Detecting Moving Targets in Clutter in Airborne SAR via Keystoning and Multiple Phase Center Interferometry

D. M. Zasada, P. K. Sanyal
The MITRE Corp., 26 Electronic Parkway,
Rome, NY 13224 (dmzasada, psanyal)@mitre.org

R. P. Perry
The MITRE Corp., 202 Burlington Road, Rte. 62,
Bedford, MA 01730-1420, rpp@mitre.org

Without motion compensation, Synthetic Aperture Radar (SAR) images of the ground are generally blurred. In 1997, MITRE reported the development technique called the Keystone Process for removing the range migration caused by the radial velocity component of each pixel's movement within the scene, whether moving or stationary with respect to the ground. When applied to multiple phase center phased array radar data, this first pass process allows for automated detection of moving targets via phase thresholding. Once detected in phase space, the moving targets can be individually and automatically focused using the procedures previously reported. Automated positioning of the detected target within the formed image is then accomplished (georegistration)

We can easily detect and accurately georegister bright (large radar cross-sections) moving targets using a phase threshold technique reported herein. However, we have found that, for smaller targets, the phase differences between the cells containing the moving target can be greatly distorted by the presence of strong ground clutter. Only after the ground clutter is cancelled will the phase difference be sufficiently dominated by the target response to allow accurate geo-positioning. Herein we describe one technique whereby the clutter may be cancelled by using multiple phase centers.

I. INTRODUCTION

Without motion compensation, Synthetic Aperture Radar (SAR) images of the ground are generally blurred. In 1997, MITRE reported development of the Keystone Process [1]. This process removes range migration caused by the radial velocity component of each pixel's movement within the scene, independent of whether the illuminated object is moving or stationary with respect to the ground. This first pass process allows for automated detection of moving targets via phase thresholding, as we have reported previously in [2, 3, 4].

II. KEYSTONE FORMATTING

Keystone Formatting simultaneously compensates for multiple target motion at multiple radial velocities... It can be derived by noting that the spectrum of a single received pulse is given by,

$$S_r(f) = P(f)\exp[-i\frac{4\pi}{c}(f+f_0)R(t)], \qquad (1)$$

where

$P(f)$ = spectrum of transmitted pulse,

f = baseband frequency $(\frac{-B}{2} \le f < \frac{B}{2})$,

f_0 = carrier frequency.

Expanding $R(t)$ in a Taylor series, we get:

$$R(t) = R(t_0) + \dot{R}(t_0)t + \frac{1}{2}\ddot{R}(t_0)t^2 + \cdots \; . \qquad (2)$$

Substituting (2) into (1) and dropping cubic and higher order terms,

$$S_r(f) = P(f)\exp[-i\frac{4\pi}{c}(f+f_0)R - i\frac{4\pi}{c}(f+f_0)\dot{R}t - i\frac{2\pi}{c}(f+f_0)\ddot{R}t^2] \; . \qquad (3)$$

The second term in the brackets contains the product $f\dot{R}t$ that gives rise to range walk. This term becomes zero when we use the temporal transformation $t = (\frac{f_0}{f+f_0})t'$.

With the above substitution, (3) can be written as,

$$S_r(f) = P(f)\exp[-i\frac{4\pi}{c}(f+f_0)R - i\frac{4\pi}{c}f_0\dot{R}t' - i\frac{2\pi}{c}(f+f_0)\ddot{R}(\frac{f_0 t'}{f+f_0})^2]. \quad (4)$$

Since the Keystone formatting does not solve the quadratic (or higher order) motion problem we also drop the quadratic term in (4) and simplify to:

$$S_r(f) = P(f) * \exp[-i\frac{4\pi}{c}(f+f_0)R - i\frac{4\pi}{c}f_0\dot{R}t']. \quad (5)$$

Notice that the substitution of t′ for t has removed the phase term that varied with both time and frequency and this removes the range-walk. Thus no matter what radial velocity the target is moving at, it will remain in a given range cell determined by its position at the center (t=0) of the coherent processing interval. Figure 1 shows the ‘keystone’ nature of the transformation.

Figure 2 shows the effect of Keystoning on the range walk. Coherent processing of the data without any compensation for target motion results in an integration loss and smearing of the target over multiple range cells. Standard motion compensation will only correct the range walk for one target at a time. The Keystone process compensates for the motion of all the targets simultaneously.

