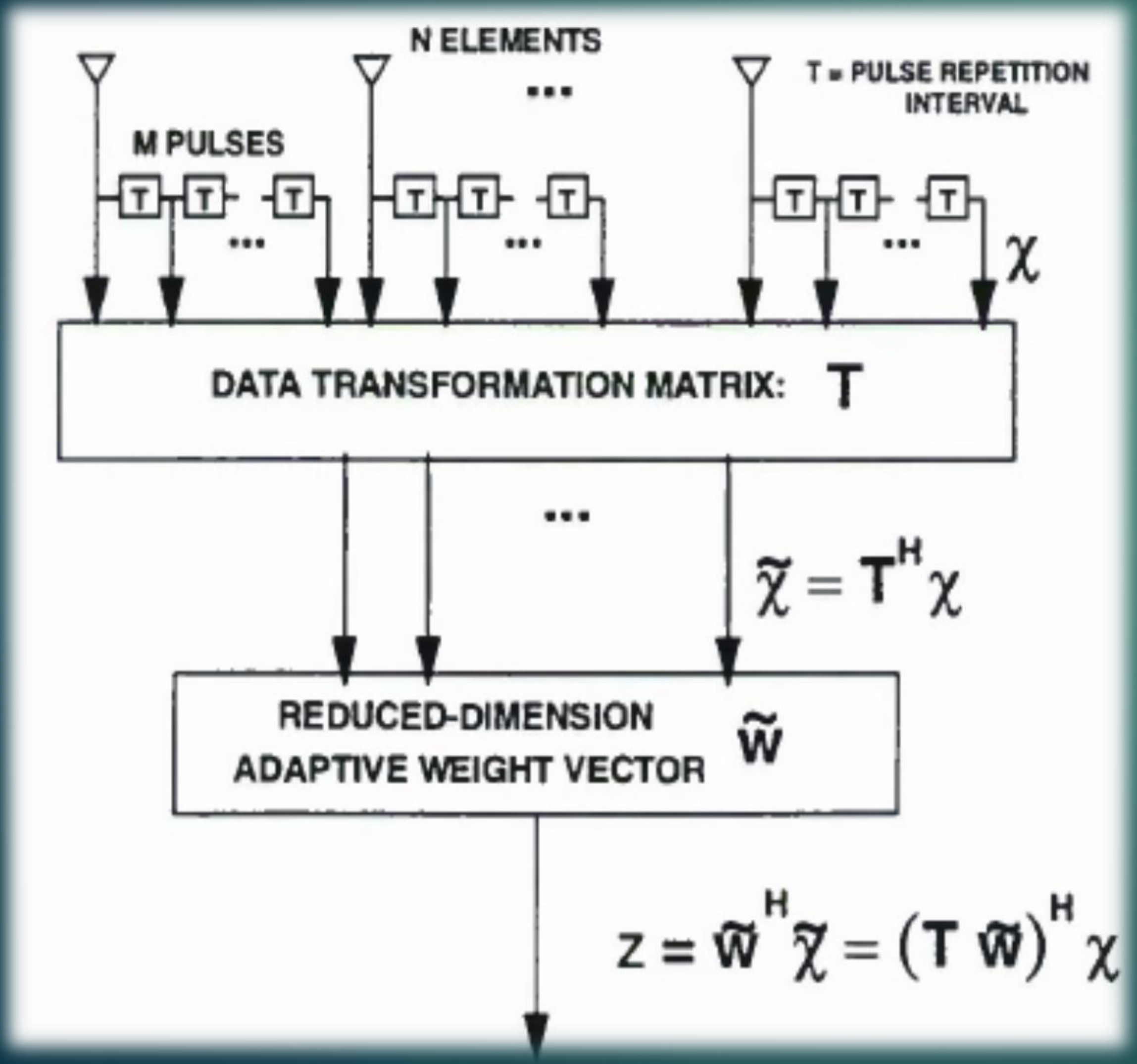


Figure adopted from [4]

Algorithms classified by domain where adaptive processing occurs.

Partially Adaptive STAP Fundamentals



- Reduced dimensionality comes from an *MN*×*D* preprocessor matrix $\mathbf{T}$:

  $\tilde{\boldsymbol{\chi}} = \mathbf{T}^H \boldsymbol{\chi} = \alpha \tilde{\mathbf{v}}_t + \tilde{\boldsymbol{\chi}}_u$ is *D*×1 where *D* << *MN*.

- After data transformation, the *D*×1 adaptive weight vector is computed:

$$\tilde{\mathbf{w}} = \tilde{\mathbf{R}}_u^{-1} \tilde{\mathbf{g}}_t$$

Where

$$\tilde{\mathbf{R}}_u = E\{\tilde{\boldsymbol{\chi}}_u \tilde{\boldsymbol{\chi}}_u^H\} = \mathbf{T}^H \mathbf{R}_u \mathbf{T}$$

