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MOMENTS ESTIMATION OFATMOSPHERICRADAR, WIND PROFILER DATA - A CASE STUDY

[1]G.MADHAVILATHA, [2]I.KULLAYAMMA, [3]PROF .S.VARDARAJAN, [4]T.RAJENDRA PRASAD,
[1]M.Tech student, Dept of EEE, S.V.U.College of engineering, Tirupati, INDIA
[2]Asst.professor, Dept of EEE, S.V.U.College of engineering, Tirupati, INDIA
[3]Dept.of EEE, S.V.U.College of engineering, Tirupati, INDIA
[4]Scientist, NARL ,Gadanki, INDIA
E-mail: Latha_sai@yahoo.com , gmlatha2009@gmail.com

ABSTRACT

Atmospheric Signal processing has been one field of signal processing where there is a lot of scope for development of new and efficient tools for Cleaning of the spectrum, detection and estimation of the desired parameters. Atmospheric signal processing deals with the processing of the signals received from the atmosphere when manually stimulated using atmospheric Radar.The signals, which processed in the present work, have been obtained from the mesosphere-stratosphere- troposphere(MST) Radar. The MST radar facilities are situated at National Atmospheric research Laboratory, Gadanki, and Tirupati, INDIA. The signal processing done in the present work concentrates mainly on the data collected from NARL located at Gadanki. This project deal with signal processing techniques. for the analysis of MST Radar signal and to extract better information about moments for wind profiler. The proposed algorithm estimates wind profiler moments and signal –to –noise ratio. The performance of this method is tested practically with atmospheric ,wind profiler data collected at NARL, Gadanki, INDIA. Signal processing of recoded experimental data is performed by MATLAB code developed in my project ,and some of the graphs were plotted.

Keywords: *Atmospheric Signal Processing, Spectrum, Detection, MST, Wind Profiler, Algorithm*

INTRODUCTION:

RADAR (Radio Detection and Ranging) is a device that sends out electromagnetic waves. These waves reflect off of objects in space, and a proportion of the original wave energy is actually bounced back towards the RADAR. The RADAR then reads this returning signal and analyzes it. This returning signal can be processed to determine many properties about the original object that the wave reflected off of. Two examples that can be determined from the returned signal are the location of the object (distance away from the radar itself) as well as the velocity of the object in relation to the radar.

CONCEPT OF RADARS

Radar itself is an abbreviation for RAdio Detection and Ranging. Radar systems send out modulated waveforms using antennas in order to transmit electromagnetic energy into a specific volume of space to search for targets. Objects (i.e. targets) within a certain volume will reflect part of the energy (radar returns or echoes) back to the radar. From these radar returns, the radar receiver then extracts information such as velocity and range, angular position, and other identifying characteristics.If relative motion exists between target and radar, the shift in the carrier frequency of the reflected wave(Doppler effect) is a measure target's relative (radial) velocity and may be used to distinguish moving targets from stationary objectsNational Atmospheric Research Laboratory (NARL) at Gadanki (13.47°N, 79.18°E) near Tirupati, India has been operating a 53 MHz atmospheric radar (Mesosphere, Stratosphere and Troposphere radar) for studying structure and dynamics of lower, middle and upper atmosphere.

MST Radar

MST Radar provides estimates of atmospheric winds on a continuous basis with high temporal and spatial resolutions. MST Radar uses the echoes obtained over the height range of 1-100 Km to study winds, turbulence. The Indian MST Radar has been operational for scientific studies of the atmosphere in the height range of 2-20 km

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(troposphere and lower stratosphere), 60-90 km (mesosphere), 100-150 km (E region) and 150-800 km (F region). The echoes from the atmosphere are due to neutral turbulence in the lower height regions and due to the irregularities in electron density in the higher altitudes. Weak echoes between 30-60 kms were due to less availability of 3 m scale refractive index fluctuations. The radar consists of a phased antenna array that has two orthogonal sets (one for east-west polarization and another one for north-south polarization) of 1024 three element Yagi-Uda antennas arranged in a 32X32 matrix over an area of 130mX130m. It generates a radiation pattern with a main lobe of 3^0 and a gain of 36 dB.India has been operating 53 MHz atmospheric radar (Mesosphere, Stratosphere and Troposphere radar) for studying structure and dynamics of lower, middle and upper atmosphere.

