Study Of Clutter And Noise Suppression Using STAP Techniques On A Radar System

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Abstract

Especially in case of airborne based radar system design for air surveillance, the normal MTI receiver cannot work properly for accurate target detection. This is mainly because the clutter in this case will not have zero Doppler Spectrums. Beside that any system noise and intentional Noise, jammer for example is also a big threat for target detection. The optimum radar should have robustness on clutter and noise signal.

This paper basically presents the effect of clutter on non stationary radar receiver and also the effect of Barrage jamming on a particular surveillance radar system and its effectiveness is observed using mat-lab simulation. On the other hand space time adaptive processing (STAP) technique is used as a counter method to negate the effect of noise jamming and clutter so that radar can operates on normal condition despite of jamming and varying clutter spectrum.

Space time adaptive processing (STAP) is based on the idea of designing a two-dimensional (space and time) filter that maximizes the output signal-to-interference noise ratio [2] by filtering the unwanted clutter and noise just by nulling in direction of jammer and clutter.

Keywords: EMC, Noise jamming, STAP, adaptive nulling, SNR, MTI.

1. Introduction:

An airborne radar collects the returned echo from the moving target on air. However, the received signal contains not only the reflected echo from the target, but also the returns from the illuminated ground surface. The return from the ground is generally referred to as clutter.

The clutter return comes from all the areas illuminated by the radar beam, so it occupies all range bins and all directions. The total clutter return is often much stronger than the returned signal echo, which poses a great challenge to target detection. Clutter filtering, therefore, is a critical part of a MTI system.

In traditional MTI systems, clutter filtering often takes advantage of the fact that the ground does not move. Thus, the clutter occupies the zero Doppler bins in the Doppler spectrum. This principle leads to many Doppler-based clutter filtering techniques, such as pulse canceller. When the radar platform itself is also moving, the Doppler component from the ground return is no longer zero. In addition, the Doppler components of clutter returns are angle dependent. In this case, the clutter return is likely to have energy across the Doppler spectrum. Therefore, the clutter cannot be filtered only with respect to Doppler frequency.

Jamming is another significant interference source that is often present in the received signal. The simplest form of jamming is a barrage (Noise) jammer, which is strong, continuous white noise directed toward the radar receiver so that the receiver cannot easily detect the target return. The jammer is usually at a specific location, and the jamming signal is therefore associated with a specific direction. However, because of the white noise nature of the jammer, the received jamming signal occupies the entire Doppler band.

STAP techniques filter the signal in both the angular and Doppler domains (thus, the name "space-time adaptive processing") to suppress the clutter and jammer returns.

2. Jamming noise jammer and clutter characteristics

Jammer transmits random noise or interfering signals of suitable frequency and power towards the radar receiver, in order to increase the noise floor of the receiver. Hence the radar receiver cannot distinguish the real echo from the noise. One way to mal-function a radar receiver is to saturate it with noise.

The radar echo signal is a periodic sequence of pulses with low strength. So as to handle these echos the sensitivity of the receiver should be high enough but on the other hand high sensitive receiver are more susceptible for jamming and interference.

The objective of jamming is to conceal the echo. As figure 1 illustrates, the average amplitude of the radar echo is overwhelmed by noise. Another way of expressing the same is, the signal to noise ratio at the input is lowered to a level beyond which the receiver cannot extract intelligence.

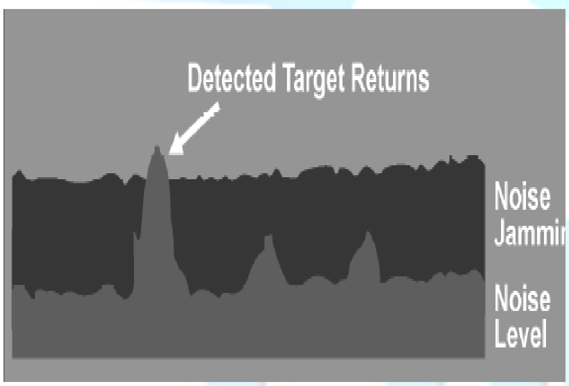

Fig1: Illustration of noise jamming.