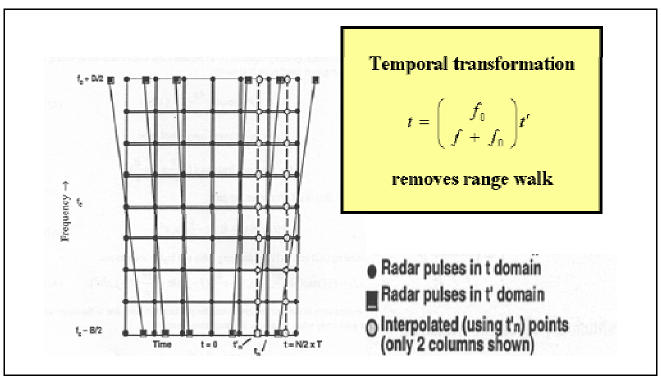

Figure 1. Keystone Formatting Performs Motion Compensation for Targets Moving at Different Velocities

However, even a linear, constant velocity motion of the collection platform results in a pseudo-acceleration of the platform relative to individual points on the ground. Thus, the SAR data has to be further compensated for this pseudo-acceleration to produce focused images. Figure 3 shows an example wherein the appropriate acceleration correction has focused the image. Figure 4 shows a Google Earth image of the same geographical area; the correspondence is quite clear.

In a SAR image that has been focused with the Keystone Process and the appropriate ground acceleration correction, moving objects may still appear unfocussed, since they each may have a different acceleration relative to the radar platform as compared to the point on the ground where the target is located at any instant. Once detected, the moving targets can be individually and automatically focused using the procedures previously reported in [1].

A second effect that the motion of the target has is that it causes the moving targets to appear at locations different from their true instantaneous locations on the ground. This is due to the coupling of the cross-range position to the target radial velocity and the fact that the moving target and the ground under it have different radial velocities relative to the platform. The result is the well known ‘train off the track’ phenomenon.

III. Simultaneously Detecting and Positioning Moving Targets in SAR

Complimentary to the Keystone Range-Doppler-Intensity (RTI) image, we also form a phase interferometry image. In the interpherometric phase image, all points on the ground nominally appear as a continuum of phase differences while the moving targets appear as discontinuities. By threshold comparisons within the intensity and the phase images, we [3] and others [2] have shown that it is possible to detect and georegister moving targets in the SAR. An example is shown in Figure 5. In particular, using a QuickSAR technique [3] comparing sequential short-duration, elliptically pixelleted SAR images, we have obtained excellent results detecting moving targets against background scenes and correctly georegistering them in composite images.

IV. Clutter Cancellation

Although we can easily detect and accurately georegister bright (large radar cross-sections) moving targets using these techniques, we have found that, for smaller targets, the phase differences between the cells containing the moving target are greatly distorted by the presence of strong ground clutter in those cells. Only after the ground clutter is cancelled will the phase difference be sufficiently dominated by the target response to allow correct georegistration. Our current Keystone QuickSAR processing chain is shown below in figure 6. The pale yellow process blocks indicate the additional steps required for clutter cancellation. Two pairs of phase centers are used to form two new phase centers with reduced background clutter (figure 7). This is accomplished using a linear least squares planar best fit to the differential phase surface for each pair to obtain the complex weights to reduce their clutter. A new reduced clutter interferometer pair is then formed and processed to detect (figure 8) and position the moving targets (figure 9).

Interferometric phase discontinuities are automatically detected via a threshold process. This series of steps result in far more consistent automatic detection and track initiation on small, slow moving, targets than via phase thresholding without prior clutter cancellation.

REFERENCES

[1] Richard P. Perry, Robert C. DiPietro and Ronald L. Fante, The MITRE Corporation, 1999. SAR Imaging of Moving Targets. IEEE Transactions on Aerospace and Electronic Systems, Vol. 35, No. 1, pp. 118-199

[2] Stockburger, E. F., Held, D. N., Interferometric Moving Target Imaging, IEEE International Radar Conference, 1995

[3] Sanyal, P. K., Perry, R. P., Zasada, D. M., 'Detecting Moving Targets in SAR via Keystoning and Multiple Phase Center Interferometry', IRSI-2005, Bangalore, India, December 2005

[4] Sanyal, P. K., Perry, R. P., Zasada, D. M., 'Detecting Moving Targets in SAR via Keystoning and Multiple Phase Center Interferometry', IEEE Radar2006, Oneida NY, April 2006.