MST Radar Techniques

There are two main Techniques
(i)Doppler beam swinging Technique
(ii)Spaced antenna drift Technique

Doppler beam swinging Technique:

The DBS technique assumes a homogeneous atmosphere over a spatial range around the radar site, but this assumption provides erroneous results during thunderstorm and cyclonic activity This technique uses a narrow beam pointed in at least 3 directions and measures the Doppler shift of directions and at least two more means in scattered off-zenith in two perpendicular directions are used to measure the radial velocity in each beam direction.

Spaced antenna drift Technique

This method uses three or more spaced antennas and received signals are cross correlated to determine the offset of cross correlation functions, yielding horizontal velocity component.

CONFIGURATION OF INDIIAN MST RADAR

The phased antenna array of the Indian MST radar consists of two orthogonal sets, for each polarization, of 1024 three element Yagi-Uda antennas arranged in a 32x32 matrix over an area of 130 m x 130 m [8]. The two sets are collocated with pairs of crossed Yagis mounted on the same set of poles. An inter antenna spacing of 0.71□is used in both principal directions which allows a grating lobe free beam scanning up to an angle of about 24o from the zenith..The array is illuminated in either of the polarization using 32 transmitters operating at 53 MHz of varying power, each feeding a linear sub array of 32 antennas. The power distribution across the array follows an approximation to modified Taylor weighting in both principal directions. The weighting function was arrived at to realize a -20 dB level for the first side lobe of the radiation pattern .The desired power distribution across the array is accomplished in one principal direction by the differential powers of the transmitters and the other direction by appropriate coupling coefficients of the series feed network. The radar beam can, in principle, be positioned at any look angle, but it is currently programmed to sequence automatically any combination of seven look angles: zenith in X and Y polarization, either □20o or □10o off-zenith in magnetic EW and NS , and 14.8o due north to look transverse to the Earth's magnetic field A total transmitter power of 2.5 MW (peak) is provided by 32 transmitters ranging in power from 15 kW to 120 kW, each feeding a subarray of 32 Yagis. The transmitter consists of four amplifier stages and associated power monitoring and controlling, and safety interlock circuits. The amplifier chain consists of a solid state amplifier (SSA), predriver (PDR),driver (DR) and high power amplifier (HPA). The input to the transmitter is a low level (1mW) pulse-modulated (coded/uncoded) signal at 53 MHz generated by mixer which receives as inputs a 5 MHz pulse modulated signal and an appropriately phase-shifted 48 MHz local oscillator (LO) signal. It is possible to transmit both coded and un coded pulses with pulse repetition frequency (PRF) in the range 62.5 Hz to 8 kHz, keeping the duty cycle from exceeding the limit. The uncoded pulses can be varied in pulse width from 1 to 32 □s in multiples of two. The coded pulses can be varied in pulse width from 1 to 32 □s in multiples of two. The coded pulse are either 16 or 32 baud biphase complementary pairs with a baud length of 1 □s, providing a range resolution of 150 m. The output of the transmitter is connected to an antenna subarray though a transmit-receive (T/R) duplexer and a polarisation selection switch. The Duplexer, which serves to switch the antenna array between the transmitters and receiver channels, are realized by means of distributed and lumped hybrid couplers, and PIN diodes. The front end units of the receiver, consisting of a blanking switch, a low noise amplifier (LNA), and a mixer-preamplifier for each of the 32 channels, are located in the four transmitter huts, eight in

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each of them. The quadrature (I and Q) outputs of the receiver are limited to 0.5 volts and given to a preprocessor unit consisting of two identical channels of A/D converter (ADC), decoder and coherent integrator, and a common interface. The ADC is of 12 bit resolution to match the dynamic range of the receiver and of 500 ns conversion time to meet adequately the requirement of 1 MHz sampling rate. The decoding operation essentially involves cross correlating the incoming data from the ADC with the replica of the transmit code. Coherent integration is a processing step introduced to effect a significant reduction in the volume of the data without compromising in any way the information to be derived from the signal.

