

# Detecting Moving Targets in Multiple-Channel SAR via Double Thresholding

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## Abstract

Well executed SAR images are picture-like and it is possible to identify various kinds of targets, e.g., trucks, ships, etc. However, from a single SAR image, it is not possible to determine which surface targets are moving. In many applications, it is imperative to detect objects that are moving and track them through stop-go-stop motion. We have developed a technique for detecting moving surface targets in a single frame of multi-channel SAR image using phase-interferometry. In this paper, we present results using airborne SAR data.

## Introduction

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 [1] 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.

The Keystone Process removes the range migration effect of the constant radial velocity component of each pixel's motion relative to the platform from the processed image, whether of the ground itself or from moving targets embedded within the scene. This first pass process allows for automated detection of moving targets via amplitude thresholding.

However, even a linear, constant velocity motion of the collection platform results in an acceleration of the platform relative to individual points on the ground. The SAR data has to be compensated for this acceleration to produce focused images of the ground.

An alternative to the Keystoning process is to 'motion stabilize' the data about a chosen point in the scene whose coordinates are known. This process makes use of the moving platform's known instantaneous coordinates during a pulse to compute the instantaneous range from the point on the ground and then subtract this range from the

range data collected with the pulse. This pre-processing makes the chosen point, referred to as the collection reference point (CRP), to appear at zero Doppler. Figure 1 shows such a scene-center stabilized image of a runway system. The figure shows both the Google image of the scene and the SAR image formed airborne radar collected over this area. The CRP for this image is at the lower left corner of the long runway.

During this collection, there were several GPS-equipped targets moving in a circle near the CRP. There was also a GPS-equipped Cessna propeller-driven aircraft moving on the ground in a separate circle. The left insert in Figure 3 shows these circular paths on the runway.

An 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 phenomenon of 'boat off the wake' or the 'train off the track'.

The Doppler,  $f_D$ , of a point at  $\theta$  radians from the normal to the platform velocity vector  $V$  is given by

$$f_D = \frac{2V \sin(\theta)}{\lambda}$$

which, for a small angle  $\theta$ , reduces to

$$f_D = \frac{2V\theta}{\lambda}$$

If a moving target has the Doppler  $f_{targ}$ , then it will appear shifted in cross-range by an angle  $\theta$  such that

$$f_{targ} = \frac{2V\theta}{\lambda} \text{ or } \frac{2v_{targ}}{\lambda} = \frac{2V\theta}{\lambda} \text{ or } \theta = \frac{v_{targ}}{V}$$

At a range  $R$ , this amounts to a linear shift in cross-range of

$$CrossRangeShift = R\theta = \frac{Rv_{targ}}{V}$$

For  $R = 22 \text{ km}$ ,  $V = 208 \text{ m/s}$  and  $v_{\text{targ}} = 30 \text{ m/s}$ ,

$$\text{cross-range-shift} = \frac{22 \cdot 10^3 \cdot 30}{208} = 3.173 \text{ km}$$

Because of this Doppler-to-cross range coupling, objects moving with respect to the underlying ground appear at locations shifted from their actual locations in the SAR image. But it should be recognized that while moving targets appear at shifted locations, they retain the phase value corresponding to their actual location on the ground.

This feature is exploited to detect moving targets via phase interferometry, which is explained in the next section.

The right-insert in Figure 3 shows a close-up of the area of the runway where the targets are operating, overlaid with the GPS-based computed positions. The target positions are indicated by their assigned numbers, with the green numbers indicating the actual positions on the ground while the numbers in red indicate where they appear in the SAR image.

