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Omni Scanning DPCA using Two Passive Antennas with Vertical Separation

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Abstract : In tactical theater, it is crucial to detect ground moving targets and to locate them precisely. This problem can be resolved by using SAR (Synthetic Aperture Radar) sensors providing GMTI (Ground Moving Target Indication) capability. In general, to implement a robust GMTI sensor is not simple because of the strong competitions between target signals and clutter signals from the ground, and low speed of moving targets. Contrary to the case that a delay canceller is mostly suitable for ground surveillance radars, DPCA (Displaced Phase Centered Antenna) or STAP (Space Time Adaptive Processing) techniques have been widely adapted for GMTI function of modern airborne radars.

In this paper, a new scheme of DPCA using two passive antennas with vertical separation is proposed, which also provides good clutter cancellation performance. The proposed scheme realizes full azimuth coverage for DPCA operation on an airborne platform, which is impossible with classical DPCA configuration. Simulations using various conditions have been performed to validate the proposed scheme, and the results are acceptable.

Key Words : SAR, GMTI, DPCA, STAP, Delay Canceller.

1. Background

In tactical theater, it is very important to detect ground moving targets as potential threats. Compared to ground based radars, detecting moving targets on the ground is not a simple task for airborne radars. In airborne case, ground clutters have Doppler frequencies caused by the relative motion between radar and the ground. Therefore, Doppler frequency of a slow moving target may fall in the Doppler spectrum of ground clutters as shown in Fig. 1 (Stimson, 1998; Edde, 1993; Skolnik, 1980).

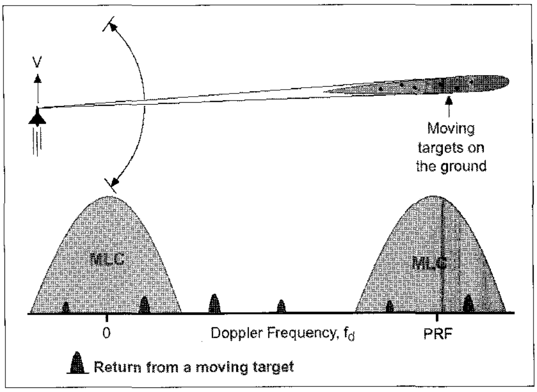

Figure 1. Doppler spectrum of GMT (Stimson, 1998).

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In order to isolate moving targets from ground clutters, DPCA is introduced for airborne radars. With DPCA, the forward antenna transmits and receives a pulse (n) at a position in space. Exactly one PRI later, at the same position the apt antenna transmits and receives a pulse (n+1). This alternating pulsing delayed by PRI is the basic concept of DPCA (see Fig. 2). For the pulse (n) and pulse (n+1), if there are moving targets illuminated by radar, there will be phase variation due to target motion. Otherwise, no phase variation will occur because ground clutters are assumed to be stationary.

With pulse train received by DPCA operation, a delay canceller is applied to isolate moving targets from clutter signals. Pulses of the same range bin are fed into delay canceller, which subtracts the very previous pulse exactly delayed by PRI from the current pulse. And the output of delay canceller is delivered to Doppler filters to detect targets (see Fig. 3)(Stimson, 1998; Levanon, 1988).

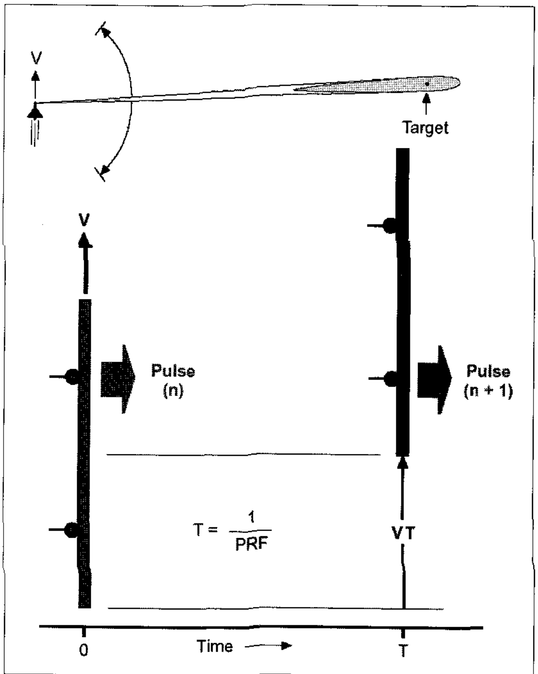


Figure 2. DPCA operation (Stimson, 1998).