WINDPROFILER THEORY AND TECHNOLOGY

Theory. Radar (RAdio Detection And Ranging) technology has undergone continuous refinement since its introduction early this century. "Radar is an addition to man's sensory equipment which genuinely affords new facilities." So starts the Massachusetts Institute of Technology (MIT)Radiation Laboratory Series, a set of 27 textbooks published in 1947, which thoroughly describes the radar technology critical to the defeat of the Axis Powers in World War II. Theoretical studies in the 1950s indicated that radio waves are scattered by turbulence in the atmosphere in a predictable way that might allow monitoring of atmospheric parameters. Conventional weather radars detect reflections from objects in the air (e.g., hydrometeors), rather than the air itself. Wind profiling radars, on the other hand, depend on the scattering of electromagnetic energy by minor irregularities in the index of refraction, which is related to the speed at which electromagnetic energy propagates through the atmosphere. When an electromagnetic wave encounters a refractive index irregularity, a minute amount of energy is scattered in all directions. Backscattering, i.e., scattering of energy toward its point of origin, occurs preferentially from irregularities of a size on the order of one-half the wavelength of the incident wave. Because the refractive index fluctuations are carried by the wind, they can be used as tracers. Also, because these irregularities exist in a size range of a few centimeters to many meters, most wind profilers operate at frequencies well below those of conventional weather radars. Experiments in the 1960s verified the theory and showed that atmospheric structure from the surface up into the stratosphere could be detected and many atmospheric processes studied (e.g., Hardy and Katz 1969). In the mid-1970s the National Oceanic and Atmospheric Administration (NOAA) Aeronomy Laboratory began a research program that showed for the first time that tropospheric winds could be measured by very-high-frequency (VHF) (30–300 MHz) Doppler radar that used the Doppler frequency shift of signals scattered from atmospheric turbulence to monitor wind profiles from near the surface to well into the stratosphere (Ecklund et al. 1979).

The general principles of the wind profiler are detailed by, among others, Balsley and Gage (1980) and Rottger and Larsen (1990). Here we primarily address a specific type of radar wind profiler, the ultrahigh-frequency (UHF) (300–3000 MHz) Doppler system that is widely used in the United States. Other radar frequencies, primarily VHF but also microwave, are mentioned where applicable. A different method of wind measurement with numerous variations, called the spacedantenna(SA) method, may also be used to derive wind profiles. The SA method has not been widely used in the United States, but Doviak et al. (1995) describe a 33-cm-wavelength SA system.

Description of the Technology.

The UHF Doppler wind profiler produces vertical profiles of the horizontal and vertical wind by measuring the radial velocity of the scatterers as a function of range on three or five antenna beam positions (Fig. 2-1). The method of wind measurement is described in detail by Strauch et al. (1984); the following is a brief summary.

One antenna beam is pointed toward zenith, and the other two or four beams are pointed about 15 degrees off-zenith with orthogonal azimuths (three-beam systems) or orthogonal and opposite azimuths (five-beam systems). The beam-pointing sequence is typically repeated every 1–5 min. More than one range resolution mode may be used at each beam position. The Doppler

velocity spectrum is computed for each radar resolution cell during a dwell period; more than 105 radar pulses are commonly used to measure each Doppler spectrum. Useful radial velocity estimates can be made with a per-pulse signal-to-noise ratio (SNR) below -40 dB.