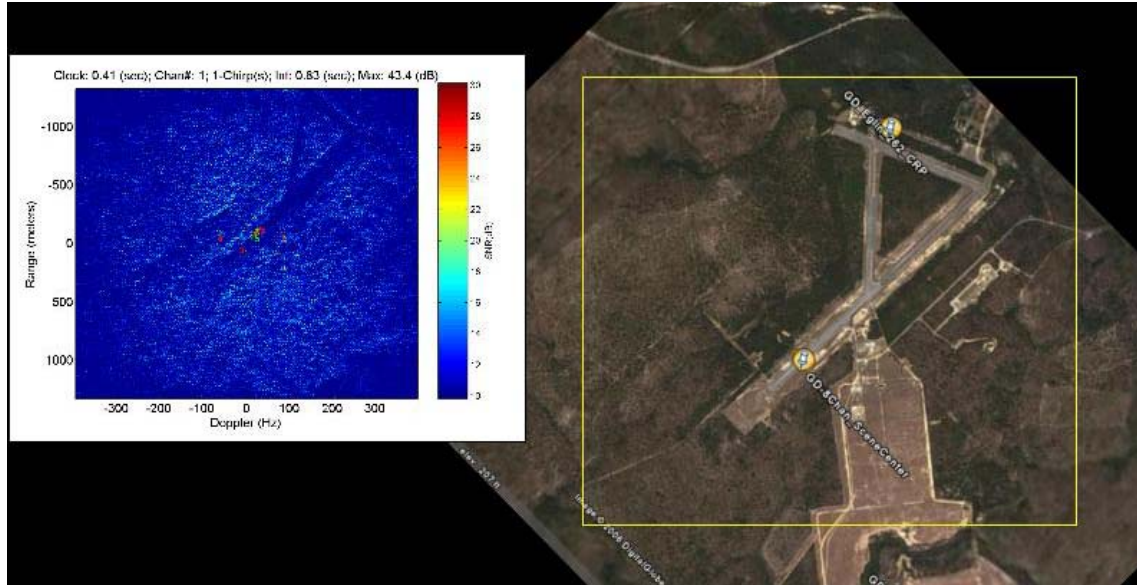


Figure 1. Scene Center Motion-Stabilized SAR Image Eglin Runway Complex (DCS Data)

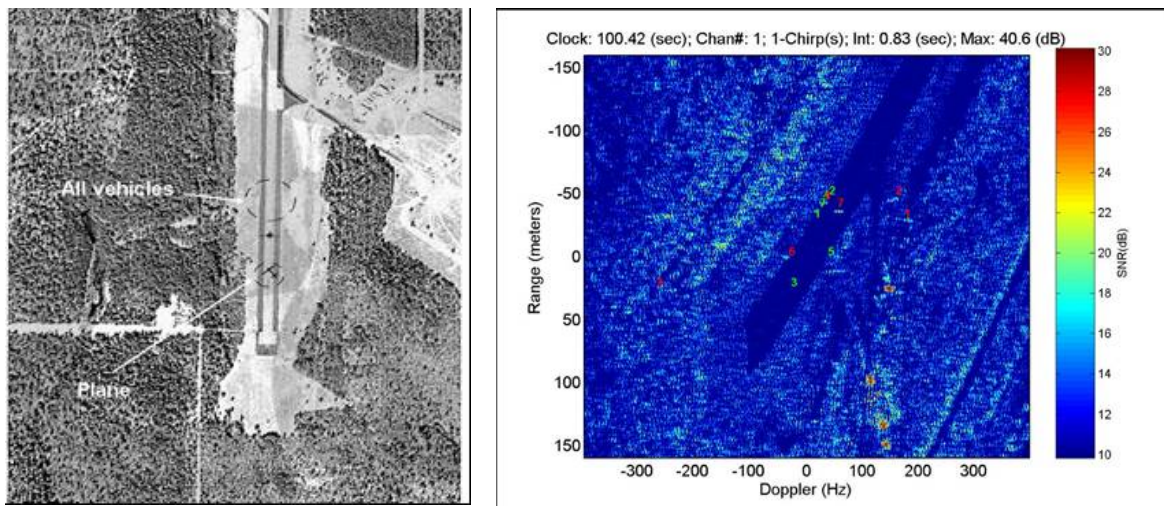


Figure 2. Circling Targets on the Eglin Runway Complex and the RDI Image of the target area

## Detecting Moving Targets in the Phase Difference Image

Complimentary to the standard SAR or the Range-Doppler-Intensity (RDI) image, we can also form a phase-difference or phase-interferometry image. When forming the SAR image, we display only the magnitude at each

pixel but the phase at pixel is also available. The phase-interferometry image is a plot of the phase difference of two SAR images created from any two channels of a multi-channel radar. Figure 3 shows the phase difference image corresponding to the RDI image in Figure 2

