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Estimation Of Power, Doppler Width, Mean Doppler And Radial Velocities For 53mhz Pilot Active Array Radar By Using Time Series Data

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Abstract: Radar data processing has been one field of data processing where there is a lot of scope for development of new and efficient tools for removing the noise, detection and estimation of desired parameters. This paper deals with the description of an algorithm for processing the data obtained from pilot active array radar which is developed at National Atmospheric Research Laboratory (NARL).The data obtained from pilot active array radar is processed for the estimation of power, Doppler width, mean Doppler (spectral moments) and radial velocities using specific windowing technique. This data processing done is partly on-line and partly offline. The on-line processing significantly compresses the data via time averages and usually produces power spectra and off-line calculations involve parameter extraction. Data processing of recorded experimental data is performed by the developed MATLAB code and the results were plotted. The derived velocity components are validated by comparing the velocity components obtained from GPS data at NARL.

Keywords: radar data processing, active array radar, power spectra, radial velocity.

I. INTRODUCTION

RADAR stands for 'Radio Detection and Ranging'. The Indian mesosphere-stratosphere-troposphere (MST) radar located at National Atmospheric Research Laboratory is being operated for atmospheric research applications, but the problem with the existing transmitter units is that they may cause instability due to which interference arises in the radar data. Also the characteristics of these transmitter units are degraded due to internal vibrations and temperature variations resulting in the degradation of overall SNR[1].[Considering all these factors, an R&D project was taken up to upgrade the Indian MST radar to an active phased array system using the solid- state transmit -receive (TR) modules. A 133-element pilot active array radar is a pulsed Doppler radar of 53-MHz developed at National Atmospheric Research Laboratory (NARL) for probing the atmosphere up to mid troposphere [2]. This radar is developed with an objective to validate the technology concepts like out-door installation of solid-state transmit-receive (TR) modules, beam steering, optical interference and control, fiber-based phase calibration etc. This system is being operated in the DBS mode with typical height coverage up to 8-12km.Details of the system configuration and parameter extraction from data processing steps are presented in the succeeding sections.

II. SYSTEM CONFIGURATION

The 133-element array is configured with seven segments, each comprising a 19-element hexagonal sub-array. Figure1 shows the schematic configuration of the radar and control system. Radar system consists of solid state TR modules, exciter, back- end receiver, digital receiver and radar controller. Exciter contains a reference master oscillator, which generates the reference clock to all other subsystems. Also a 53MHZ pulse modulated bi-phase coded RF waveform is generated using DDS (Direct Digital Synthesizer) section in the exciter. The RF signal distribution and switching network acts as a router in feeding this RF waveform to the outdoor TR modules located in the antenna field. Each element in this antenna array is fed with 1-kw power by its TR module [3]. The dedicated signals that are received from array and TR modules are combined and are directed to the instrumentation room via RF co-axial cables and delivered to the back-end receiver. The back-end analog receiver amplifies and band-limits the received signal and fed to the direct digital receiver (DRx).This direct digital receiver performs the analog-to-digital conversion (ADC), digital down conversion (DDC), pulse compression, and coherent averaging. There ends the signal processing. The data then obtained is further processed i.e. data processing (commonly referred to as off-line data processing) is performed to compute and display the spectral moments and radial velocity components. Radar controller controls and monitors the functioning of all other radar subsystems.

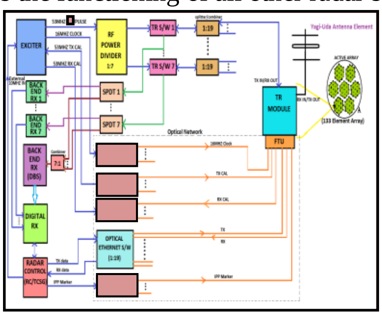

Fig 1: Block Diagram of pilot active array radar

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Subsystem details can be explained as below:

Antenna Array:

The 133-element array is organized into seven segments each being a hexagonal shaped sub array comprising of 19 elements in it. Inter element spacing is taken as 4m. The antenna element is a three-element Yagi. The array is quasi-circular in shape with a diameter of about 50m.