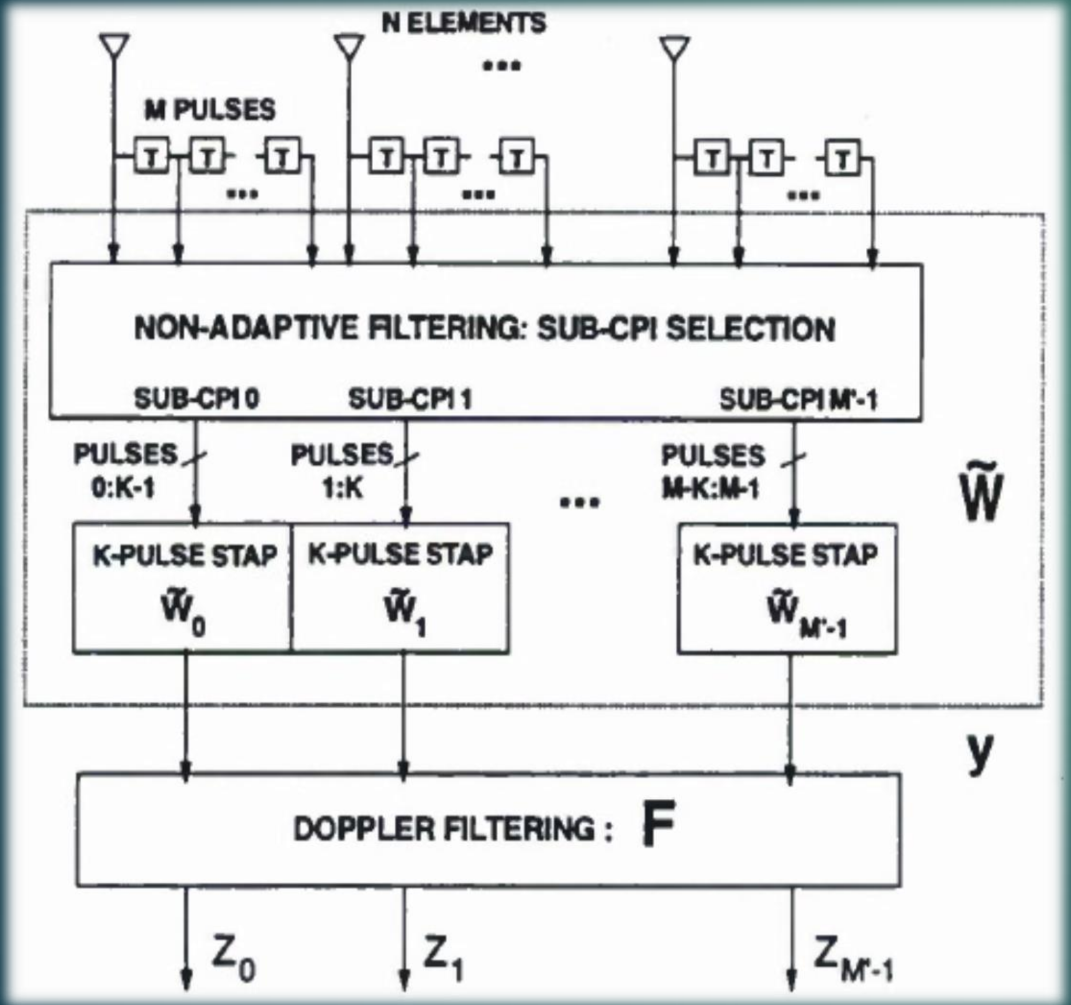
is the *D*×*D* covariance matrix of the transformed data.

ELEMENT SPACE STAP
Case I: Pre-Doppler Processing "Adapt then Filter"

- Adaptively Combine returns from few (2 or 3) pulses at a time.
- Retain Full Spatial Adaptivity.
- Adaptive temporal and spatial processing is followed by a fixed, non-adaptive, Doppler filter bank providing coherent integration over the full CPI.
- Preprocessor Matrix is: $\mathbf{T} = \mathbf{J}_p \otimes \mathbf{I}_N$,

where $\mathbf{J}_p = \begin{bmatrix} \mathbf{0}_{p\times K} \\ \mathbf{I}_K \\ \mathbf{0}_{(M-K-p)\times K} \end{bmatrix}$ is an $M\times K$ pulse selector matrix.

ELEMENT SPACE STAP
Case I: Pre-Doppler Processing "Adapt then Filter"



- Using more than one pulse provides temporal adaptivity required for clutter cancellation.
- Full spatial adaptivity provides the means to null jamming at the same time.
- Adaptive (temporal & spatial) processing is followed by a non-adaptive, Doppler filter bank providing coherent integration over the full CPI and the means for velocity estimation.

