Basic study on the Ionospheric Observations of the PANSY radar; Adaptive Sidelobe Cancellation Techniques for the FAI Clutters

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Introduction

- PANSY radar [1]
  - ✓ A large VHF active phased array at Syowa Station, Antarctica
  - ✓ Can observe Ionospheric incoherent scatterings in addition to the MST radar functionalities
  - ✓ Has supplemental antenna array for Field Aligned Irregularities (FAIs)
- Ionosphere observation of the PANSY radar
  - ✓ FAIs are assumed to be clutters because of their strong coherent backscattering (Fig. 1)
- Objective
  - ⇒ To separate FAI echoes by adaptive beam synthesis utilizing both the main and FAI array

[1] Sato et al., J. Atmos. Sol. Terr. Phy., 118A, 2-15, 2014

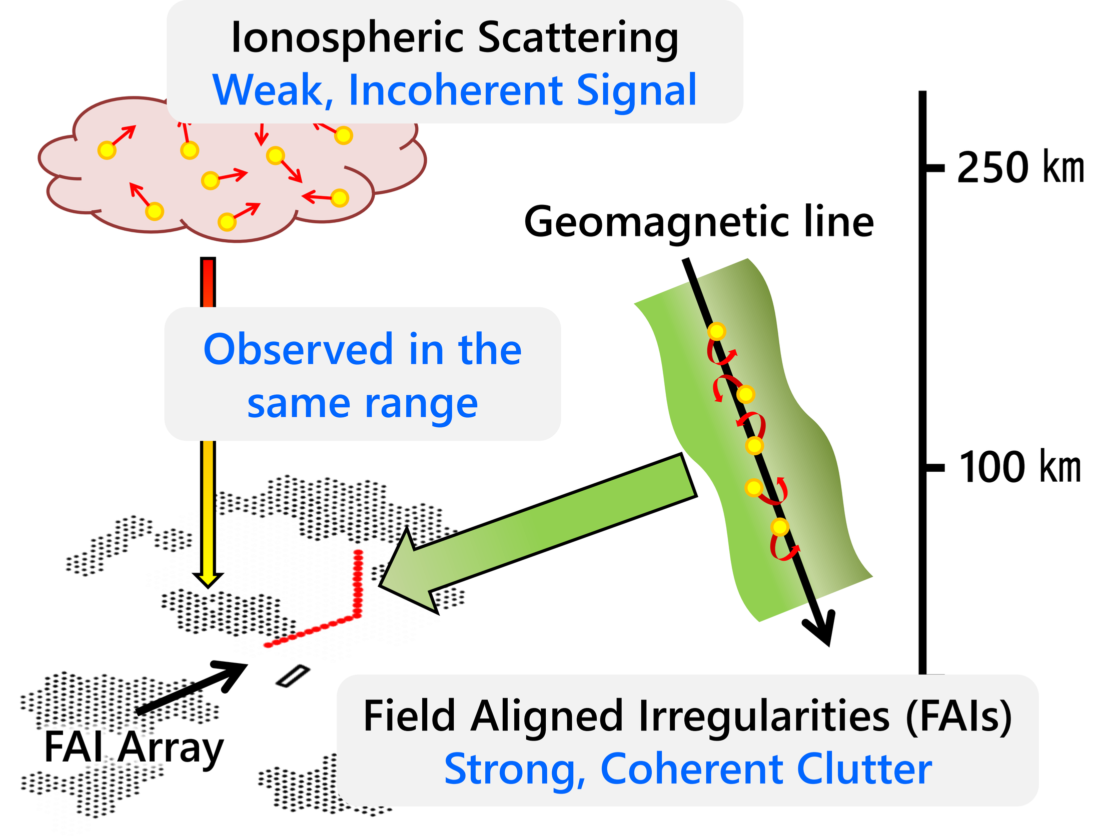
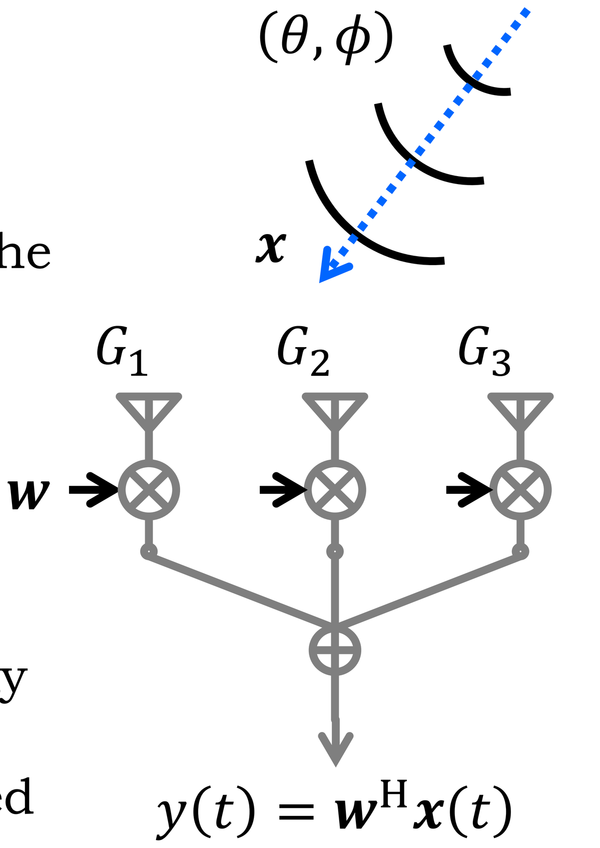