Radar system should also have the ability of picking-up echo and removing the jamming signal according to the mixed signals of echo and jamming signal, therefore, it can have a better detecting and tracking effect [9].

The signal to Noise ratio (SNR) is one of the parameter to indicate the jamming performance of the receiver [1]. More we maximize the value of SNR at radar receiver less effective will be the jamming.

Jamming technique is used to minimize the SINR of the radar seeker which leads to poor detection performance of radar [4] and is expressed as

$$SINR = \frac{\dfrac{P_t G \sigma A_r \varsigma}{(4\pi)^2 R^4 L}}{\dfrac{ERP * A_r}{4\pi R^2 B_j * L_j} + KT_0}$$

$$ERP = \frac{P_J G_J}{L_J}$$

Where, P_T*=radar transmitted power,* σ *=RCS, G =Antenna gain,* A_r*=Antenna Aperture,* ς*=Radar Pulse Width, R=Range, L=free space propagation loss, ERP=Effective radiated power of jammer,* B_j*=Jammer bandwidth,* L_j*=jammer propagation loss.*

From the above equation it is evident that, SNR is inversely related to the jamming power. At the same time received SNR value is strongly dependent on the RCS of the target.

Another main source of interference is environmental clutter. Due to the motion of the airborne radar platform, the clutter spread over wide Doppler frequency. Clutter from a specific point on the ground has a Doppler frequency that depends on the angle of the clutter position relative to the heading of the platform.

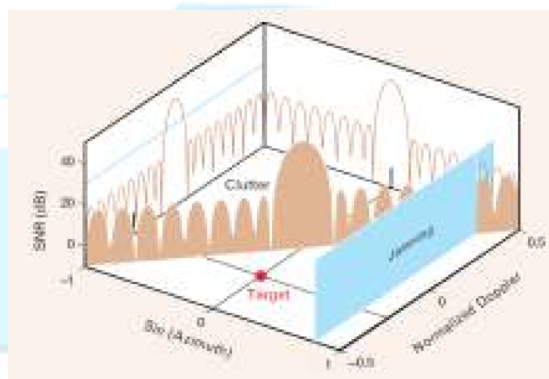

Fig 2: Demonstrate the (SNR) of clutter and jamming signal, as a function of angle and Doppler frequency.

Figure above shows the signal to noise ratio resulting from the clutter and jamming as a function of angle and Doppler frequency. The figure also reveals the view of clutter characteristics from the perspective of azimuth for given Doppler frequency and view of clutter from the perspective of Doppler frequency for given azimuth angle. As the jamming signal is noise plus barrage jamming of wide frequency band. Its value depends only on the bearing.

We can see that overall the effect is two dimensional effects so it particularly needs two dimensional filtering techniques. In such scenarios advanced signal processing performance technology is required. One such technique is known as space-time adaptive processing, or STAP.

3. Clutter and noise mitigation technique (STAP):

Space-time adaptive processing (STAP) is a signal processing technique most commonly used in radar systems to suppress jammer and clutter.

The performance of airborne surveillance radars can be severely degraded by hostile jamming sources and clutter. In such scenarios advanced signal processing performance technology is required. One such technique, known as space-time adaptive processing, or STAP, is based on the idea of designing a two-dimensional (space and time) filter that maximizes the output signal-to-interference-plus-noise ratio, thereby selectively Nulling clutter and jamming returns while at the same time retaining the target signal [2]. The filter is formed by simultaneously combining the signals received on multiple elements of an antenna array and multiple pulse-repetition intervals of a coherent processing interval. The antenna elements provide the filter's spatial dimension and the pulse-repetition intervals provide the temporal dimension. This combination can also be seen as a beam-forming operation but not as conventional electronic array but in a sense of signal processing. In this case, the array antenna provides raw data to STAP processor, while the antenna processor does not perform the beam steering.