ELEMENT SPACE STAP
Case II: Post-Doppler Processing

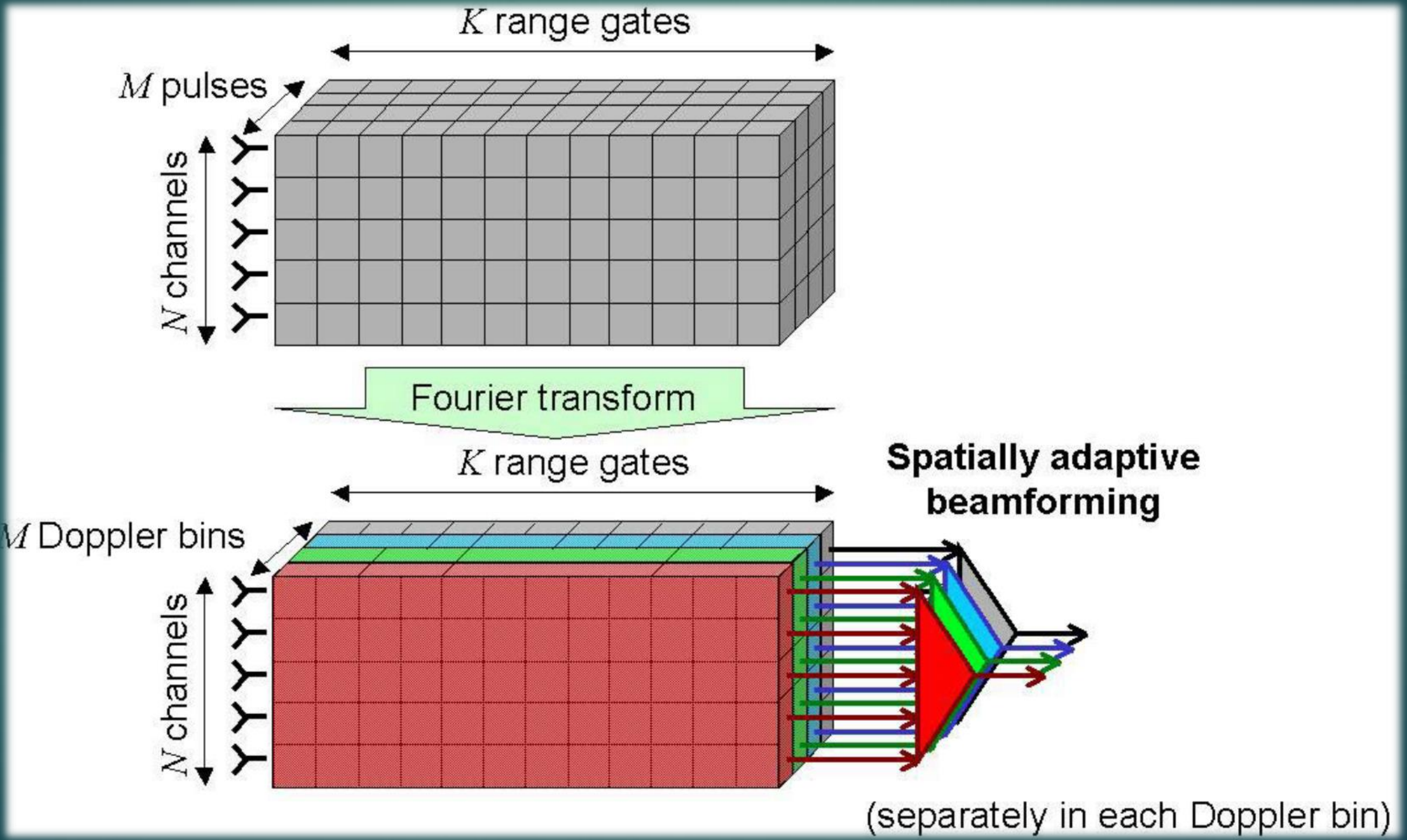


Figure adopted from [5].

ELEMENT SPACE STAP
Case II: Post-Doppler Processing

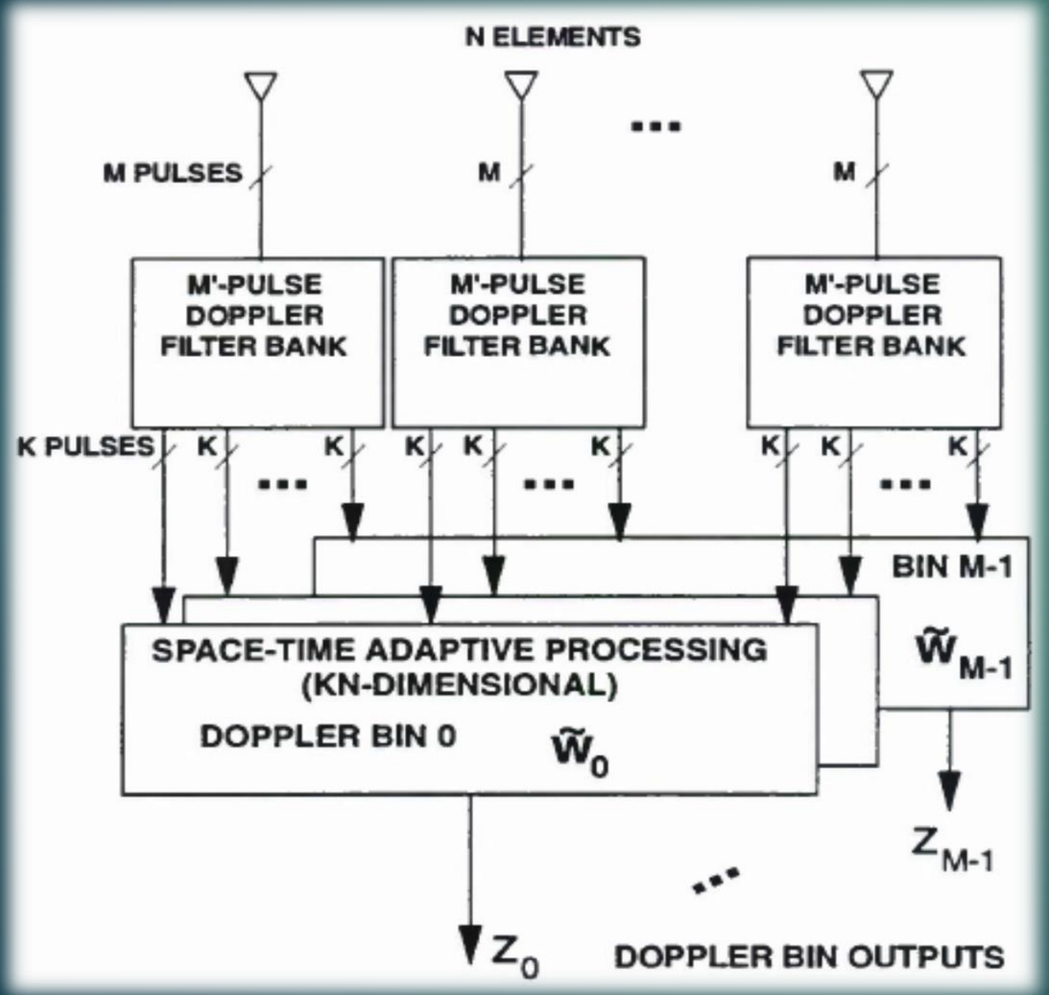
- Otherwise termed "*Factored Post-Doppler*" or "*Factored STAP*".
- Apply a single non-adaptive Doppler filter bank on each element.
- Perform adaptive spatial beamforming separately within each Doppler bin.
- It is assumed that Doppler filtering suppresses mainlobe clutter

  non-adaptively => Poor Results. (Up-to this point no temporal adaptivity).
- Performance Improvement: <u>Multiwindow post-Doppler STAP</u>

Add temporal adaptivity by employing adaptive combination of multiple Doppler bins from each element. Depending on the method of construction of the Doppler filter bank matrix $\tilde{\mathbf{F}}_m$, we may further discriminate between 2 methods:

- i) PRI-Staggered Post-Doppler ("Filter then Adapt" by Brennan & Staudaher [1])
- ii) Adjacent-bin Post-Doppler ("Extended Factored STAP" by DiPietro [2]).

ELEMENT SPACE STAP
Case II: Post-Doppler Processing *"Filter then Adapt"*



PRI-Staggered Post-Doppler STAP

- Each element has a filterbank of *M'*-pulse Doppler filters that produce *K* output pulses for each filter (Doppler bin).
- For each Doppler bin an adaptive processor combines the *K* pulses from each element to produce the output signal for that bin.