TR module:

133 numbers of solid-state 1-kw TR modules each feeding one antenna element, are installed in the antenna field. The TR modules are controlled directly by the Radar Controller PC located inside the instrumentation room.

Fig 2: TR module

Direct Digital Receiver:

The functions of down conversion, filtering, sample-rate reduction are performed by DDC to reduce the load of software processing. Pulse compression and coherent averaging are performed by the tiger SHARC processor.

Fig 3: Photographs of pilot active array at NARL (a) Array field (b) TR module (c) Control and instrumentation room

Specifications of pilot array radar

Frequency	:	53 MHZ
Bandwidth	:	1.5 MHZ
Technique	:	DBS
Antenna	:	19x7 array
Peak power	:	1-kw
Height coverage	:	1.6-12 km
Pulse width	:	1-64 microsec

III. DATA PROCESSING

Data processing takes up where the signal processing leaves off. The pilot active array radar data processing is usually partly on-line and partly off-line. The on-line processing significantly compresses the data via time averages and usually produces power spectra and the off-line calculations involve parameter extraction. Off-line data processing involves various steps which are to be implemented by the developed MATLAB code. Processing steps can be given as below:

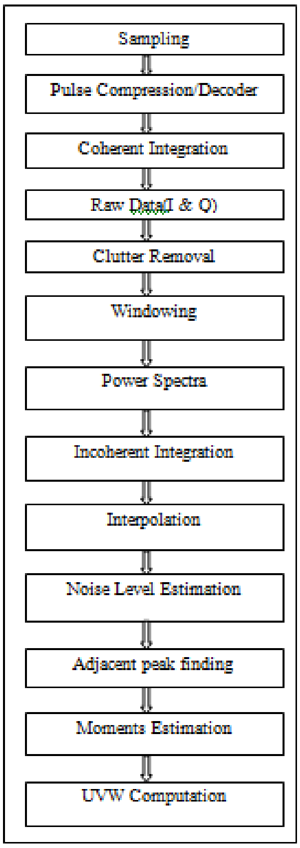

Fig 4: Data processing steps

(1) Pulse Compression/Decoder:

Maximum height coverage with better range resolution can be achieved by pulse coding technique Pulse compression can be achieved by transmitting pulses with bi-phase coding which can be performed by using Complementary codes [4]. In the decoding process autocorrelation operation is performed on the received signal with the code used for transmitting pulse and adding the ACFs resulting.

(2)Coherent Integration:

The coherent integration will reduce the data volume as well as the extraction of maximum Doppler content in it and improves the process gain by averaging the time series data for N consecutive pulses.

(3)Clutter removal:

Any DC offset value in the raw data i.e (I & Q) data can be removed by subtracting the mean value from the complex I & Q signals.

(4)Normalization:

The input data is to be normalized by applying a scaling factor corresponding to the operation done on it. This will reduce the chance of data overflowing due to the succeeding operation.

The normalization has following components:

a. sampling resolution of ADC.
b. scaling due to pulse compression in decoder.

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c. scaling due to coherent integration.
d. scaling due to number of FFT points.

(5)Windowing:
Windowing reduces the effects of spectral side lobes in the Doppler spectrum [5]. A window coefficient vector W_i is multiplied with the complex time series $\{(I_i, Q_i)\}$ where i=0 to N-1

$I_i = I_i * W_i$
$Q_i = Q_i * W_i$

The window coefficient vector W_i can be any one of the windowing techniques. Use of the data windows other than rectangular window is preferred. Hanning window is considered in this paper.