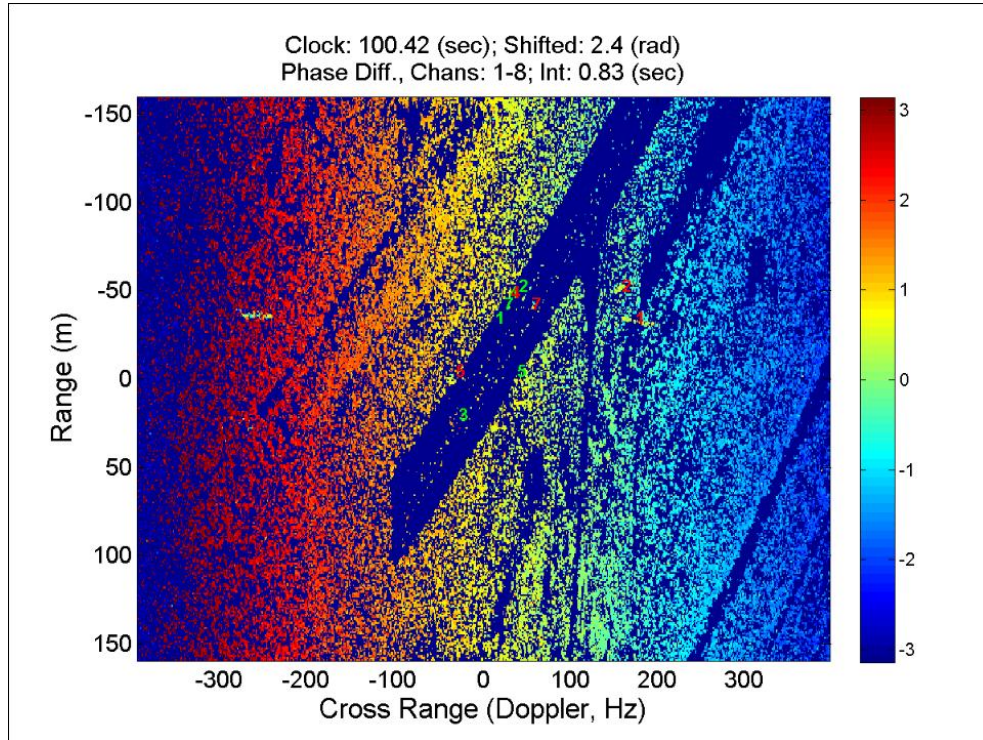


Figure 3. Circling Targets in the Runway Phase Difference Image from channels 1 and 8

For any two phase-centers (channels) on the radar that are displaced along the velocity vector of the platform, the differences of the phases of the signals received from points on the ground vary (almost) linearly with the cross range and is independent of the strength of the reflected signal. If the phase is color-coded, one would expect to see an image with no other features except a continuously varying color from left to right of the image, with spots of color anomaly indicating phase anomaly and hence a moving target.

However, when a pixel contains very little reflected power and is fully dominated by system noise, the phase difference for that pixel has no relationship to the ground position the pixel is associated with and can randomly vary between  $+\pi$  and  $-\pi$ . Since many such low power pixels are present (recall that we are working with real data), the

phase image would appear totally speckled. To cut back on this random speckle, we display the computed phase differences for pixels above a chosen threshold, with the phase difference for the weak pixels being arbitrarily set at  $-\pi$ , or, blue. This has not only greatly reduced the speckle in Figure 4 but also reveals the same features that we see in the RDI image in Figure 3.

In the interferometric phase image, all points on the ground nominally appear as a continuum of phase differences while the moving targets appear as interferometric phase discontinuities because while they appear at displaced locations, they retain their original interferometric phase values that are referenced to their actual location on the ground.



By threshold comparisons within the intensity and the interferometric phase images, we [2, 3, 5] and others [4] have shown that it is possible to detect and geo-locate moving targets in the SAR. An example is shown in Figure 3. In particular, using a QuickSAR technique [2] comparing sequential short-duration, elliptically pixelated SAR images, we have obtained excellent results detecting moving targets against background scenes and correctly geo-positioning them in composite images.

In Figure 3, one can readily see the phase anomalies associated with the moving targets 1, 2 and 5. The others are not so obvious with the unaided eye but are discernable via automatic detection algorithms.