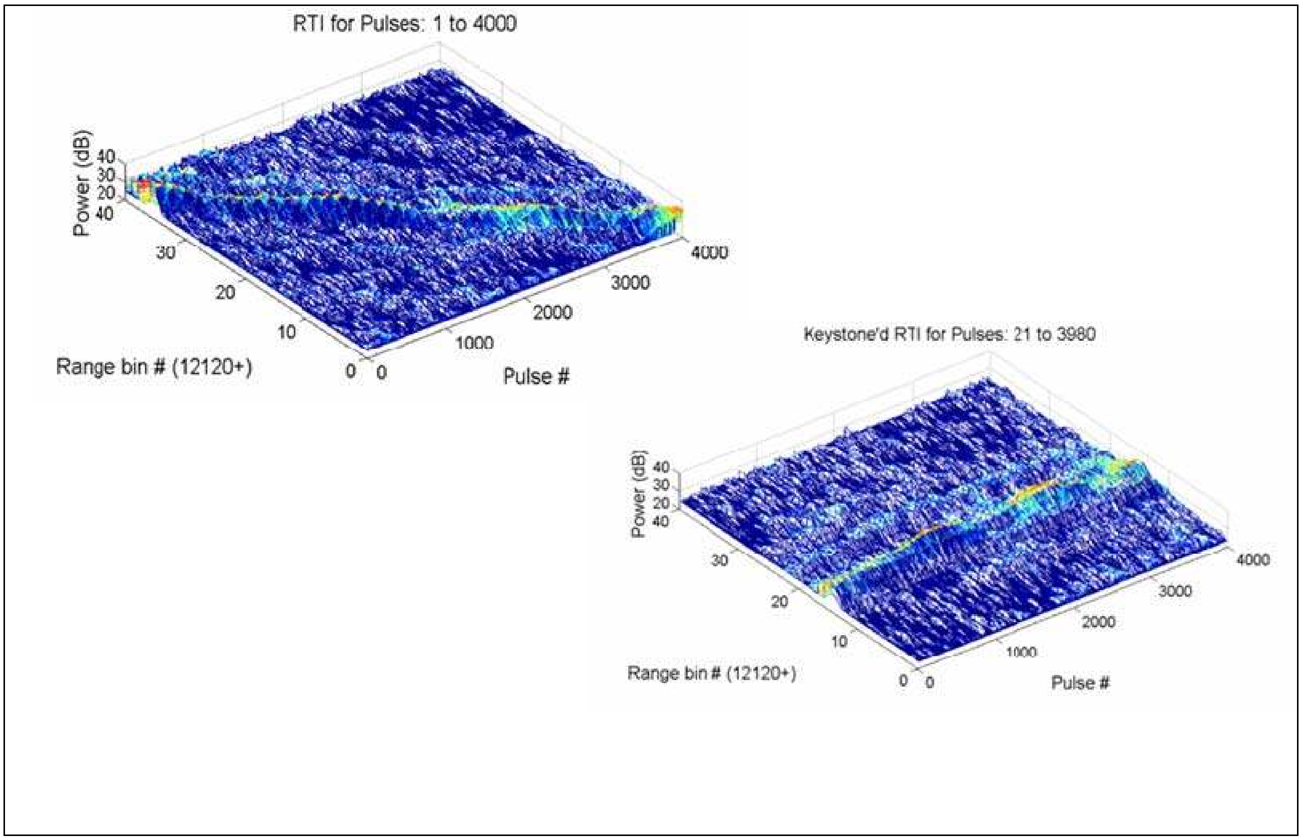

Figure 2. Keystone Formatting Performs Motion Compensation for Targets Moving at Different Velocities