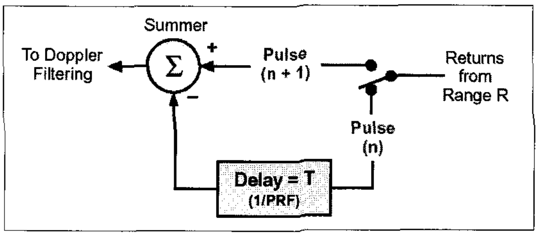


Figure 3. Delay canceller (Stimson, 1998).

2. The Proposed Method

DPCA technique using active antennas has been adapted to provide GMTI capability in airborne radars such as JSTARS, but this not only requires complex and expensive antennas but also has scanning angle limitation. Active antennas can not steer radar beam up to 90 degrees (Ender, 1999). In spite of the limitations, DPCA provides strong clutter cancellation in a simple way. In this paper, a new scheme for DPCA operation using two passive antennas is presented, which delivers the following advantages over classical DPCA.

a. Use of passive antennas

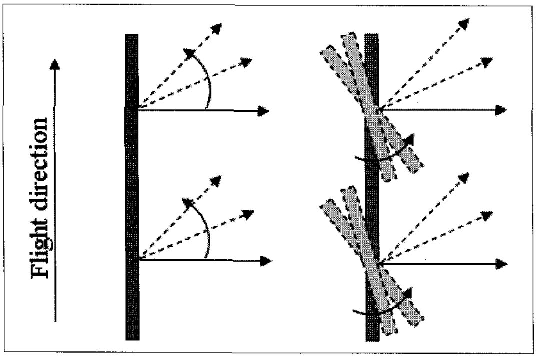
b. No scanning angle limitation

c. Less volume for antenna installation

1) Antenna Configuration

The basic idea of DPCA operation is to implement a single canceller on a moving platform using two horizontally displaced antennas which are perfectly aligned to flight direction (Fig. 4a). However, in case of using passive antennas, to provide scanning operation, antennas should be separated and can be rotated on its axis as shown in Fig. 4b.

As scanning angle increases, one antenna blocks transmission and reception of radar signals of the other antenna, and therefore the radar can not provide full coverage of scanning angle. To resolve this situation, additional displacement is introduced in vertical direction as shown in Fig. 5. With vertical



(a) active antenna (b) passive antenna

Figure 4. Scanning operation.

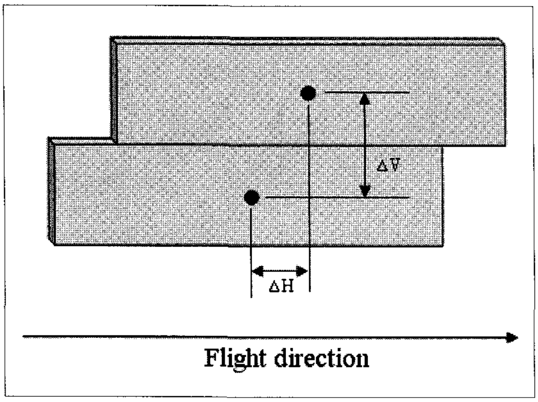


Figure 5. Proposed configuration.

separation, each antenna does not block the other antenna and full azimuth coverage can be achieved. And more, this configuration requires less volume for antenna installation.

2) Phase Compensation

With vertical separation as shown in Fig. 5, APCs (Antenna Phase Centers) are not co-aligned. Therefore, it is needed to correct received signals at antenna b as if the signals are received at antenna b' by adjusting phase of the signals (see Fig. 6).

The received signal of a range bin is the vector sum of each signal from individual scatters within the ground patch of the range bin. As it is not possible to compensate phase of each signal, slant range of a range bin is used to calculate phase correction as a

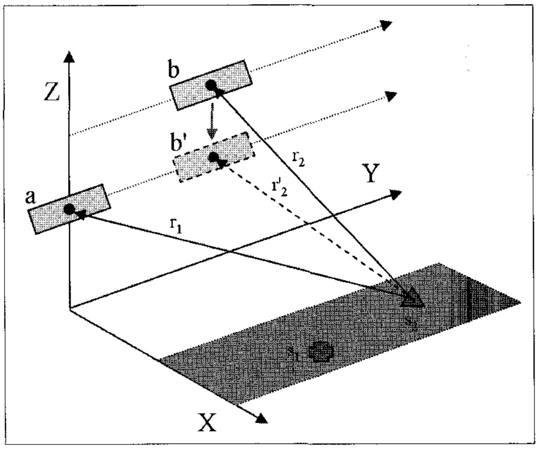


Figure 6. Radar geometry.

representative value.