For automatic detection, we fit a phase plane to the phase difference image and subtract it from the phase difference image. Now, we search for pixels that both exceed a selected magnitude threshold in the RDI image and also exceed a selected phase threshold in the reduced phase

difference image. We term this 'double thresholding'. The pixels detected as a result of the double thresholding are declared to be moving targets. Figure 4 shows the result of this process. Again, the targets 1, 2 and 5 are obvious in this plot while the others are not. But the automated process can readily detect them also.

As in any detection scheme, the realization of a desired probability of detection against a given probability of false alarm is a function of the thresholds selected. Here, we have not yet tried to optimize the thresholds employed, but our preliminary results are encouraging.

A feature of this particular plot is the absence of excessive false alarms; indeed, there are few in this particular frame. Since the targets are embedded in strong clutter, single threshold processes such as Space Time Adaptive Processing (STAP) often report many false alarms.

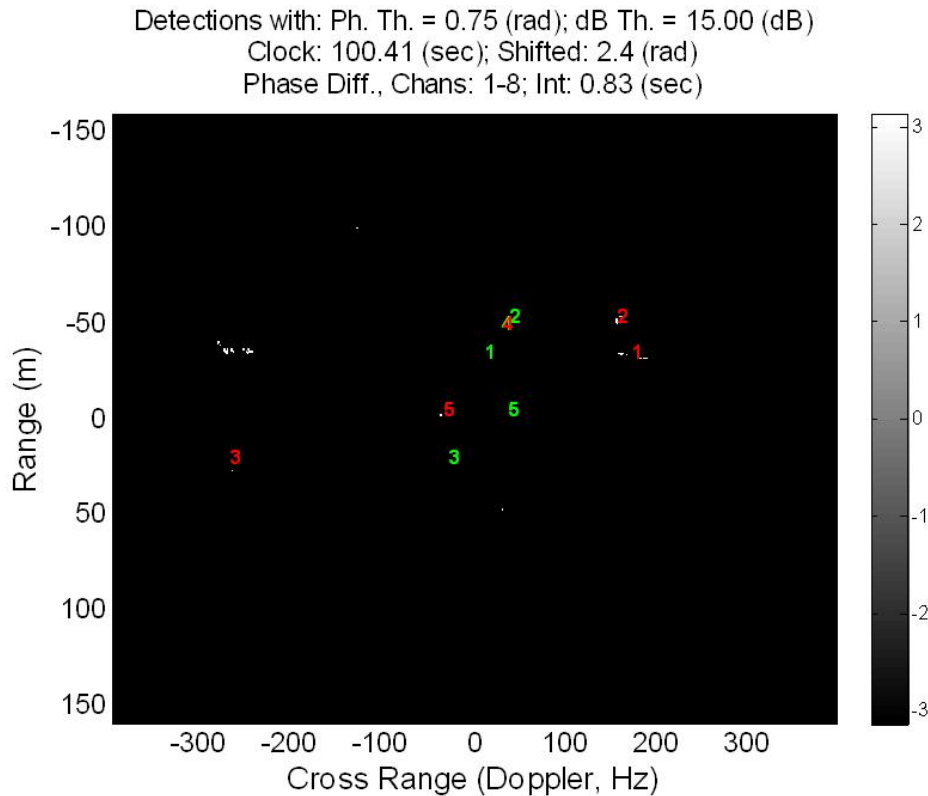


Figure 4. Detecting Circling Targets in the Phase Difference Image of the Runway

### Channel-to-channel Clutter Cancellation

Although bright (large radar cross-sections) moving targets can be easily detected and accurately geo-located using these techniques, 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 moving target response to allow correct geo-positioning. Here we report on a technique whereby the stationary ground clutter may be cancelled by using multiple phase centers. This technique is shown notionally in Figure 5 and the detailed process diagram is shown in Figure 6.

As shown in Figure 5, there are three phase centers receiving returns from a moving target as well as another patch of terrain in the neighborhood and in the SAR image. The returns from the moving target overlay the stationary patch. Thus, the pixel in the SAR corresponding to that patch on the ground contains the vector sum of the returns from the ground patch and the returns from the moving target (which in reality, is situated on a different patch of ground).