Signal processing involves

(1) coherent integration of the complex video signal, (2) spectral analysis, (3) incoherent

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integration of Doppler spectra, (4) isolation of the signal spectrum from the signal-plus-noise spectrum,
(5) Moments calculation of wind profiles. Nearly all UHF Doppler wind profilers operate like this, with very few changes in the basic technique
When the wind field is not horizontally uniform over distances of the order of the separation of the radar resolution cells (a distance that increases with altitude and is on the order of 3 km at 10 km altitude), there are potentially two types of errors in the horizontal wind measurement: (1) the horizontal wind measured at the resolution cell is in error because of horizontal gradients of *w*, and (2) the horizontal wind above the profiler is not the same as that measured at the resolution cells because of gradients of *u* or *v*. Although evaluation of the degree of local uniformity, i.e., horizontal homogeneity and stationarity, is possible using systems with more than three beams, currently implemented signal processing does not support these checks. Instead, it has traditionally been assumed either that uniform conditions exist or that time averaging (typically over 1 hour) will significantly reduce errors from these effects

SIGNAL PROCESSING

The decoding of the pulse compressed data and coherent integration need to be realized in real time. The decoding operation essentially involves cross correlating the incoming digital data with the replica of the transmit code. It is implemented by means of a correlator/transversal filter. Since decoding would normally require several tens of operations per μsec, the implementation would be difficult in software. One approach that can be adopted is to apply coherent integration first and then decode the signal, which is implemented in Sousy radar (Woodman, 1983; Woodman et.al., 1984).
Until recently, most of the signal processor designs were based LSI ICs resulting in limited flexibility. The field of digital signal processing (DSP) has been a very active area of research and application for more than two decades. This broad development has paralleled in time the development of high-speed electronic digital computers, microelectronics and integrated fabrication technologies. An ever increasing assortment of integrated circuit parts specifically tailored to perform common DSP functions is available to the design engineers as system building blocks on parts-in-trade. Effective utilization of advanced DSP IC and fast digital to analog converter has made possible the implementation of decoding without integrating and the software coding in a later stage. In the new generation radars most of the signal processing is realized in firmware with the help of DSP ICs.

Data processing and parameter extraction

The complex time series of the decoded and integrated signal samples are subjected to the process of FFT for the on-line computation of the Doppler power spectra for each range bin of the selected range window. The Doppler spectra are recorded on a Hard disk for off-line processing. There is a provision, however, to record raw data (complex time samples) directly for any application, if so desired. The off-line data processing for parameterization of the Doppler spectrum follows closely the procedure adopted at the poker flat radar (Riddle, 1983). The computation involved in the various stages of operation and its advantages is given below.

Coherent Integration

The detected quadrature signals are coherently integrated for many pulse returns which lead to an appreciable reduction in the volume of the data to be processed and an improvement in the SNR. The coherent integration is made possible because of the over sampling of the Doppler signal resulting from the high PRF relative to the Doppler frequency. In other words, the coherence time of the scattering process τ_c is much greater than the sampling interval given by the inter pulse period t_p. In the case of phase coding, a complementary pair of phase-coded pulse constitutes one radar cycle with a time interval of T_p (= $2t_p$). The odd and even pulses are coherently integrated and decoded separately before combining them to provide the complex time series for spectral analysis for each range gate. Since the integration is linear operation it can be performed before any decoding is carried out of the phase coded pulse returns (Woodman et.al., 1980).The operation of coherent integration amounts to applying a low pass filter, whose time-domain representation is a rectangular window of T_i duration. The effects of coherent integration on the signal power spectrum have been discussed by Farley (1985). The signal spectrum is weighted by that of the integration filter $\sin^2x/x^2$, where $x = \pi f T_i$ and f is the Doppler shift in Hz. The sampling operation at the

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integration time interval of T_i leads to frequency aliasing with signal power at frequencies $f \pm (m/T_i)$, where m is any integer, added to that at f. In the case of a flat spectrum, the filtering and aliasing balance each other and white noise still looks white, with no tapering at window edges. On the other hand, a signal peak with Doppler shift of $0.44/T_i$ Hz, near the edge of the aliasing window, will be attenuated by 3 dB by the filter function, whereas a peak near the center of the spectrum will be almost unaffected. One should, therefore, be conservative in choosing N_i for coherent integration so as to ensure that all signals of interest are in the central portion of the post-integration spectrum. The coherently integrated complementary pairs of coded signals are decoded for each range gate and added together to generate the final time series of the signal return for spectral analysis.