Received signals at each antenna can be expressed as (1) and signals of antenna b will have additional phase caused by vertical separation.

$$
\begin{aligned}
s^a(t) &= \sum_{i=1}^{k} a_i e^{-j\phi_i^a(t)} \\
s^b(t) &= \sum_{i=1}^{k} a_i e^{-j\phi_i^b(t)} \\
&= \sum_{i=1}^{k} a_i e^{-j(\phi_i^a(t) + \Delta\phi_i(t))}
\end{aligned} \tag{1}
$$

where $s^a(t)$, $s^b(t)$: received signal at antenna a, b

$a_i(t)$: amplitude of received signal

$\phi_i^a(t)$, $\phi_i^b(t)$: phase of received signal

$\Delta\phi_i(t)$: phase difference between received signal

The purpose of phase compensation is to remove $\Delta\phi_i(t)$ in order to ensure proper DPCA operation and $\Delta\phi_i(t)$ can be calculated by using (2) (see Fig. 7).

$$
\begin{aligned}
r'^2_2 &= x^2 + h^2 \\
r^2_2 &= x^2 + (h + \Delta V)^2 \\
\Delta R &= \sqrt{r'^2_2 - h^2 + (h + \Delta V)^2} - r'_2 \\
\Delta\phi &= -\frac{4\pi\Delta R}{\lambda}
\end{aligned} \tag{2}
$$

where h: altitude of antenna b' (same as antenna a)

ΔV: vertical separation

r_2, r_2: slant range of antenna b and b'

ΔR: path difference

$\Delta\phi$: phase difference

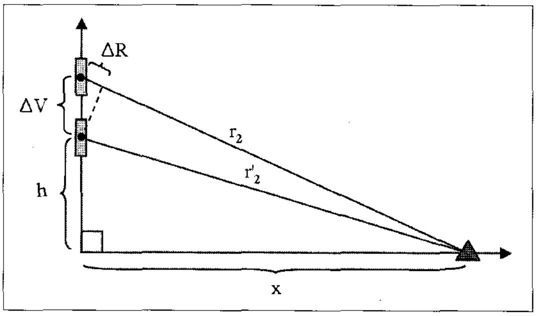


Figure 7. Geometry for calculation.

λ: wavelength

Once $\Delta\phi_i(t)$ is determined, this is subtracted from the phase of signals at antenna b.

3. Simulation and Analysis

To analyze clutter cancellation performance of the proposed method, simulations have been performed using parameters as shown in Table 1.

Using single moving target and single clutter scatter, MTI gain (improvement factor) is calculated by using (3) for the following cases.

- Case1: classical DPCA
- Case2: proposed method without phase compensation
- Csae3: proposed method with phase compensation

$$I = \frac{SCR_o}{SCR_i} \tag{3}$$

where I : MTI gain

SCR_o: SCR at filter output

SCR_i: SCR at filter input.

Based on the approach explained in previous section, simulation codes are developed in Matlab™, which consist of the following processing steps.

a. setup parameters

b. generate raw signals

c. perform DPCA operation

d. calculate MTI gain

e. plot the result

Finally, simulation results of the three cases have been produced and investigated in order to verify the validity of the proposed approach as follows.

Table 1. Simulation parameters.

Maximum radial velocity	120 m/s
PRF(30% margin)	18000 Hz
PRI	1/18000 sec
Altitude	10000 m
Radar velocity vector	[0, 90, 0] m/s
Target velocity vector	[-1, 1, 0]*10 m/s
Horizontal separation	0.05 m
Vertical separation	0.15 m
Target RCS	10 dB
Clutter RCS	10 dB
Pulses integrated	512
Integration time (CPI)	512/18000 sec
Carrier wavelength	0.031 m
Signal phase noise	0.01λ/PRI(3.6°/PRI)
APC perturbation	0.5/CPI in x 1e-3/PRI in x, y, z
Slant range	10 km ~ 100 km
Squint angle	0° ~ 90°

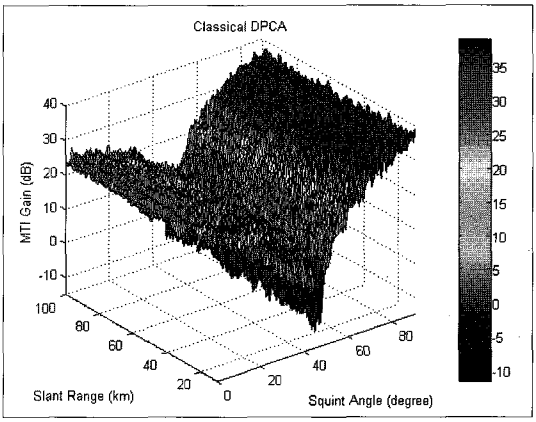


Figure 8. MTI gain of Case1.