Let the complex images formed at the three channels, numbered 2, 5 and 8 be designated  $I^2$ ,  $I^5$  and  $I^8$  respectively. Let the pixel in question be from the  $i^{\text{th}}$  row and the  $j^{\text{th}}$  column of the SAR image. Let the returns from the ground patch and the moving target to the  $k^{\text{th}}$  phase center be denoted, respectively, as  $s_{g(i,j)}^k$  and  $s_t^k$

When we compute the phase difference for that pixel (i,j) relative to the channels 2 and 5, we compute

$$\Delta\phi_{i,j}^{2,5} = \phi(s_{g(i,j)}^2 + s_t^2) - \phi(s_{g(i,j)}^5 + s_t^5)$$

Clearly, if the target signal is much weaker than the ground return (which is the desired signal when forming the SAR but is the clutter when the goal is to detect the moving targets), the phase difference computed above will reflect the ground return and no phase anomaly, and hence no moving target, will be detected. Even if the target is detected, the phase difference will be greatly influenced by the ground return. Better results can be had if the ground return can be cancelled.

Now, ideally (i.e., in the absence of system noise and moving targets) the images  $I^2$ ,  $I^5$  and  $I^8$  are simply phase shifted versions of each other and given the phase shifts, one image can be used to cancel another. To estimate the phase shift, we perform a least square error fit to the phase difference image. Let this smoothed phase difference be denoted by  $\hat{\Delta}\phi^{2,5}$ . If we now subtract the image from channel 5 modified by this smoothed phase from the channel 2 image, we get the clutter-cancelled image

$$I^{2/5} = I^2 - I^5 \exp(j\hat{\Delta}\phi^{2,5})$$

In this clutter-cancelled image, the clutter is cancelled but not the moving target returns because the true phase difference between the target return in the pixel (i,j) is not the same as the smoothed phase difference in pixel (i,j). Figure 7 shows some preliminary results of enhancing moving target returns by channel-to-channel cancellation of the ground clutter.

For improved geolocation, we need to compute another clutter cancelled image

$$I^{5/8} = I^5 - I^8 \exp(j\hat{\Delta}\phi^{5,8})$$

From the two clutter-cancelled images, we can compute a better phase difference for the moving targets and hence perform a better geo-location. A future paper will be devoted to this part of our continuing work.