$W_i = 0.5 - 0.5 \cos(2\pi i/N), i = 0$ to N-1

The on-line data processing ends here and begins the offline data processing using MATLAB. The steps involved in offline data processing can be described as below:

(1)Power Spectrum:
Power Spectrum can be obtained from the complex spectrum by converting the time series data into frequency domain using FFT.

(2)Incoherent Integration:
Incoherent integration refers to averaging the power spectrum number of times. The advantage of incoherent integration is that it improves the signal detectability and SNR.

(3)Interpolation:
A strong DC value may present in the spectrum. This is removed by replacing the zero Doppler bins by the average of adjacent Doppler bins on the either side and by interpolating.

(4)Noise level Estimation:
Mean noise level for each range bin is calculated using Hildebrand-Sekhon method and is removed from the power spectra for the estimation of spectral moments [6]. Adjacent peak picking is used for effective moment estimation.

(5)Moments Estimation:
The zeroth, first and second moments refers to the total power, mean Doppler and variance and can be calculated as follow [7]:

$$\text{Total power } M_0 = \sum_{i=0}^{N-1\sim} P_i$$

$$\text{Mean Doppler } M_1 = (1/M_0) \sum_{i=0}^{N-1\sim} P_i f_i$$

$$\text{Variance } M_2 = (1/M_1) \sum_{i=0}^{N-1\sim} P_i (f_i - M_i)^2$$

$$\text{Doppler Width} = \sqrt{M_2}$$

n_i=number of coherent integrations

$$\text{Signal to Noise Ratio} = 10\log\left[(M_0/N*L)\right] \text{ db}$$

Where N=number of fft points
L=noise level
P_i=Power spectrum
$f_i = (i-N/2)/(IPP*n_i*N)$
IPP=inter pulse period

(6)UVW Computation:
For representing the observation results in physical parameters, the Doppler frequency and range bin have to be expressed in terms of corresponding radial velocity and vertical height.

Height $H = ((c*t_R*\cos\theta)/2)$
Velocity $V = ((f_d*\lambda)/2)$
Where c=velocity of light
f_D=Doppler frequency
θ=Beam tilt angle
t_R=Range time delay

Radial velocities obtained from five beams is used to calculate U (zonal),V (meridional) and W(vertical) components of the wind vector, by solving the following equation. V_x, $V_y$and V_z corresponds to U, V and W respectively [7]. Where i is the beam number, V_{Di} is the radial velocityof that beam, θ_x, θ_y, θ_z are the angles that the beam makes with x, y and z axis.

$$\begin{bmatrix} V_x \\ V_y \\ V_z \end{bmatrix} = \begin{bmatrix} \sum_i \cos^2\theta_{xi} & \sum_i \cos\theta_{xi}\cos\theta_{yi} & \sum_i \cos\theta_{xi}\cos\theta_{zi} \\ \sum_i \cos\theta_{xi}\cos\theta_{yi} & \sum_i \cos^2\theta_{yi} & \sum_i \cos\theta_{yi}\cos\theta_{zi} \\ \sum_i \cos\theta_{xi}\cos\theta_{zi} & \sum_i \cos\theta_{yi}\cos\theta_{zi} & \sum_i \cos^2\theta_{zi} \end{bmatrix}^{-1} * \begin{bmatrix} V_{Di\cos\theta xi} \\ V_{Di\cos\theta yi} \\ V_{Di\cos\theta zi} \end{bmatrix}$$

IV. RESULTS

Data is collected from the radar on 1st May 2014. Experimental parameters are shown in the table 1. The collected data is processed with the algorithm explained above in fig 4. Moments, Signal to Noise ratio computed using MATLAB are shown in figure 5. U and V computed are compared with the GPS are shown in the figure 6. Also results obtained for signal to noise ratio, U, V and comparison with GPS with hanning window can be shown in figure 7.