ELEMENT SPACE STAP
Case II: Post-Doppler Processing *"Filter then Adapt"*

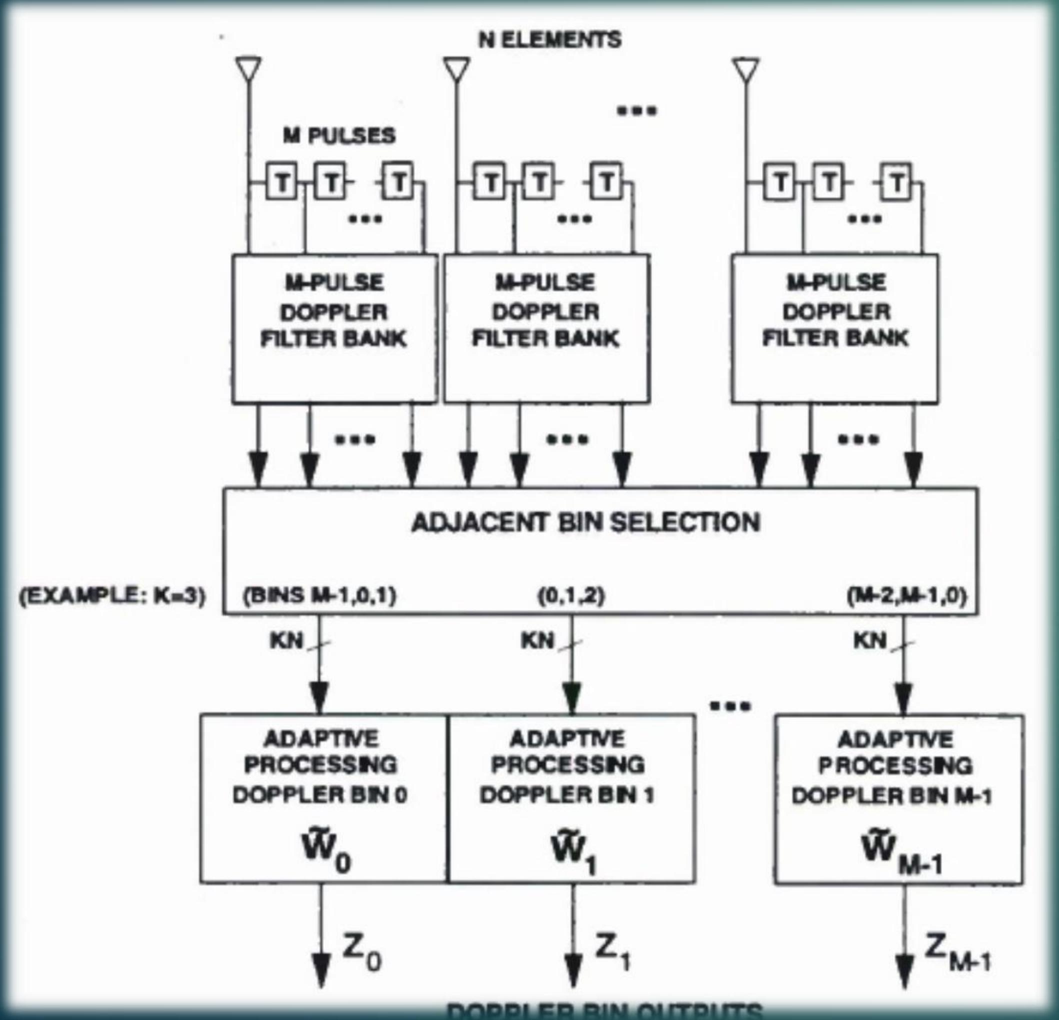
- PRI-Staggered Post-Doppler Preprocessor : $\mathbf{T_m} = \tilde{\mathbf{F}}_m \otimes \mathbf{I}_N$,
  - $\tilde{\mathbf{F}}_m$ is an *M*×*K* matrix whose columns form a set of *M-pulse* FIR Doppler filters applied to the incoming signals on each element.
  - For PRI-Staggered Post-Doppler STAP:

$$\tilde{\mathbf{F}}_m = \text{Toeplitz}\left(\left[\mathbf{f}_m \; ; \; \mathbf{0}_{(K-1)\times 1}\right], \left[f_{m0} \; ; \; \mathbf{0}_{1\times(K-1)}\right]\right)$$

  - $\mathbf{f}_m = \mathbf{t}_f \odot \mathbf{u}_m$ is the *m*-th bin Doppler filter impulse response.

m: index of the target Doppler bin of interest

ELEMENT SPACE STAP
Case II: Post-Doppler Processing *"Factored STAP"*



Adjacent-Bin Post-Doppler STAP

- A single length *M* Doppler filterbank is present on each element.
- The *m*-th Doppler bin output is formed by adaptively combining the spatial samples from a cluster of *K* adjacent Doppler bins centered at the *m*-th bin center frequency.

ELEMENT SPACE STAP
Case II: Post-Doppler Processing *"Factored STAP"*

- Adjacent-Bin Post-Doppler Preprocessor : $\mathbf{T}_m = \tilde{\mathbf{F}}_m \otimes \mathbf{I}_N$,
  - $\tilde{\mathbf{F}}_m$ is an $M \times K$ matrix whose columns form a set of *M-pulse* FIR Doppler filters applied to the incoming signals on each element.
  - For Adjacent Beam Post-Doppler:

$$\tilde{\mathbf{F}}_m = [\mathbf{f}_{m-P}, \dots, \mathbf{f}_m, \dots, \mathbf{f}_{m+P}]$$