STAP processor, then finally filter these raw data called snapshot in both space and time dimension in order on proceed all the radar signal leaving behind clutter and jammer signal.

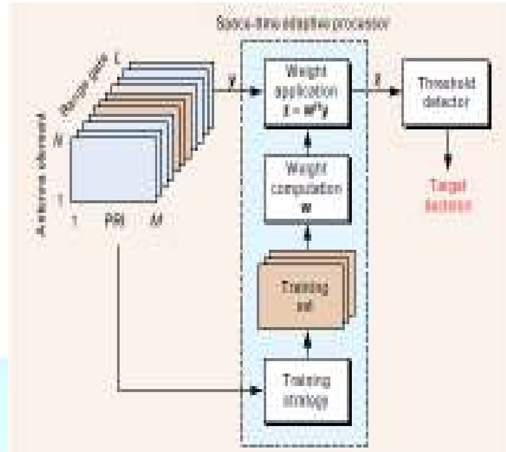

Fig 3: STAP Radar receiver working scheme

In simple sense a beam is formed with chosen spatial and frequency directions matched to the target signal, and possessing nulls in the directions and frequencies of adaptively sensed interferers. The STAP beam forming weights are computed from radar returns containing information on the spatial and temporal characteristics of the interference. Actually for this purpose it uses fixed set of training signals for this adaptive sensing.

The weights especially used for STAP processing are target steering vector and interference covariance matrix.

Target steering vector specify the match filter parameter just for target signal so that the target signal SNR valve is increased. This steering vector is formed by cross product of the vector representing the Doppler frequency and the antenna angle of elevation and azimuth.

The doppler frequency offset vector is expressed as

$$F_d = e^{-2 \pi n f_{dop}}$$

For n=1…..N-1

and spatial angle vector is expressed as

$$A_\theta = e^{-2 \pi m \sin(\theta)}$$

For m=1…M-1

The target steering vector t is the cross product of F_d and A_θ.

The interference covariance matrix S must compute for all range bin. The covariance matrix for a particular range bin can be expressed as

$$S = Y^{*}.Y^{T}$$

Here y is a data cube for a particular range bin.

The covariance matrix represents the degree of correlation across both antenna array inputs and coherent pulse .The main intention here is to characterize undesired signals and create an optimum filter to remove them. The undesired signals include noise, clutter and jammers [8].

The optimal adaptive weight vector **w** for a given steering vector **t** is related to the interference covariance matrix **S** through the relationship

$$Sw = t$$

$$w = tS^{-1}$$

The process of computing the adaptive weight vector **w** from the estimated covariance matrix **S** and steering vector **t** is called *sample matrix inversion.* The beam-forming operation is just a matrix-vector multiplication,

$$z = w^{T} y$$

Where, **y** is the input data for a specific range gate. Where, **z** is a complex scalar, which is then fed into the detection threshold process. Where decision is made based on the result of this signal processing output.

A space-time adaptive processor combines received beam-forming signal in the space and time dimension to achieve the specific filter response for a particular target angle and Doppler frequency. The STAP processor applies many of these filters, each covering a different target angle and velocity to detect targets within the range of interest.

4. Simulation Result:

Simulation is carried out in Matlab 2014b.

	Position(3-D)	Range	Relative angle (az,el)	Speed
Radar	(1000,1000,500)	-	-	202 m/s
Target	(3000,1000,1000)	2061	(0,14)	18 m/s (31.5 m/s w.r.t radar)
Jammer	(2500,2000,1000)	3354	(33,15)	0m/s

Table 1: Radar specification for simulation.