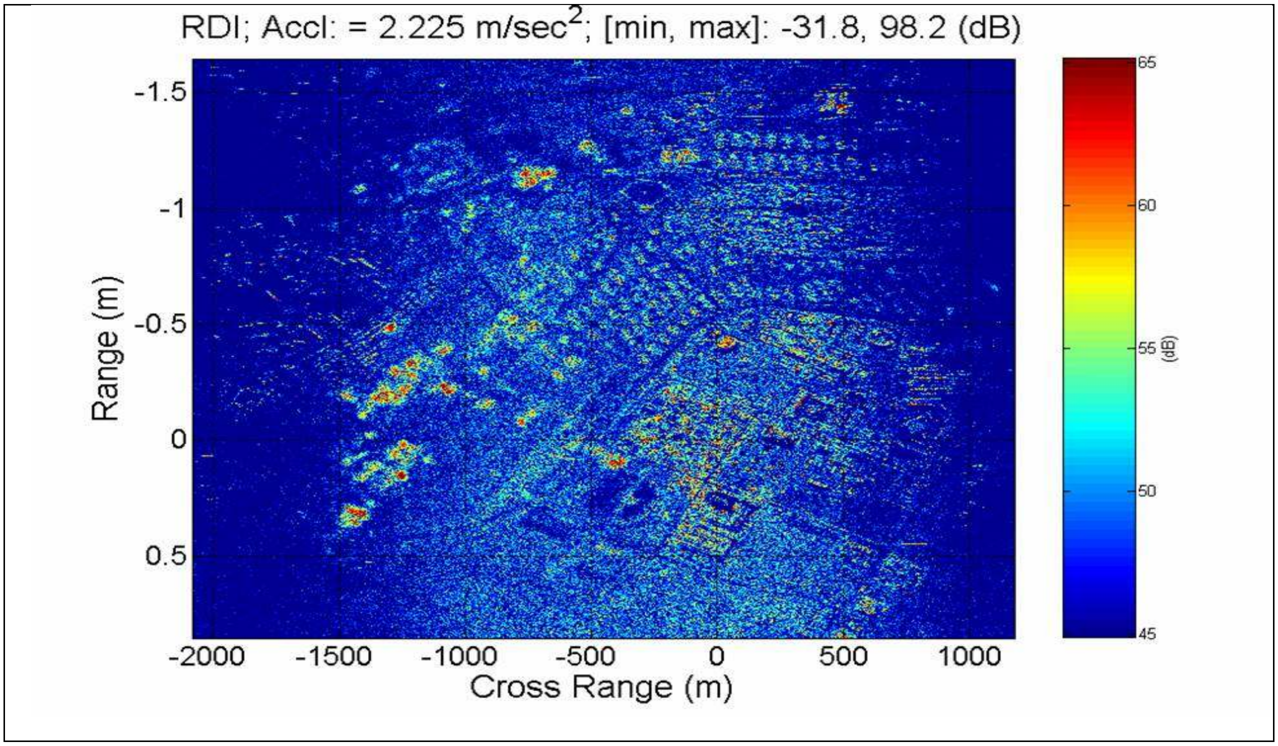

Figure 3. SAR Images of Ft. Huachuca created from LiMIT Data Collected by Lincoln Laboratory

Figure 4. Google Earth image of geographical area corresponding to the SAR Images of Ft. Huachuca in figure 1