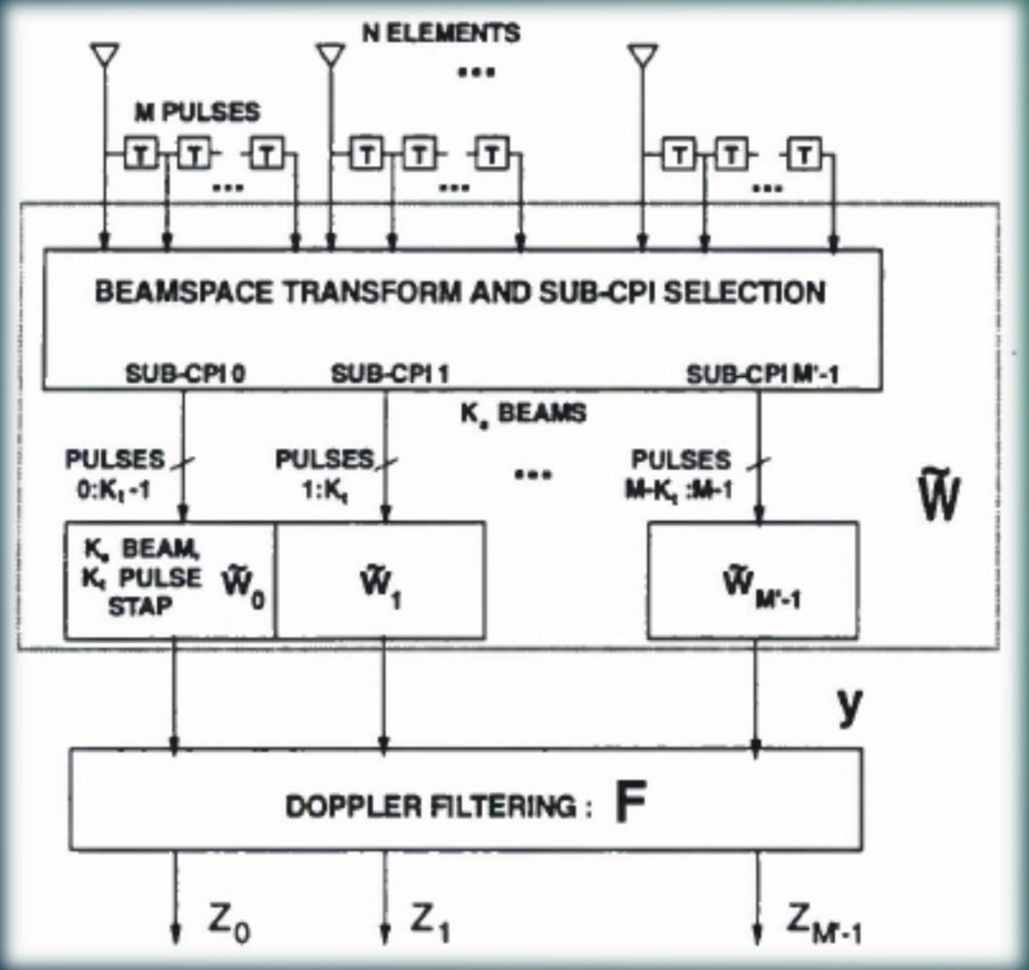
where the m-the bin output adaptively combines signal from Doppler bins *m-P, … , m+P*.

  - $\mathbf{f}_m = \mathbf{t}_f \odot \mathbf{u}_m$ is the *m*-th bin Doppler filter impulse response.

BEAMSPACE STAP
Case III: Pre-Doppler Processing

- Element outputs are preprocessed (non-adaptively) with an $N \times K_s$ Beamformer matrix $\tilde{\mathbf{G}}$, to produce a small number of K_s beam outputs.
- Next, only the beam outputs from a small, K_t-pulse, sub-CPI are adaptively processed at a time.
- The adaptive problem dimensionality reduces to: $K = K_s \times K_t \ll N \times M$.
- A separate adaptive problem is solved for each sub-CPI and the outputs are coherently processed with an $M' = M - K_t + 1$ pulse Doppler filter bank.
- Depending on the method of construction of the Beamformer matrix $\tilde{\mathbf{G}}$, we further discriminate between 2 methods:
  - i) Displaced-Beam pre-Doppler (or Displaced Phase Center pre-Doppler).
  - ii) Adjacent-Beam pre-Doppler.

BEAMSPACE STAP
Case III: Pre-Doppler Processing



Displaced-Beam pre-Doppler

- Dual of PRI-Staggered post-Doppler STAP.
- A single $N \times K_S$ Beamformer Matrix is applied to each element producing K_S Output Beams.
- For each Beam, an adaptive processor combines the K_t output pulses to produce the output signal for that sub-CPI.
- Finally, the outputs are coherently processed with an non-adaptive M' pulse Doppler filter bank $\mathbf{F}$.

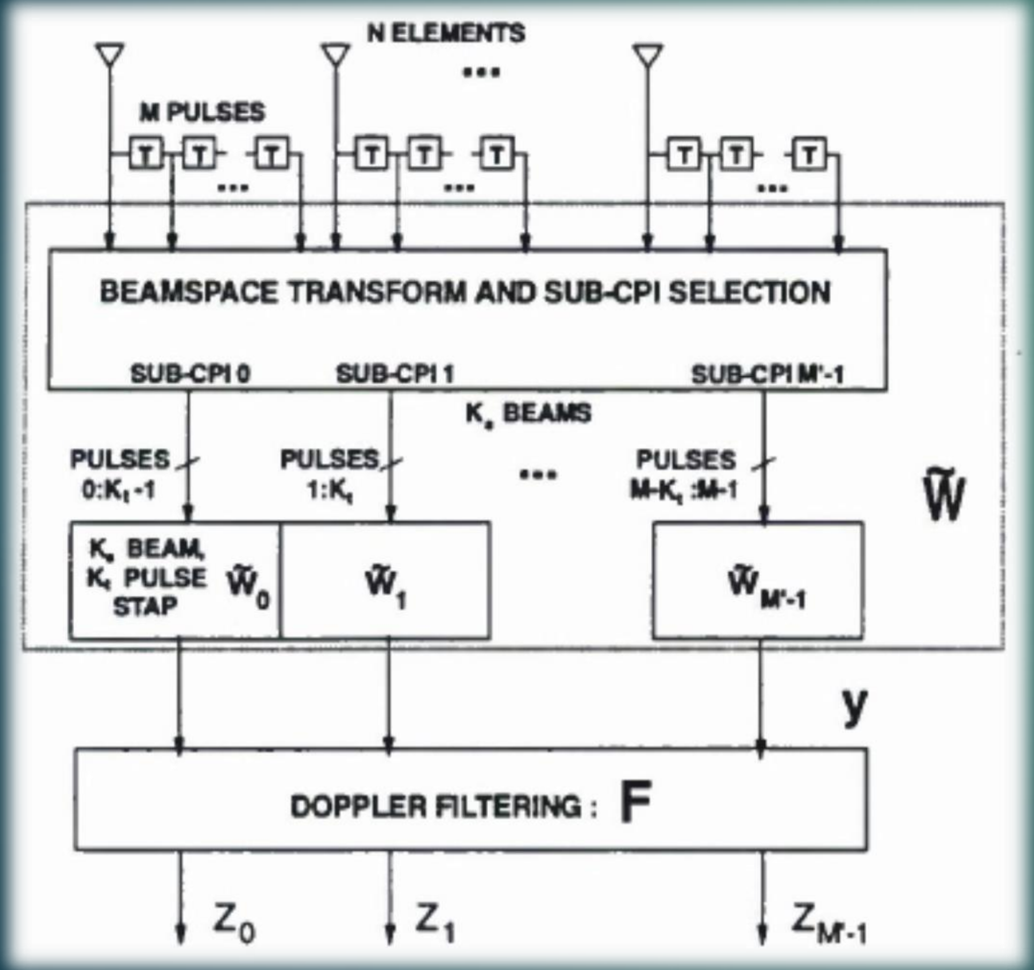
BEAMSPACE STAP
Case III: Pre-Doppler Processing