Fig. 1 Ionosphere observation of the PANSY radar and FAI clutter

Method

- Norm Constrained Tamed Adaptive (NC-TA) [2]
  - ✓ Based on Capon beamformer
  - ✓ Has additional constraint about the norm of the optimal weight $\boldsymbol{w}$ to control the SNR loss
    - ⇒ Because the weight norm increase directly connects to the increase of the noise level
  - ✓ Norm constraint can be calculated by the desired SNR loss L
- Gain weighting
  - ✓ Can handle large main array + small sub array
  - ✓ The steering vector $\boldsymbol{A}(\theta,\phi)$ is weighted by the directional gains of each channel to the desired direction

[2] Hashimoto et al., J. Atmos. Oceanic Technol., 31, 2749–2757, 2014



$$R_{xx} \coloneqq \boldsymbol{x}\boldsymbol{x}^{\mathrm{H}}$$
$$\boldsymbol{C} \coloneqq \boldsymbol{G} \circ \boldsymbol{A}(\theta,\phi)$$
$$L \coloneqq \text{SNR Loss (Antilog)}$$
$$U = \frac{1}{L}$$
Find $\alpha > 0$ such that
$$\hat{R}_{xx} = R_{xx} + \alpha I$$
$$\boldsymbol{w} = \frac{\hat{R}_{xx}^{-1}\boldsymbol{C}}{\boldsymbol{C}^{\mathrm{H}}\hat{R}_{xx}^{-1}\boldsymbol{C}}$$
$$|\boldsymbol{w}|^2 \le U$$

Fig. 2 The model for adaptive signal processing

Experiment

- A test observation is made on Feb 15, 2015
  - ✓ A Helicopter is targeted assuming FAI clutter
  - ✓ Helicopter has GPS track recorder as the "true position" for the phase calibration
    (Note phases of the main array can be known by self test)
  - ✓ 16 channels (8 for main array, 8 for FAI array)

Other Radar Parameters

Center Frequency	47MHz
Peak Power	520 kW
Main Array Element	1045 Crossed Yagi (vertical)
FAI Array Element	24 Yagi (30° elevation)
Sampling Interval	8 ms
Range Resolution	150 m