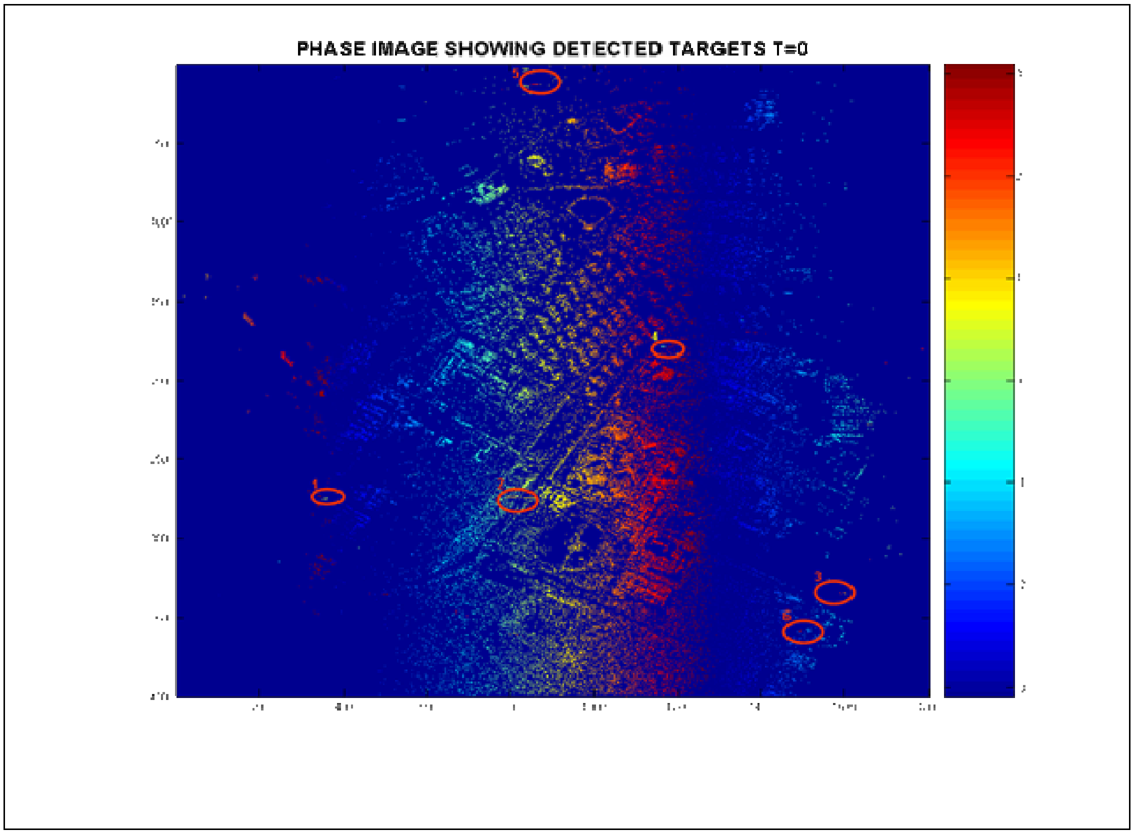

Figure 5. Automatically Detecting Moving Targets in the Ft. Huachuca Phase Image

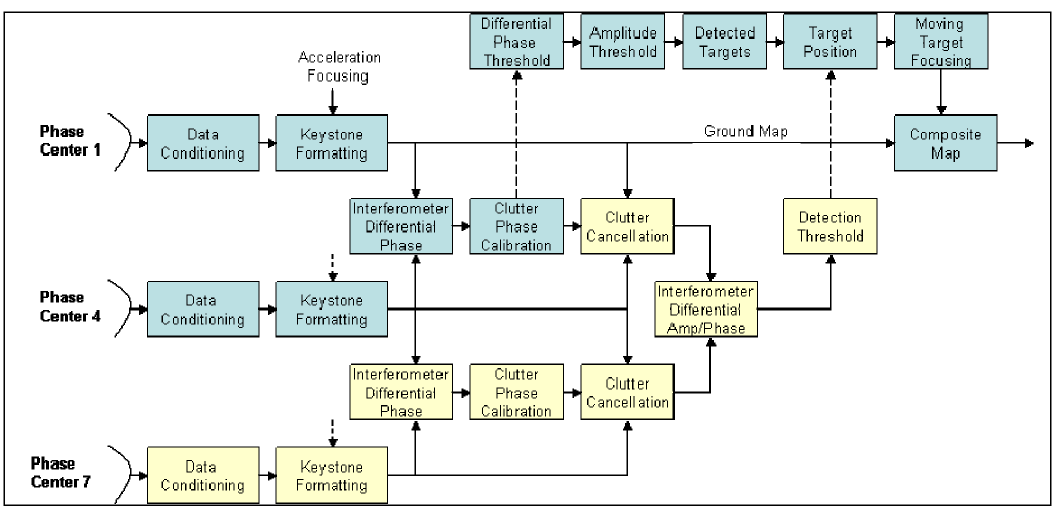

Figure 6. Block Diagram of Moving Target Detection and Tracking Using Multiple Phase Centers