- Displaced-Beam pre-Doppler Preprocessor : $\mathbf{T_p} = \mathbf{J}_p \otimes \widetilde{\mathbf{G}}$,
  - where $\mathbf{J}_p = \begin{bmatrix} \mathbf{0}_{p\times K} \\ \mathbf{I}_K \\ \mathbf{0}_{(M-K-p)\times K} \end{bmatrix}$ is an $M\times K$ pulse selector matrix.
  - For Displaced-Beam pre-Doppler STAP:

$$\widetilde{\mathbf{G}} = \text{Toeplitz}\left([\mathbf{g}\,;\ \mathbf{0}_{(K_s-1)\times 1}], [g_0\,;\ \mathbf{0}_{1\times(K_s-1)}]\right)$$

  - $\mathbf{g}$ is a $N'\times 1$ beamformer vector.
- <u>Same Form of Beamformer Matrix as with DPCA</u>.

BEAMSPACE STAP
Case III: Pre-Doppler Processing



Adjacent-Beam pre-Doppler

- Dual of Adjacent-Bin post-Doppler STAP.
- Utilizes a set of adjacent beams each using the full aperture.

BEAMSPACE STAP
Case III: Pre-Doppler Processing

- Adjacent-Beam pre-Doppler Preprocessor : $\mathbf{T_p} = \mathbf{J}_p \otimes \widetilde{\mathbf{G}}$,
  - where $\mathbf{J}_p = \begin{bmatrix} \mathbf{0}_{p\times K} \\ \mathbf{I}_K \\ \mathbf{0}_{(M-K-p)\times K} \end{bmatrix}$ is an $M\times K$ pulse selector matrix.
  - For Adjacent-Beam pre-Doppler STAP:

$$\widetilde{\mathbf{G}} = \mathbf{G}\mathbf{J}$$

  - $\mathbf{G}$ is a $N\times N$ beamformer matrix whose columns are beamformers steered to different angles.
  - $\mathbf{J}$ is a $N\times K_S$ selector matrix that chooses the columns of $\mathbf{G}$ so as to form a cluster of adjacent beams centered around the transmit direction.