Parameter	Value	Unit
Pulse width	0.33	µs
PRF	30	Khz
Carrier freq.	10	Ghz
Sampling freq.	6	Mhz
Tx. Power	5.2	KW
Tx.ant. gain	20	-
SNR (req)	4.99	-

Gaussian Noise, Jammer power=100w, Jammer freq=(9.9-10.1)GHz

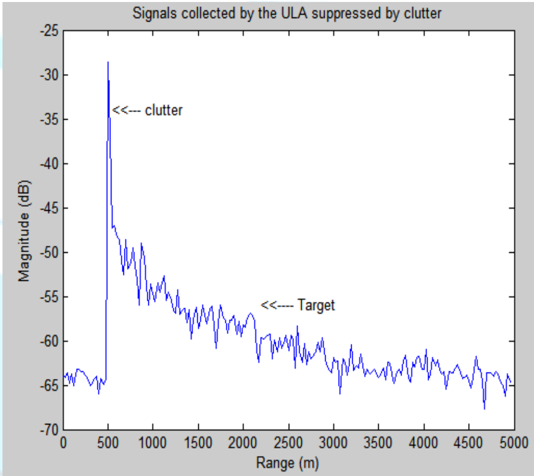

Fig 5: Waveform received by radar receiver under heavy ground clutter.

Here we can see a first spike at range of 500m, i.e for indication of clutter from ground as the radar is moving 500m above the ground. Similarly clutter return strength goes on decreasing due to angle effect asdescribed in theory. Here the target return is masked by clutter as shown in figure above.

Table 2: Configuration of Radar, Jammer and Target for simulation

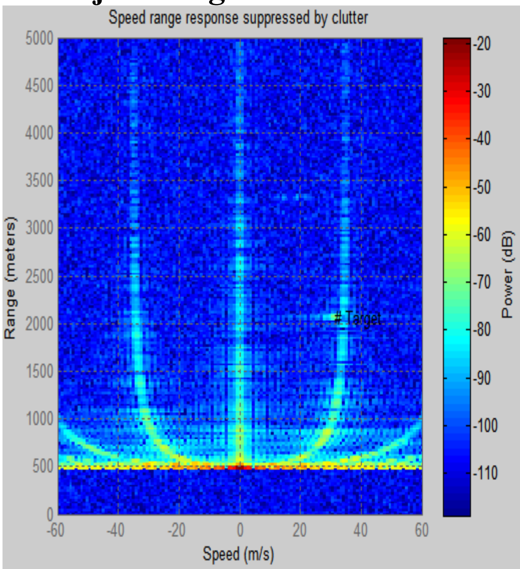

Fig 6: Range speed response of echo signal at radar receiver under heavy ground clutter.

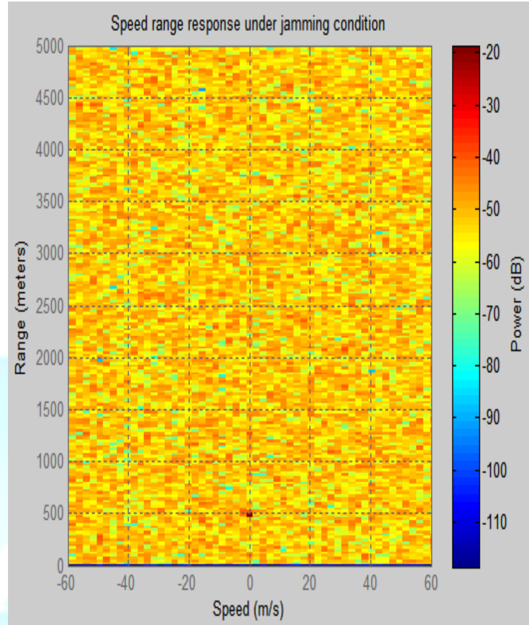

Fig 8: Range Speed response of echo signal at radar receiver under barrage jamming and heavy ground clutter.

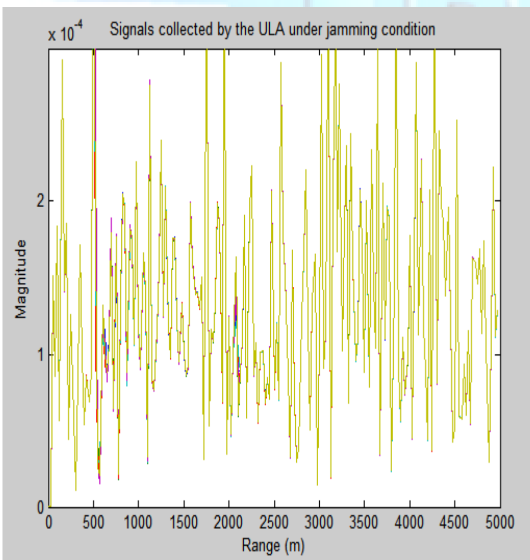

Fig 7: Waveform received by radar receiver during barrage jamming plus ground clutter.