Normalization of the Pre-Processed data

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 any other succeeding operation. The Normalization has following components.

a. sampling resolution of ADC

b. scaling due to pulse compression in decoder

c. scaling due to coherent integration

d. scaling due to number of FFT points.

if Δv - ADC bit resolution (10/16384),

w - Pulse width in microsecond,

M - Number of IPP integrated = Integrated time /inter pulse period,

N - Number of FFT points,

then the Normalization factor

The complex time series { I_i , Q_i where i = 0, . . ,N-1} at the output of the signal processor is scaled as

$$\tilde{I}_i = s * I_i$$

$$\tilde{Q}_i = s * Q_i$$

Windowing

It is well known that the application of FFT to a finite length data gives rise to leakage and picket fence effects. Weighting the data with suitable windows can reduce these effects. However the use of the data windows other than the rectangular window affects the bias, variance and frequency resolution of the spectral estimates. In general variance of the estimate increases with the uses of a window. An estimate is said to be consistent if the bias and the variance both tend to zero .The advantage of the incoherent number of observations is increased. Thus, the problem associated with the spectral estimation of a finite length data by the FFT techniques is the problem of establishing efficient data windows or data smoothing schemes.

Fourier analysis

Spectral analysis is connected with characterizing the frequency content of a signal. A large number of spectral analysis techniques are available in the literature. This can be broadly classified in to non-parametric or Fourier analysis based method and parametric or modal based methods.

Fourier proposed that any finite duration signal, even a signal with discontinuities, can be expressed as an infinite summation of harmonically related sinusoidal component; that is

Where A_K and B_k are Fourier coefficients and Ω_0 is the fundamental angular frequency. Application of Fourier analysis to discrete series of data and its fast computation algorithm Fast Fourier transform (FFT) made this technique so popular in the spectral analysis. FFT is applied to complex time series $\{(I_i, Q_i), i = 0,1, . . . ,N-1\}$ to obtain complex frequency domain spectrum $\{ (X_i, Y_i), i = 0, ... , N-1\}$

$$Xi+Yi=1/N \sum_{K=0}^{N-1} (I_k+jQ_k) \exp(-2\Pi\, i_k/N) \quad i=0,\ldots N-1$$

Power Spectrum

Power spectrum is calculated from the complex spectrum as

$$Pi=Xi^2+Yi^2 \quad i=0,..N-1$$

Incoherent Integration (Spectral averaging)

Incoherent integration is the averaging of the power spectrum number of times.

where m is the number of spectra integrated.

$$P_i= 1/m \sum_{K=1}^{m} P_{ik} \quad i=0,\ldots N-1$$

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The advantage of incoherent integration is that it improves the detect ability of the Doppler spectrum.The detect ability is defined as

$$D = P_S/\sigma_{s+n}$$

Where P_S is the signal power and σ_{S+N} is the standard deviation of the power spectral density.

Power spectrum cleaning

Due to various reasons the radar echoes may get corrupted by ground clutter, system bias, interference, image formation etc.. The data is to be cleaned from these problems before going for analysis.

Clutter/ DC removal: The presence of ground clutter presents a source of additional problem. Different techniques have been used to cancel or minimize its effect. Ground clutter signals have a spectral signature which consists essentially of a single spectral line at the origin with a strength which depends on the ground shielding of the radar. At tropospheric and stratospheric heights it is at least comparable to the signal and often many orders of magnitude larger. Strictly it is very difficult to remove these signals, one way to eliminate its biasing effect is to ignore the frequencies around zero (dc) frequency. This is possible only when the spectral offset is larger than its width. This is also can be removed in time series by taking out the bias in I and Q channel and then perform the Fourier analysis. Spikes (glitches) in the time series will generate a constant amplitude band all over the frequency bandwidth. Once Fourier analysis is done, it is difficult to identify the correct Doppler in the range bin. These points may be removed from the range bin and adjusted to noise floor or doing an incoherent integration of the spectrum and replace

Parameter Estimation.