BEAMSPACE STAP
Case IV: Post-Doppler Processing

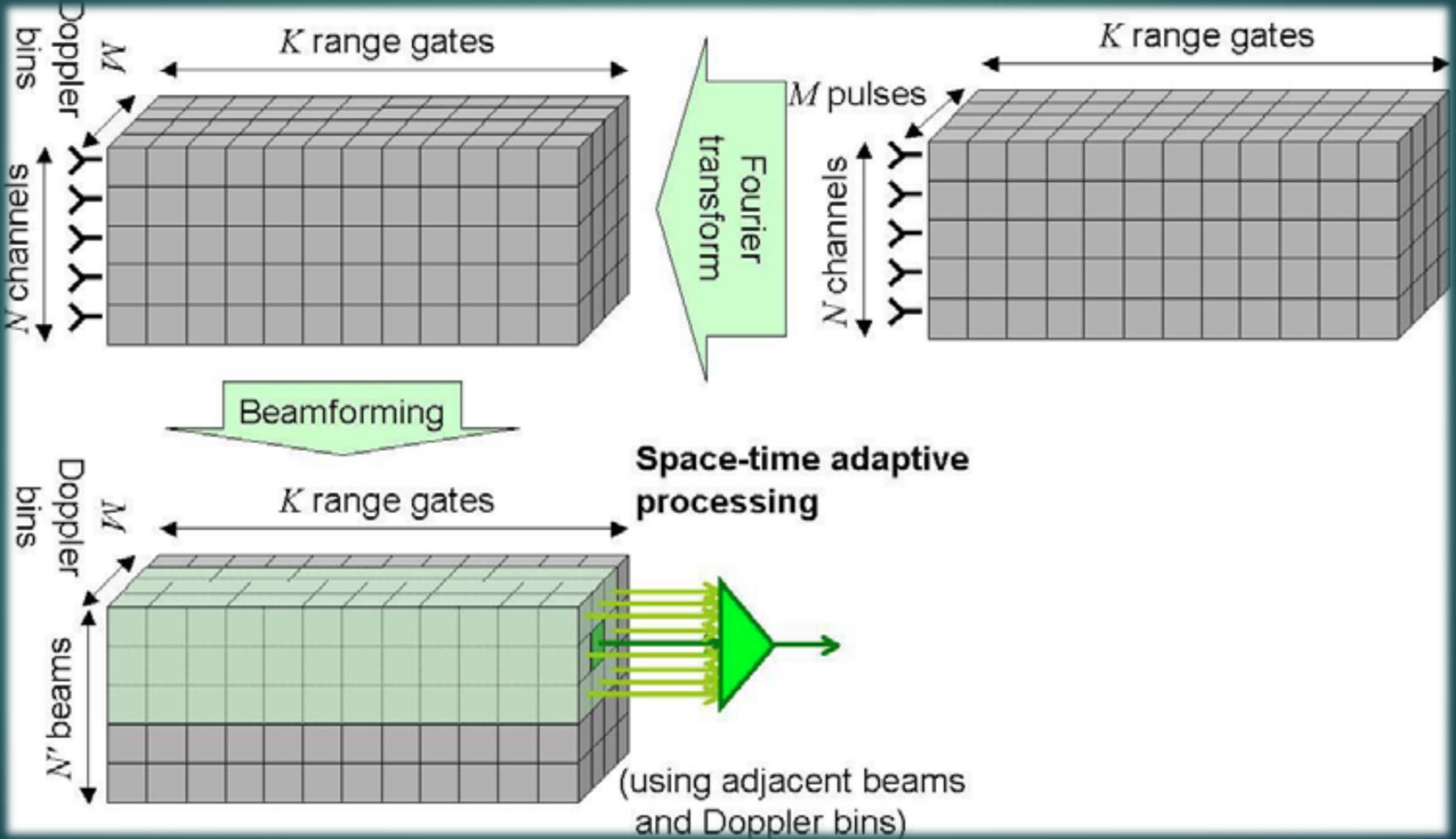
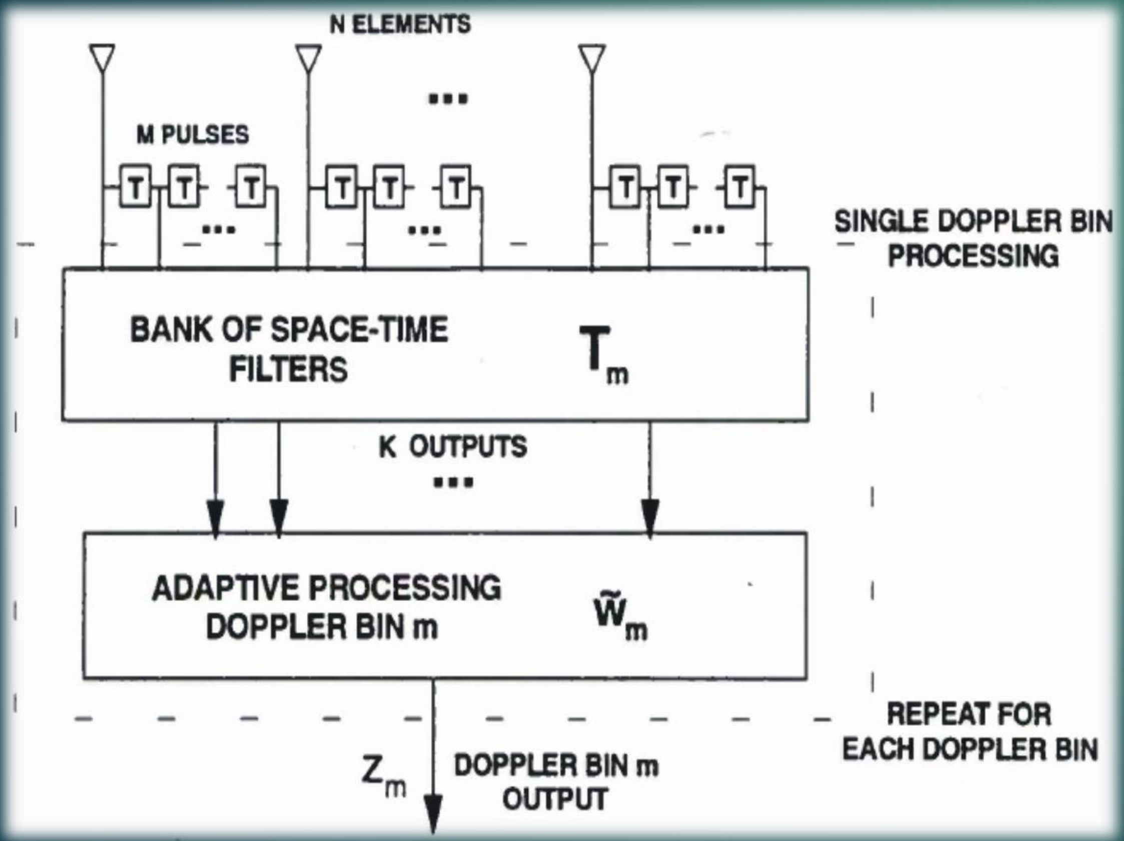


Figure adopted from [5].

BEAMSPACE STAP
Case IV: Post-Doppler Processing

- Preprocessing with a bank of small space-time filters.
- Cascade spatial beamformers on each pulse with Doppler filters on each beam.
- The filtered signals are then adaptively combined to produce Doppler bin outputs. This is repeated for every Doppler bin.
- Combined beamforming and Doppler filtering provides substantial suppression of portions of interference, localizing it prior to adaptation.
- Depending on the way of construction of the preprocessor filtering matrix $\mathbf{T}_m$ we can further discriminate between 2 methods:
  - i) Displaced Filter Beamspace post-Doppler: $\mathbf{T}_m = \tilde{\mathbf{F}}_m \otimes \tilde{\mathbf{G}}$
  - ii) Adjacent Filter Beamspace post-Doppler: $\mathbf{T}_m = (\mathbf{F} \otimes \mathbf{G})\mathbf{J}_m$ by Cai & Wang [3].