Table 1: Experimental Specifications

	Parameter	**Range**
1.	Pulse width	8μsec
2.	IPP	160μsec
3.	Baud length	1μsec
4.	Beams	5
5.	FFT points	256
6.	Coherent Integrations	256
7.	Incoherent Integrations	4
8.	Mode of Operation	DBS
9.	Range bins	64

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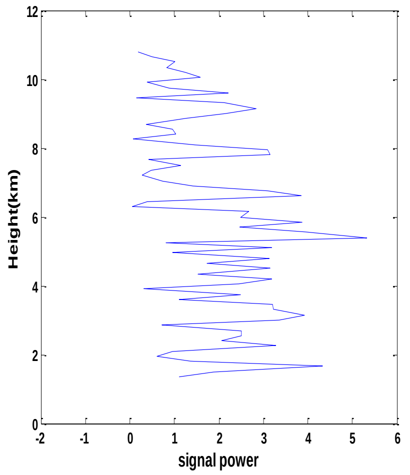

Fig 5(a): Moments (signal power)

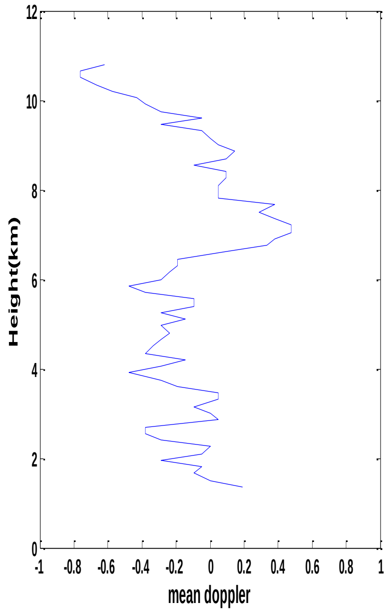

Fig 5(b): Moments (mean Doppler)