The valley at angle 45 is caused by target orientation used in simulation. At this angle, radial velocity of the target becomes zero (refer to Table 1).

The pattern of gain fluctuation in Fig. 9 is caused by the facts that phase error between antenna b and antenna b' is modulated by 2π and the change rate of ΔR is decreased along the slant range.

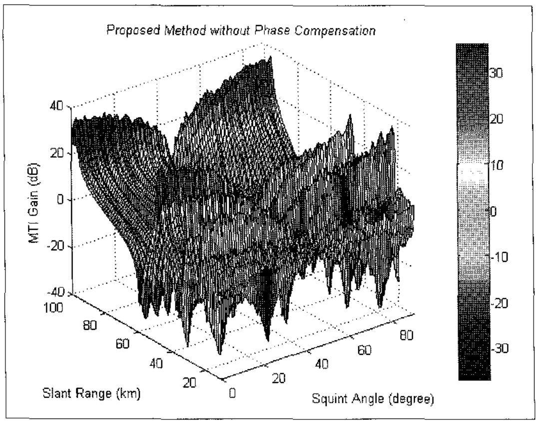


Figure 9. MTI gain of Case2.

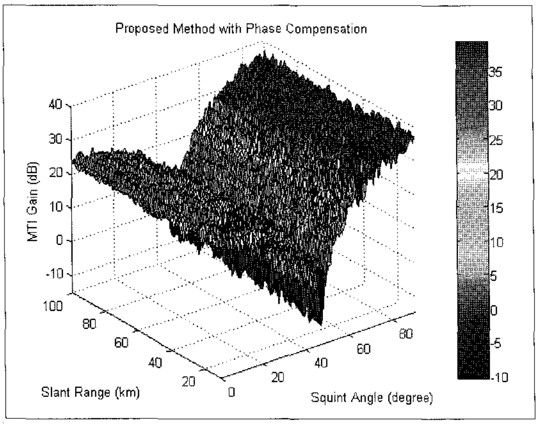


Figure 10. MTI gain of Case3.

Though the proposed method can not compensate the phase error completely, cancellation performance is almost the same as Case1 (see Fig. 11).

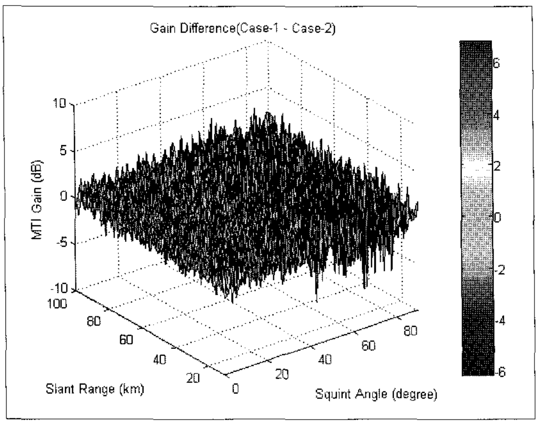


Figure 11. Gain difference (Case1 - Case3).

Table 2. Gain statistics.

	Mean	Std
Case 1	21.481638	9.2535059
Case 2	0.9822032	10.380273
Case 3	21.435130	9.2547521

Table 2 shows mean and standard deviation of the gains of three cases.

4. Conclusion

In the domain of airborne targets detection for ground based radars, delay line canceller has been widely used to detect airborne threats such as aircrafts and missiles. However, for airborne radars to detect the ground moving targets is more complex because of clutter interferences and relatively low speed of ground moving targets. This leads to a DPCA solution that performs single line delay cancellation by using two antennas horizontally separated by PRI distance.

The GMTI implementation using classical DPCA is simple but has some constraints. It can not operate at all scanning angle in azimuth. To resolve this limitation, additional vertical separation between antennas is introduced and the proposed scheme requires less volume for antenna installation in general.

Simulations have been performed to see the validity of the new method. MTI gain defined as the ratio of output SCR to input SCR is calculated in the following cases.

- Case 1: classical DPCA
- Case 2 : proposed method without phase compensation
- Case 3 : proposed method with phase compensation

Simulation results show that phase compensation due to the vertical separation is mandatory and the compensation scheme is valid with marginal gain loss.

MTI gain of the proposed method is very close to that of classical DPCA and the statistics of gain differences between two cases supports the validity of the proposed method for resolving the aforementioned limitations of classical DPCA.

Having a good solution using passive antennas for GMTI capability implies many advantages in manufacturing cost, calibration effort and maintenance over active antenna solutions, which is the motivation of this research and further analysis will be performed.

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