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Mutual Coupling Compensation for Adaptive Clutter Rejection in a Multistatic Atmospheric Radar

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1. Introduction

Adaptive array techniques are presented for clutter rejection in combination with multistatic atmospheric radar [1] in which ground clutters are observed extremely stronger than the desired atmospheric echoes. The adaptive clutter rejection technique requires a highly accurate steering vector to point the scattering center to preserve a weak desired echo while rejecting the other part effectively.

In a practical system, however, receiver array can persistently be suffered from shadowing and electromagnetic coupling between antennas which bias the steering phases. These effects lead to pointing errors and it is not easy to predict analytically the phase biases that changes from a direction to another.

In this study, we propose a compensation method of the phase biases based on an assumption that the bias should change moderately in the angular space to be observed. In our method, the phase biases are estimated by observed atmospheric echo and it does not need any additional physical measurement.

2. Observation System

The multistatic radar system is constructed based on the Equatorial Atmosphere Radar (47MHz, 5kW(ave)), West Sumatra, Indonesia, which is a conventional high gain monostatic atmospheric radar, with two auxiliary digital receiver arrays that are designed for this study with fully adaptive capabilities. The two of receiver arrays consisted of a dozen of antennas each and were set at ∼1100m in the west (named Site-A) and ∼1300m (named Site-B) in the south from the EAR.

The major specifications of the hardware of the receivers are as follows. Antenna: 4-element Yagi. Pre-amplifier: gain=25dB, NF<2dB. AD Converter: resolution=14bits, sampling rate=64MHz. Demodulation and down-conversion is made real-time and stored to hard-disc drives separately for each antenna after the pulse decompression and the coherent integration of 32 times.

We must remember that each receiver system has different intrinsic phase caused by characteristics of the individual analog part (antenna, cable, etc) and the difference of sampling timing. (or *integration timing* might be a more accurate term which is not synchronized between receivers while the sampling clock signal of 64MHz is commonly used for all the receivers constituting one site.) At an receiving antenna, the (relative) phase of an observed echo from a target indexed by i has a relation to its position r and the intrinsic phase φ given by

$$\psi_i = k_i \cdot (r - r_0) + \varphi$$

where r_0 is the reference point and k_i is the wavenumber vector. Note that k and r are known. Therefore, we can straitforwardly determine φ of each antenna by measuring several ψ_i.

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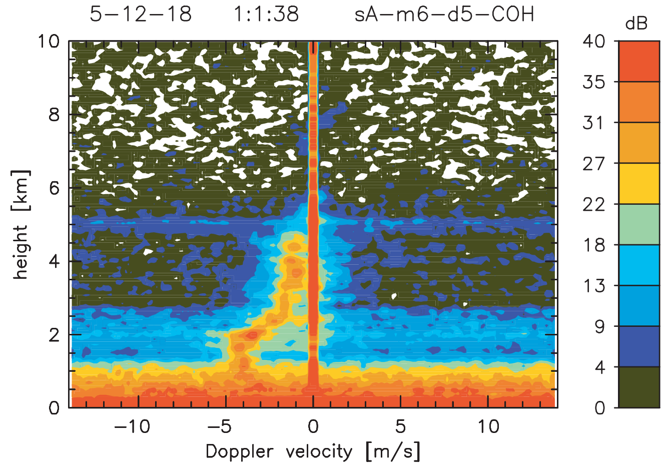

Figure 1: Doppler spectrum observed at Site-A with only post-set beamsteering. The intense stripe crossing from the bottom to the top at the velocity of 0 indicates ground clutters while the curved band shown up to the height of 5km means the atmospheric echo.

3. Post-set Beam-steering and Adaptive Clutter Rejection

Beamforming that is necessary to increase the gain to a target can be made in the post-process of observations owing to its independently recorded signals. It is worth noting that, from a receiver array of multistatic atmospheric radar, a target volume formed by a transmitted pulse moves at the speed of light.