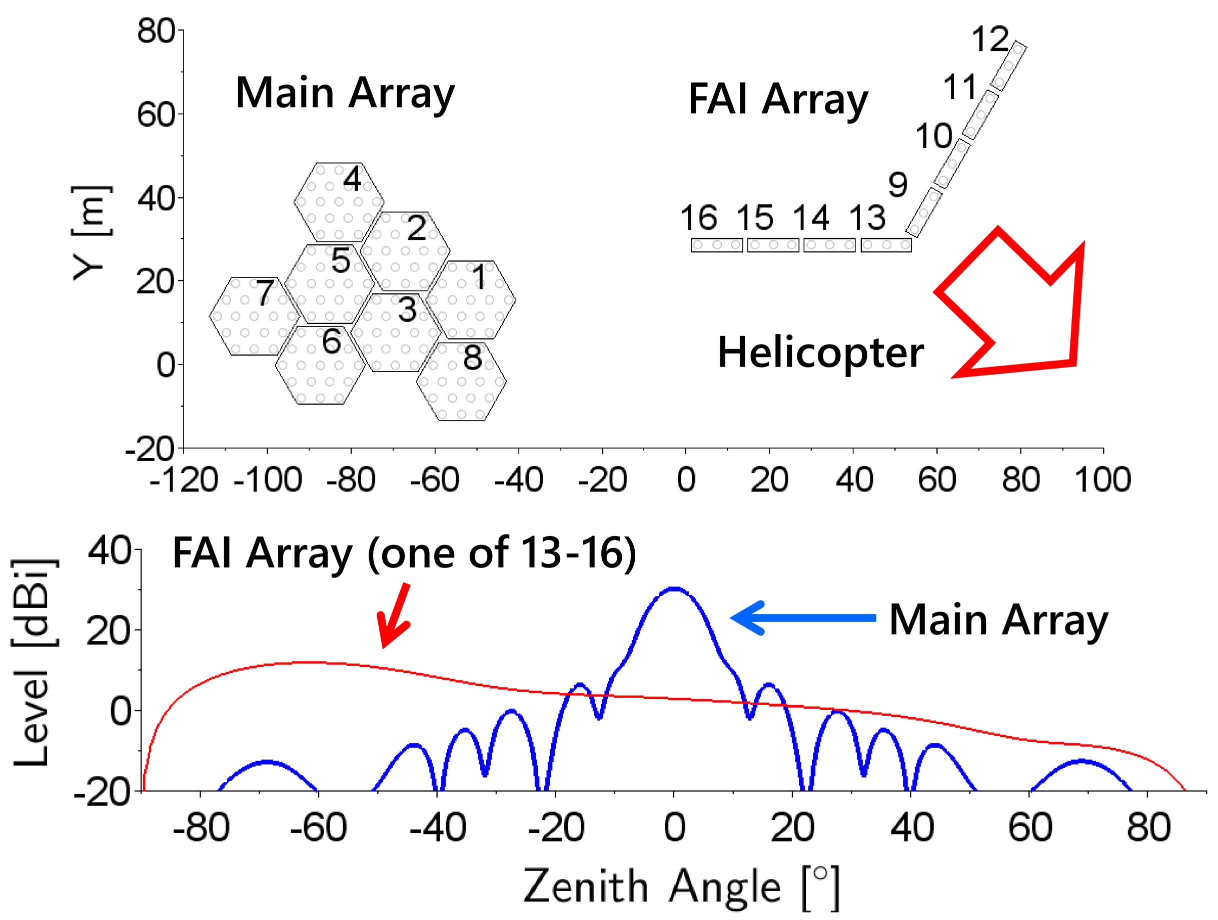


Fig. 3 Antenna position and beam pattern (Azimuth = 0°) of main and FAI array

Helicopter Echoes

- Characteristics of the helicopter echoes
  - ✓ The target has 3 blades for the main roter
  - ✓ Backscattering from a blade can only be observed when the line of sight becomes perpendicular to the blade
  - ⇒ Both the time series and the Doppler spectrum of the roter signal become series of impulses (Fig. 4)
    For this case, the roter has 3 blades and rotates about 400 RPM
- Phase Calibration of the FAI array
  - ✓ Applied the low pass filter to extract the signal from the helicopter body (shown in a rectangle of Fig. 4)
  - ✓ Performed the least square fitting between the phases of the observed signals and the true phases calculated from the antenna-helicopter distances obtained by GPS
  - ⇒ Phase errors are still remaining, and the gradients are different channel-by-channel (Fig. 5)
  - ⇒ Caused by inaccuracy of GPS truth?