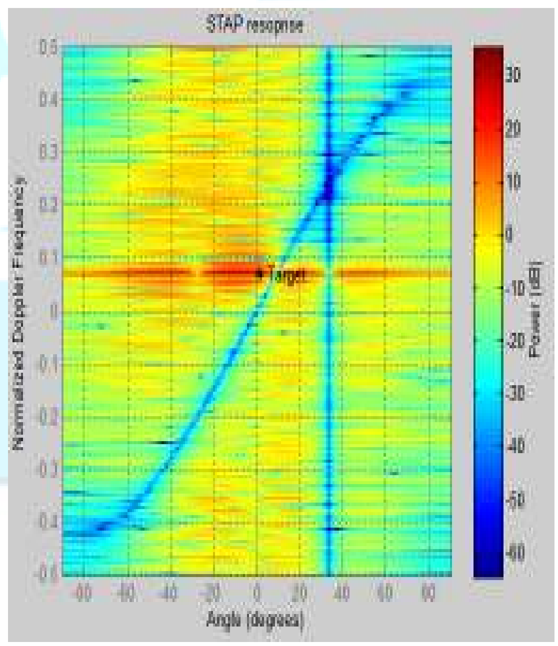

Fig 9: STAP Nulling in the direction of jammer and clutter.

(*Vertical blue line indicates Nulling in direction of jammer i.e. 33 azimuth angle, and the diagonal blue indicates Nulling for the ground clutter that is angle and Doppler dependent due to motion of radar.)*

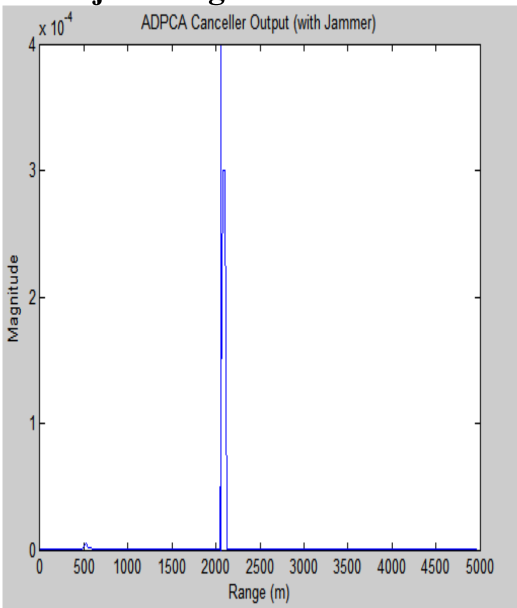

Fig 10: Received Waveform after STAP radar receiver.

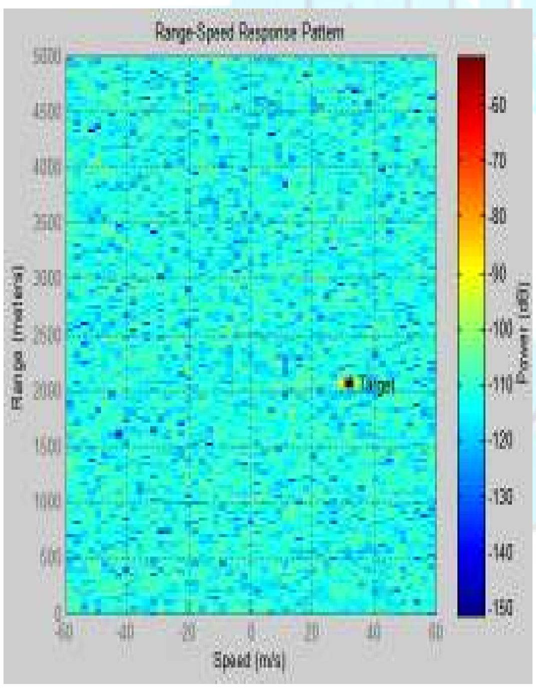

Fig 11: Speed Range response of radar echo after STAP receiver.