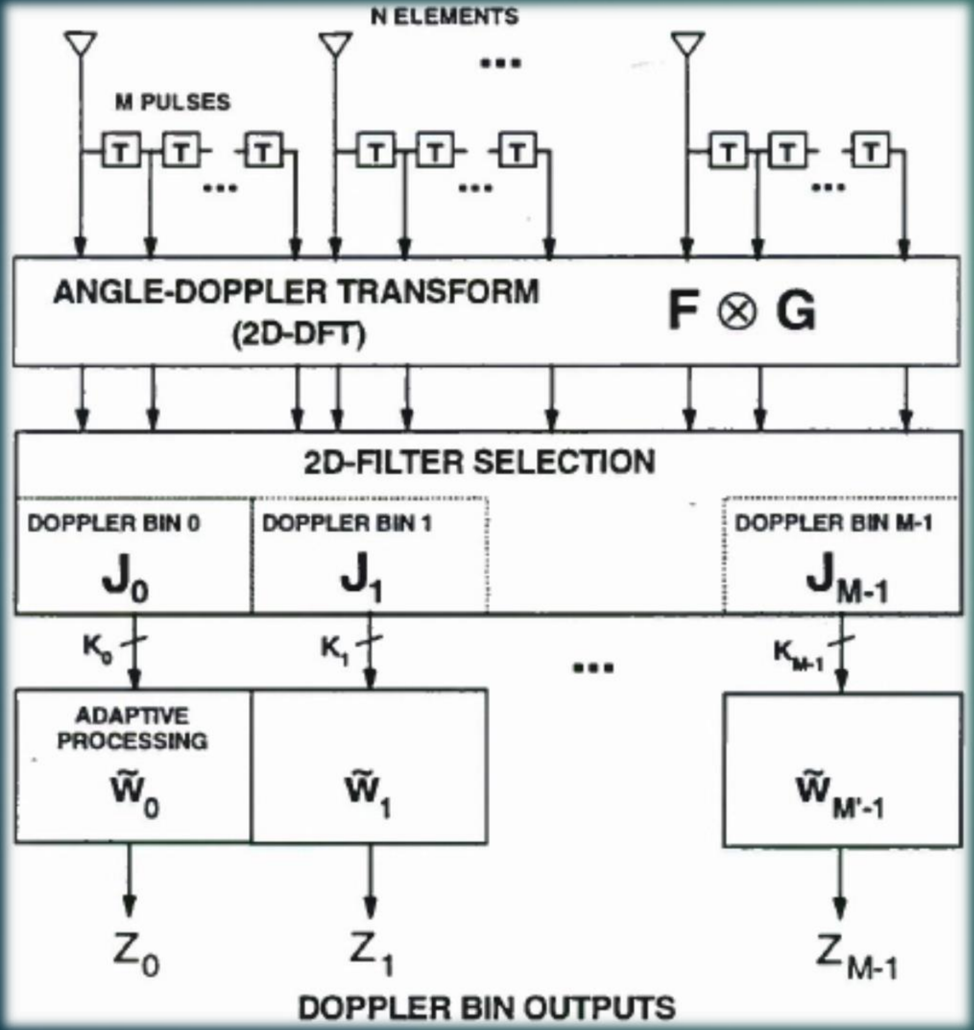
BEAMSPACE STAP
Case IV: Post-Doppler Processing



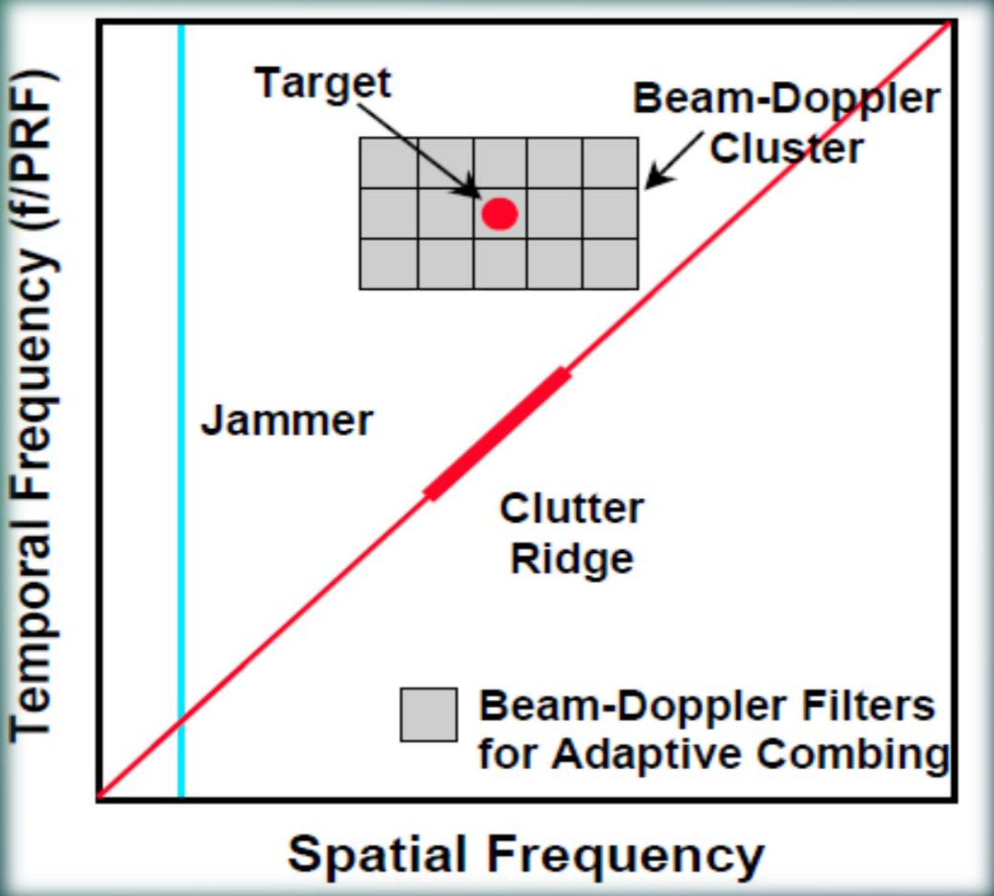
Displaced Filter Beamspace post-Doppler

- This preprocessor is *separable* because it may be implemented by cascading multiple beamformers on each pulse with multiple Doppler filters on each beam (or vice versa).

BEAMSPACE STAP
Case IV: Post-Doppler Processing



Adjacent Filter Beamspace post-Doppler



Partially Adaptive STAP References

[1] L.E. Brennan, F.M. Staudaher, "Subclutter Visibility Demonstration", Technical Report RL-TR-92-21, Adaptive Sensors Incorporated, March 1992.

[2] R. DiPietro, "Extended Factored Space-Time Adaptive Processing for Airborne Radar Systems", Proceedings of the 26th Asilomar Conference on Signals, Systems and Computing, Pacific Grove, CA, Oct. 1992, pp 425-430.

[3] H. Wang, L. Cai, "On Adaptive Spatial-Temporal Processing for Airborne Surveillance Radar Systems", *IEEE Trans. Aerospace and Electr. Sys.*, vol. 30, no.3, July 1994, pp 660–669.

[4] Y. Dong, "Overview of STAP Algorithms", DSTO-TN-0992, March 2011.

[5] Bürger W., "Space-Time Adaptive Processing: Algorithms", In *Advanced Radar Signal and Data Processing*, Educational Notes RTO-EN-SET-086, Paper 7.