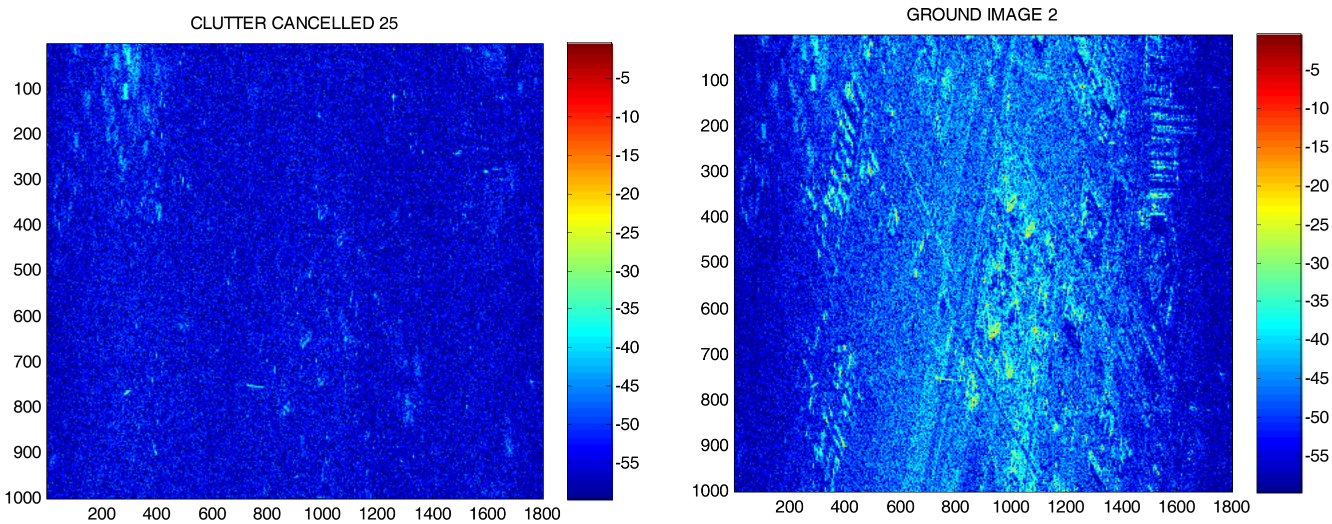

Figure 7. Cancellation of Ground Clutter. Right panel is clutter background, Left panel is clutter residue after cancellation.

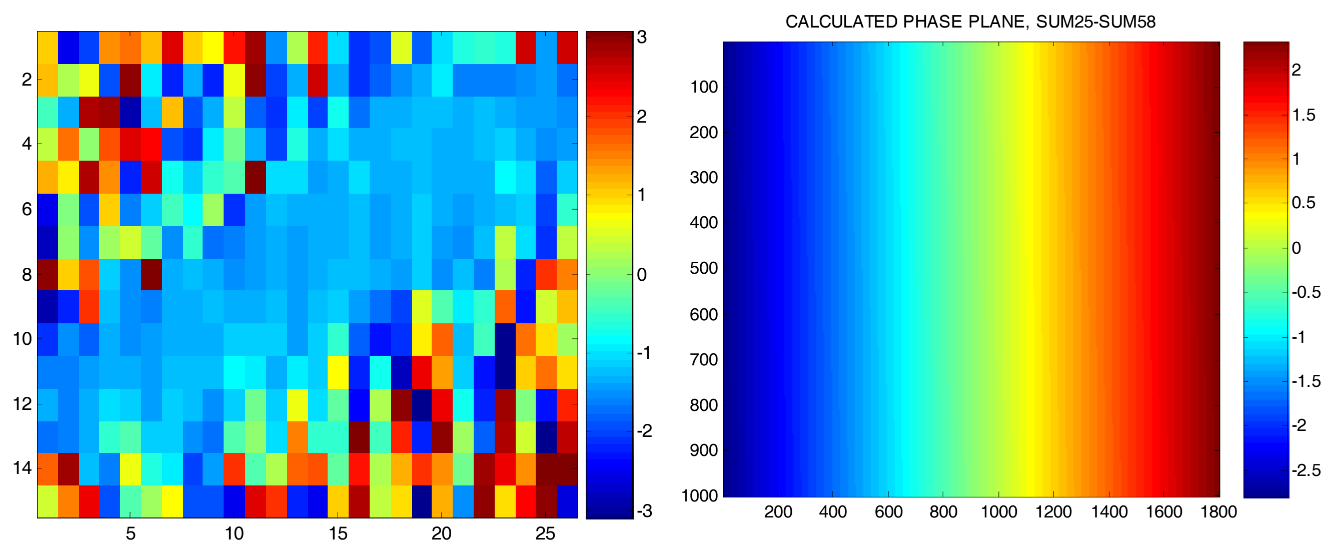

Figure 8. Improvement in Contrast in the Phase Image (left panel) due to Clutter Cancellation (Target Auto-detected) Geopositioning accomplished via fitting smoothed target phase to phase reference plane (right panel) matching