Special case: When target and jammer in same direction

Target pos(2500,2000,1000), Jammer pos(2500,2000,1000)

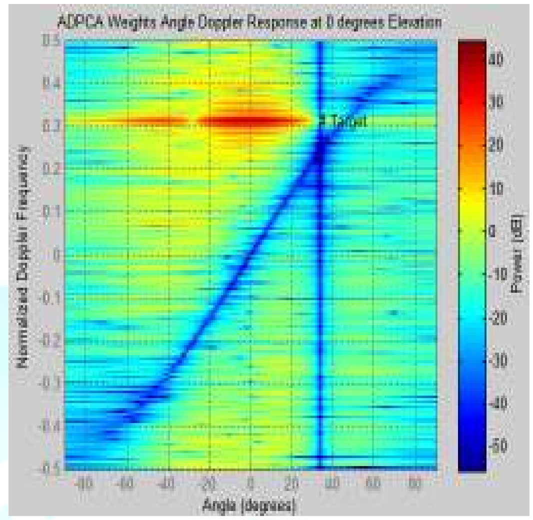

Fig 19: STAP Nulling in direction of jammer and clutter. *(Target and jammer same direction)*

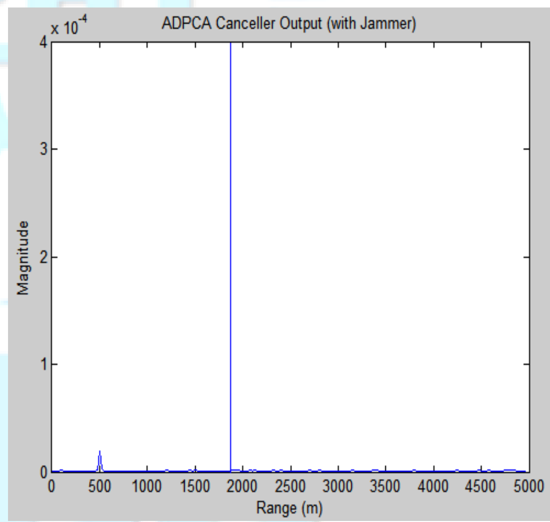

Fig 20: Received waveform at radar receiver *(No target echo)*

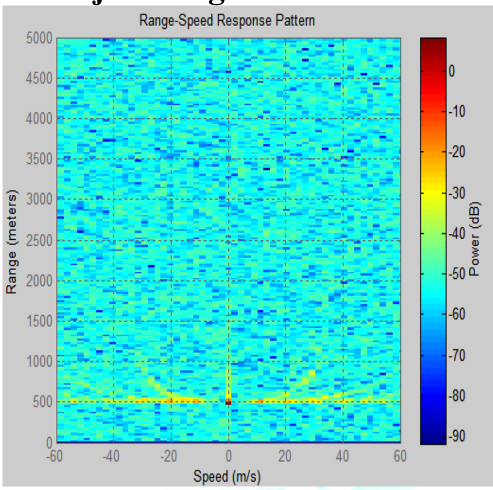

Fig 21: Speed Range response of radar received echo signal.

5. Conclusion:

In this paper barrage jamming and ground clutter were considered to disturb the operation of an air surveillance radar. STAP i.e. two dimensional filtering technique is deployed to make radar free from jamming and un-necessary clutter. Here we have demonstrated both jamming and mitigation using matlab simulations. This techniques works almost well but it is observed that when jammer and target are in the same direction STAP is unable to detect the target.

Multiple STAP radar receiver separated by enough distance can overcome this defect but it is quietly costly.

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