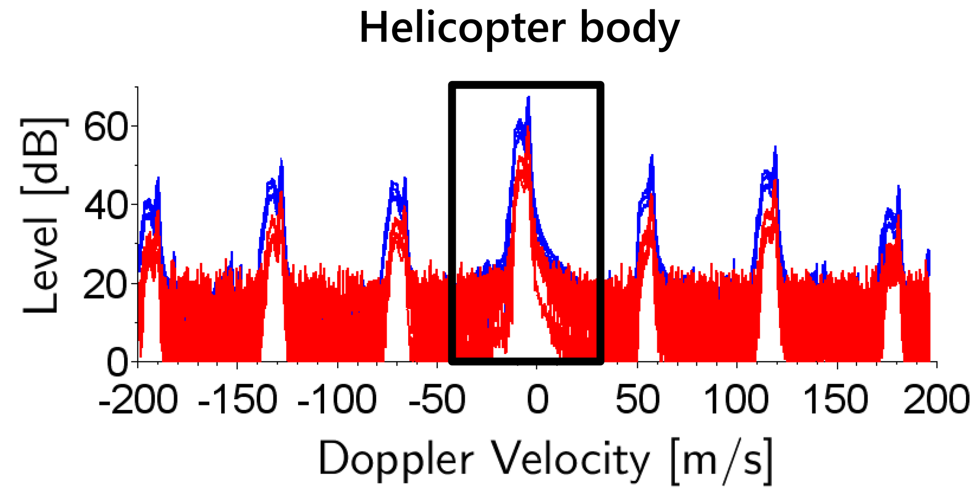


Fig. 4 Doppler spectrum of the helicopter echoes for 32 seconds

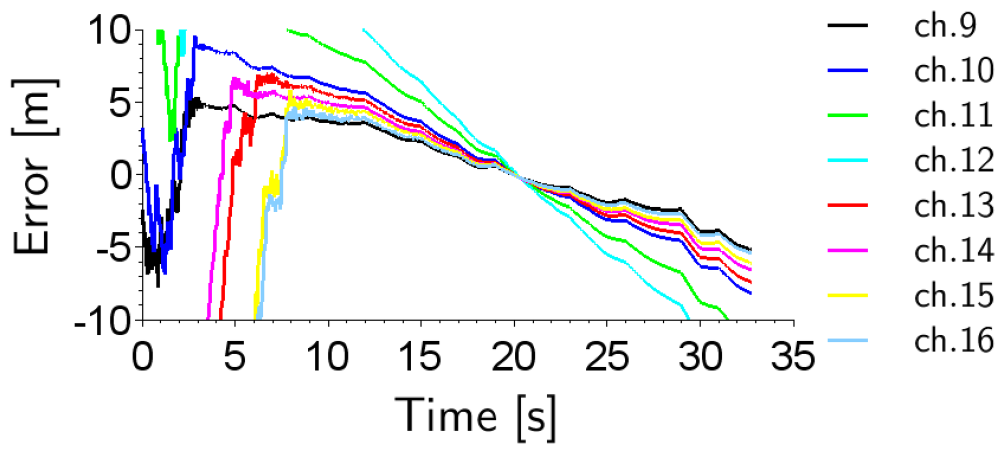


Fig. 5 Phase errors for each channel after calibration (converted into distance)

Results and Discussions

- Two methods are compared on the same data
  - ✓ Ordinary 8-channel uniform NC-TA by main array only
  - ✓ 9-channel Gain-weighted NC-TA with main and FAI array
    - ✓ Main array is nonadaptively synthesized into 1 channel (Fig. 6)
    - ✓ FAI array is used separately (8channel)
  - ⇒ Permissive SNR loss is set to 0.5 dB for both settings
  - ⇒ Desired direction is set to the zenith
- Gain-weighted NC-TA by the FAI array worked fine
  - ✓ Showed better performance than the uniform NC-TA against the helicopter clutters in front of the FAI array (Fig. 7)
  - ✓ Ground clutters is difficult to suppress because the FAI array does not have the sensitivity to other directions