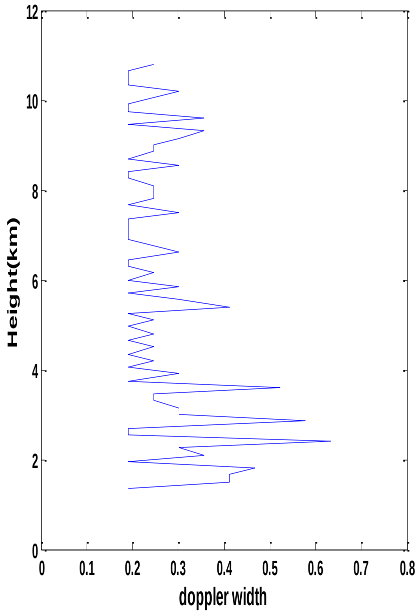

Fig 5(c): Doppler width

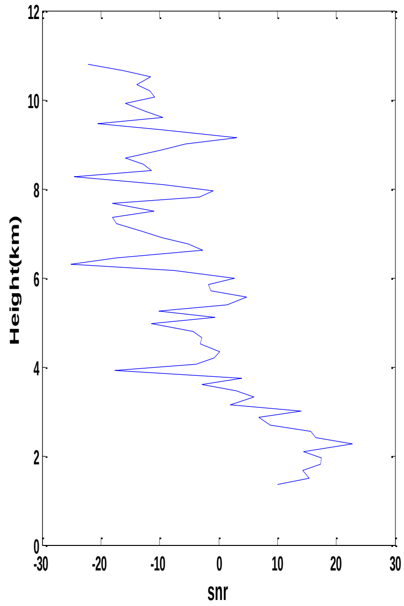

Fig 5(d): Signal to Noise ratio

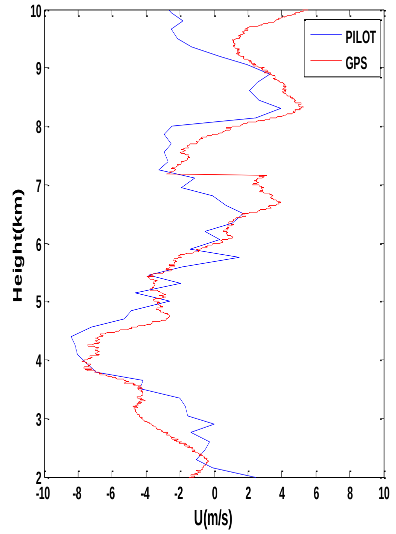

Fig 6(a): U (zonal) component

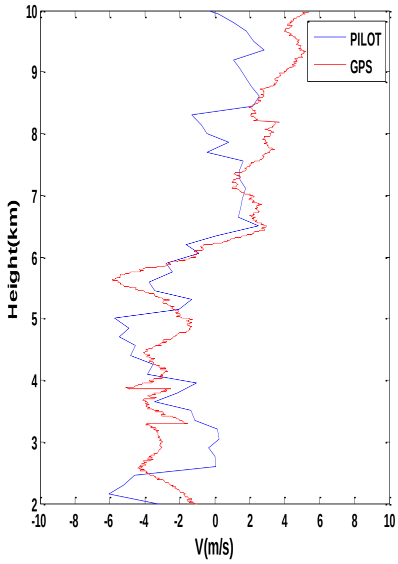

Fig 6(b): V (meridional) component

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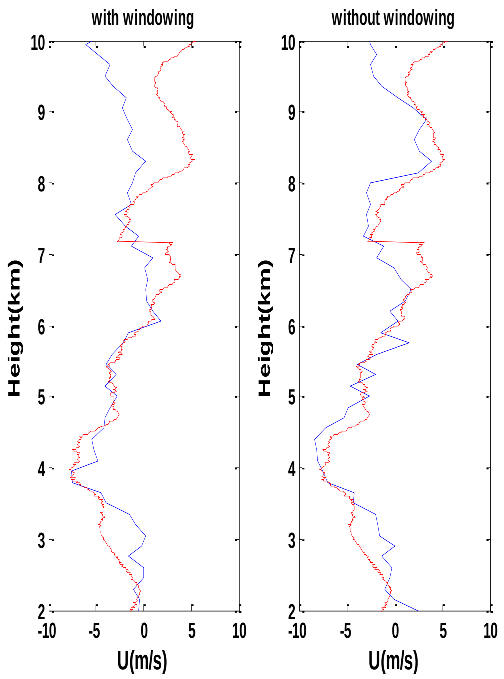

Fig 7(a): U (zonal) component with hanning window

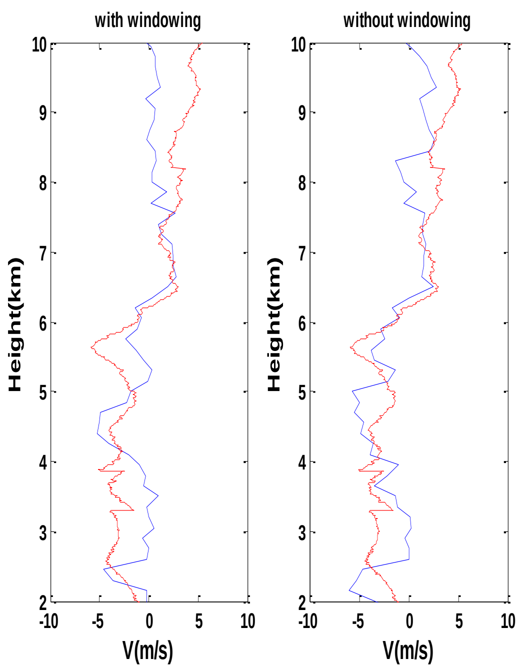

Fig 7(b): V (meridional) component with hanning window

V. CONCLUSION

Matlab code has been implemented successfully for the estimation of spectral moments and for the computation of U, V, and W components. Also a good agreement is seen between the pilot and GPS from the comparison plots shown in fig 6 and 7.

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