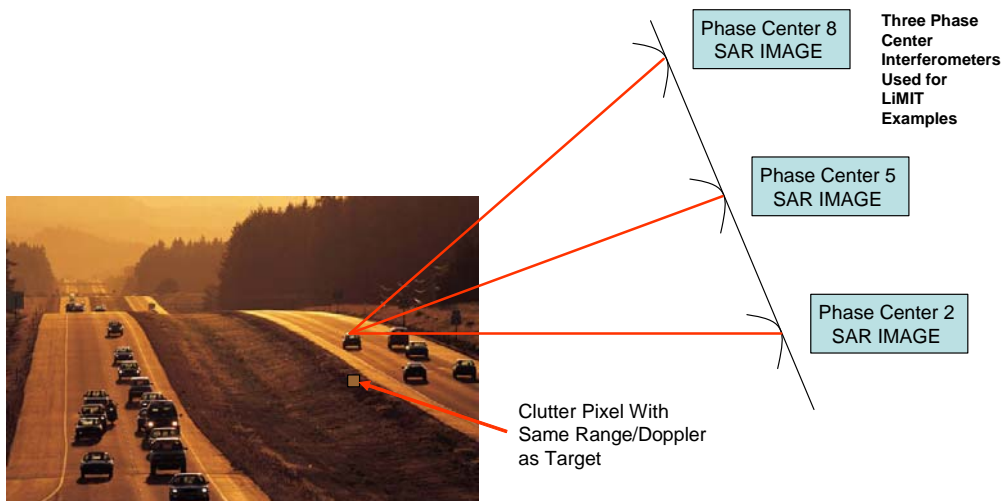


Figure 5. Clutter May be Cancelled by using Multiple Phase Centers

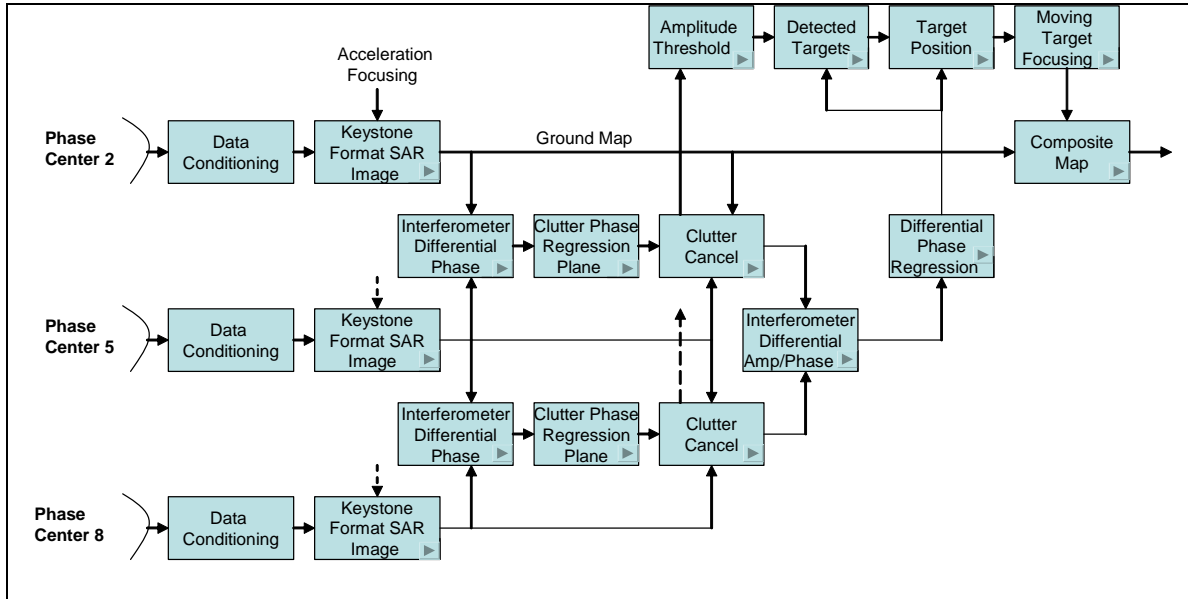


Figure 6. Block Diagram of Moving Target Detection and Tracking Using Multiple Phase Centers

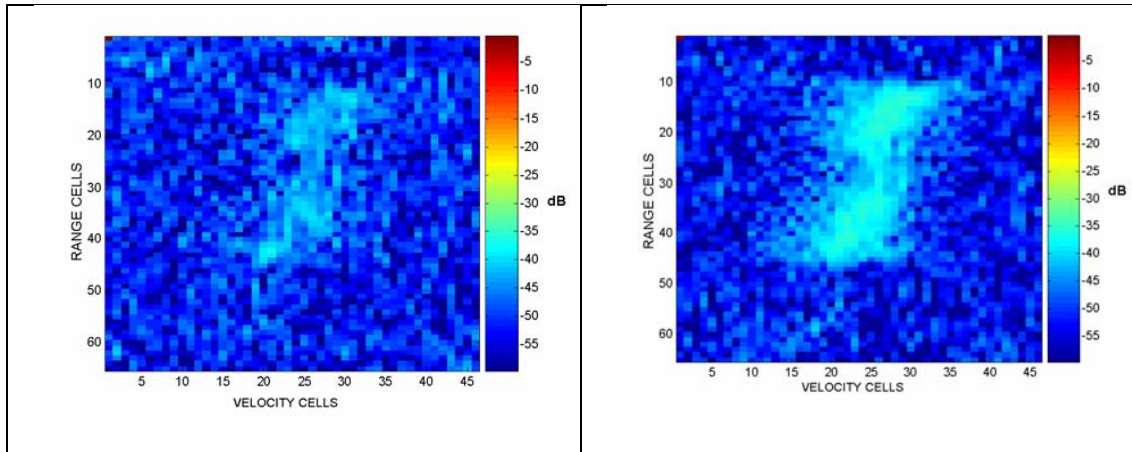


Figure 7. Improvement in Contrast in the Phase Image due to Clutter Cancellation

## CONCLUSIONS

In this paper we have described a novel technique for detecting moving targets in synthetic aperture images (SAR). We have included some results from real data. Our work shows that we can have consistent, automatic detection targets embedded in SAR images where a 'clutter' background must be suppressed to reliably and automatically detect slow moving targets.

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