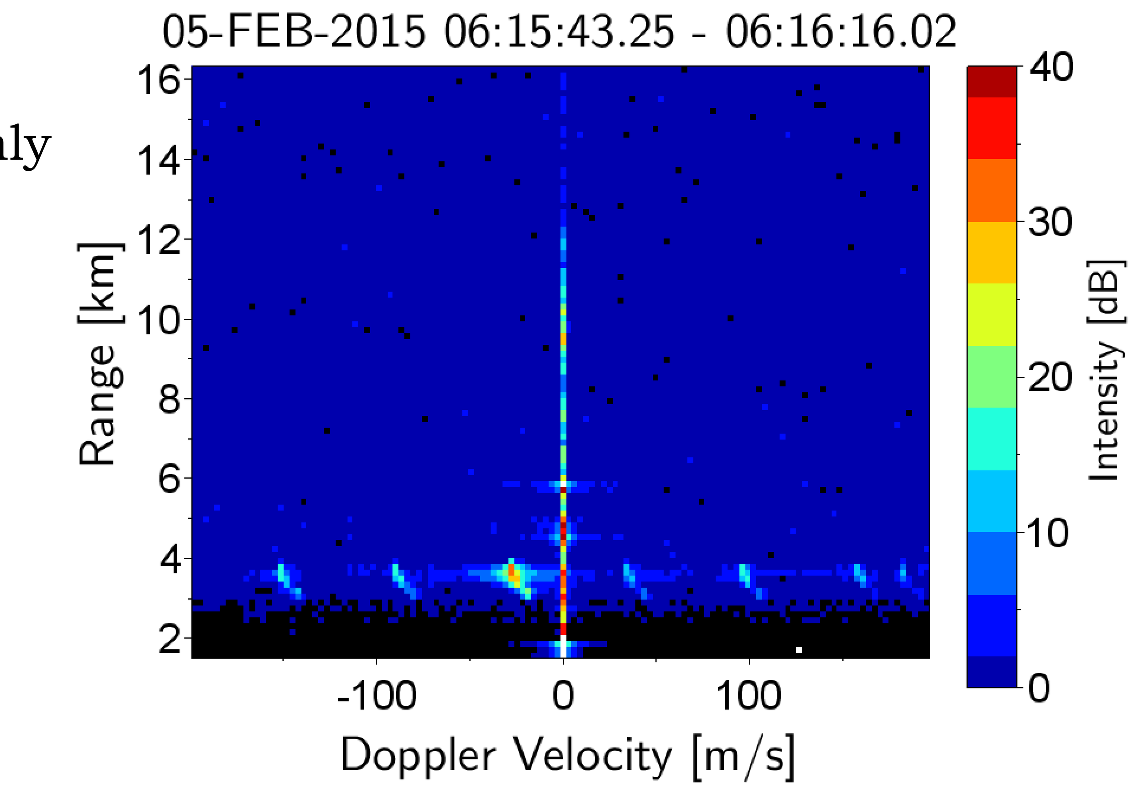


Fig. 6 Whole Doppler spectrum obtained by the nonadaptive beamforming method

Conclusion and Future Works

- The gain-weighted NC-TA is tested with the FAI array of the PANSY radar
- The method worked well against the helicopter clutters
- Further accuracy is needed for the phase calibration
- Now working on the more plactical observation data
  - ✓ Ionosphere observation with whole 55-channels main array and FAI array

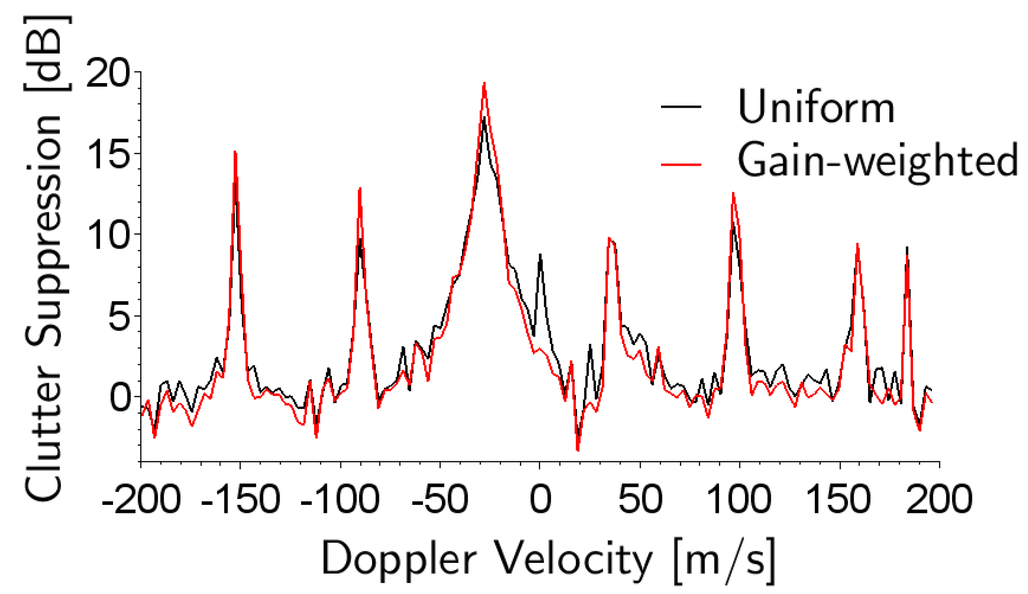


Fig. 7 The clutter suppression ratio at the range where the helicopter exists obtained by both uniform and gain-weighted NC-TA