In addition to the beamforming following a target, adaptive clutter rejection must be simultaneously performed. The algorithm employed for this purpose is the DCMP-CN (Directional Constraint Minimum Power with Constrained Norm) [2] that is derived by the principle; Minimize the average output power by controlling weight vector with a fixed response toward a pointed direction with limited degrees of freedom, states

$$\begin{aligned} &\text{minimize} && \left(P_{\text{out}} = \frac{1}{2} w^{\mathrm{H}} R w\right) \\ &\text{subject to} && w^{\mathrm{H}} c = 1 \text{ and } w^{\mathrm{H}} w < 1 + \delta \end{aligned}$$

where w is the weight vector, c is a steering vector defining the directional constraint, R is a correlation matrix of the input signals and δ is the allowance of weight controllability. The second condition functions to stabilize the output and δ is set to 0.5 in the following analyses. The solution is given by appropriate numerical optimization methods.

Applying this algorithm to an observed data, ground clutters are removed. Figure 1 and 2 shows a Doppler spectrum observed at Site-A without and with the clutter rejection, respectively. However, the atmospheric echo is also strongly suppressed because of imperfect phase constraint caused by mutual coupling and shadowing of antennas, despite the fact that the DCMP-CN algorithm is more stable againt this kind of errors than the DCMP algorithm.

4. Mutual Coupling Compensation

The mutual coupling and shadowing effect have somehow elusive nature and very hard to measure or predict in a real antenna array. We therefore measure these effect by using observed atmospheric echoes with a similar manner as the intrinsic phase measurement, with a small modification as

$$\psi_i = k_i \cdot (r - r_0) + \varphi(\theta, \phi)$$

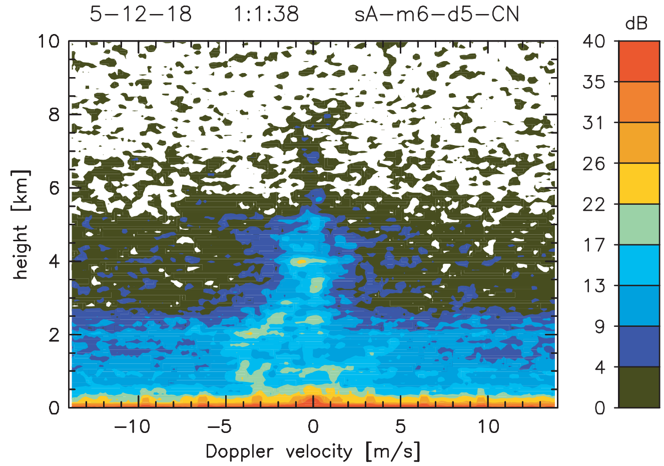

Figure 2: Same as Fig. 1 but with the adaptive clutter rejection.

where θ and ϕ are the zenith angle and the azimuth, respectively, and $\varphi(\theta, \phi)$ is the extended intrinsic phase function that includes the phase bias system caused by electromagnetic effects.

In order to represent the electromagnetic-inductive phase rotation system, we simply modeled φ as a linear function of the sine of the angular variables as

$$\varphi(\theta, \phi) = A \sin\theta \sin\phi + B \sin\theta \cos\phi + C.$$

Then we can estimate A, B and C from sufficient number of ψ_i measured at several brightest points in an observed data set.

To resolve the ambiguity of $\pm 2\pi N$ in modeling the phase rotation as a linear function, every phase value is set to fall within $\pm\pi$ from the adjacent direction (closest point in the $(\sin\theta \sin\phi, \sin\theta \cos\phi)$ space.). Figure 3 shows a result of fitted plane of the phase rotation system at certain antenna in Site-A.

The phase rotation systems are thus estimated for each antenna with the same manner and we can then estimate the phase biases by picking up the fitted function at any direction (θ, ϕ) of interest. Figure. 4 is a resulting Doppler spectrum that maintains the desired atmospheric echo while the clutters are still successfully rejected.

5. Conclusion

To compensate phase biases caused by mutual coupling and shadowing of antennas, a novel compensation method was presented. Our result showed this simple method, which does not require any physical measurement of electromagnetic coupling, sufficiently functions to estimate accurate phase biases caused by coupling and shadowing. Some alternative method that inductively estimates the phase biases can also be considered but analytic estimation must be much heavier and more sensitive to model errors (antenna parameters, for example) than our method.

References

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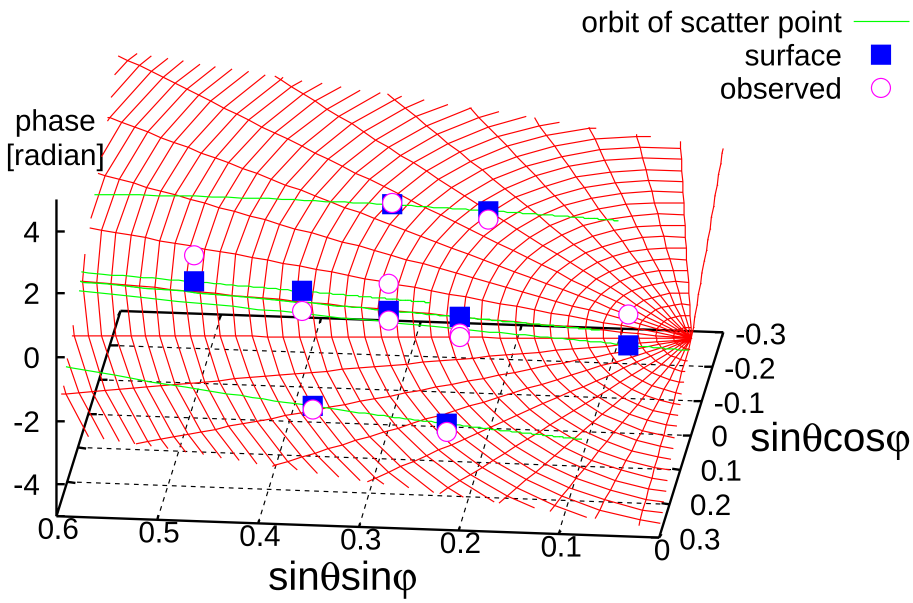

Figure 3: Fitted linear function and the measured phase in observed data (open circles) of an antenna in Site-A. Closed squares show the point on the surface at each corresponding open circle to show the residual difference. Green lines indicate the pass of the center of scattering volumes observed from the site.

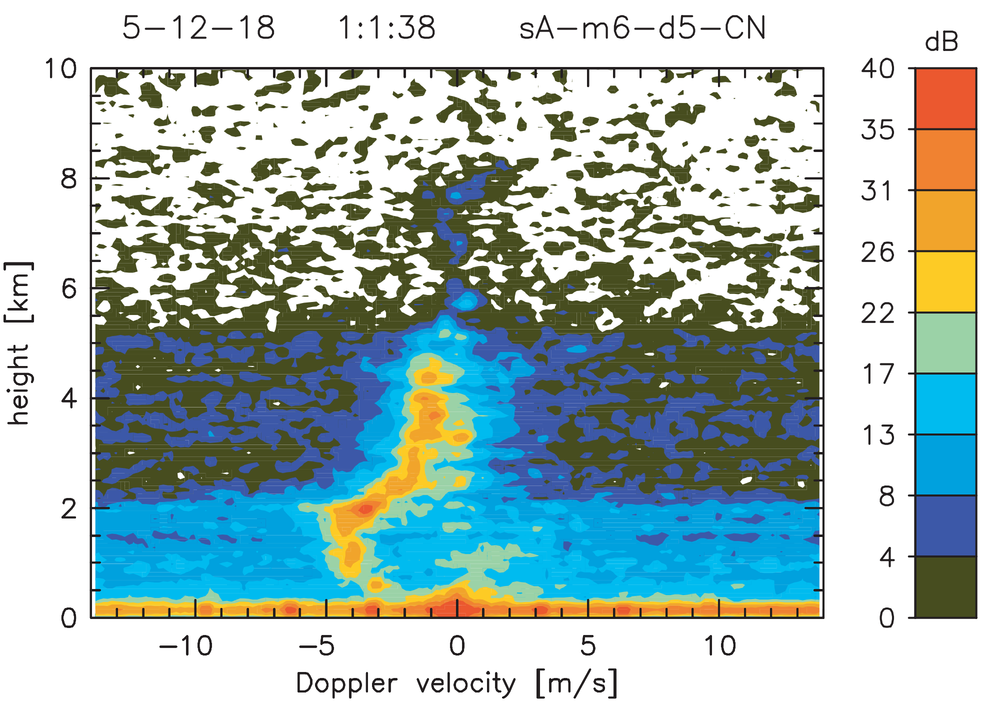

Figure 4: Same as Fig. 2 but with the electromagnetic coupling compensation.