MST radar echoes are produced by fluctuations in the index of refraction of the atmosphere. In most cases, these are turbulence-induced fluctuations. Because of the random nature of the turbulence, radar returns from turbulence-induced fluctuations represent stochastic processes and have to be characterized statistically. The returns from any one height form a random time series and can be considered stationary within an integration time and Gaussian in nature (Woodman 1985;. To characterize the process, it is essential to know the turbulence intensity, mean radial velocity and velocity dispersion, which are a measure of physical properties of the medium. If the spectrum is Gaussian, these three parameters contain all the information which we can obtain from the radar echoes

Noise level estimation

There are many methods adapted to find out the noise level estimation. Basically all methods are statistical approximation to the near values. The method implemented here is based on the variance decided by a threshold criterion, Hildebrand and Sekhon (1974). This method makes use of the observed Doppler spectrum and of the physical properties of white noise; it does not involve knowledge of the noise level of the radar instrument system. This method is now widely used in atmospheric radar noise threshold estimation and removal.The noise level threshold shall be estimated to the maximum level L, such that the set of Spectral points below the level S, nearly satisfies the criterion,

Step 1:

Reorder the spectrum { P_i, i = 0, . . . N-1} in ascending order to form. Let this sequence be written as{ A_i, i = 0, . . . N-1} and $A_i < A_j$ for i < j

Step 2: compute

$$P_n = \sum_{i=0}^{n} A_i/(n+i)$$

$$Q_n = \sum_{i=0}^{n} A_i^2/n+1 - P_n^2$$

and if $Q_n > 0, R_n = P_n^2/(Q_n * M)$

Where M is the number of spectra that were averaged for obtaining the data.

Step 3:

Noise level(L)=P_k where k=min[$_1{}^n$

Moments Estimation

The extraction of zeroth, first and second moments is the key reason for on doing all the signal processing and there by finding out the various atmospheric and turbulence parameters in the region of radar sounding. The basic steps involved in the estimation of moments, Woodman (1985) are given below.

Step 1.

Reorder the spectrum to its correct index of frequency (ie. $-f_{maximum}$ to $+f_{maximum}$) in the following manner.

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Step 1

Spectral index	0	1
ambiguous freq.		$-f_{maximum}$
N/2		N-1
Zero freq.		$+f_{maximum}$

Step 2:

Subtract noise level L from spectrum

Step 3:

i) Find the index l of the peak value in the spectrum,

$$ie \quad \tilde{P}_l \geq \tilde{P}_i \quad for\ all\ i = 0, \cdots\cdots N-1$$

ii) Find m, the lower Doppler point of index from the peak point.

$$ie \quad \tilde{p}_i \geq 0 \quad for\ all\ m \leq i \leq l$$

iii) Find n the upper Doppler point of index from the peak point

$$ie \quad \tilde{p}_i \geq 0 \quad for\ all\ l \leq i \leq n$$

Step 4:

The moments are computed as

i) $M_0 = \sum_{i=m}^{n} \tilde{P}_i$ represents zeroth moment or Total Power in the Doppler spectrum.

represents the first moment or mean Doppler in Hz

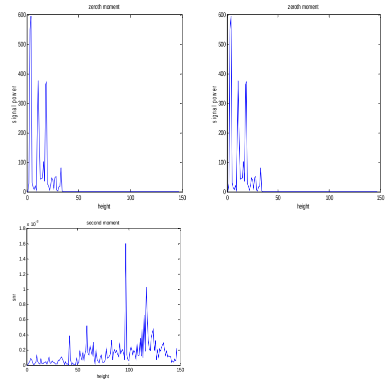
$$iii) \quad M_2 = \frac{1}{M_0} \sum_{i=m}^{n} \tilde{P}_i (f_i - M_1)^2$$

represents the second moment or variance, a measure of dispersion from central frequency.

Where IPP - is interpulse period in microsec.

Calculation of spectral moments of spectrum with composite structure is done in a slightly different way from the procedure explained above. This type of spectrum normally comes in the upper atmospheric region (Ionosphere). Here the spectra shows multiple spikes and wide, so after the removal of mean noise level the spectra may be crossing from positive values to negative many times. The Doppler point to be checked is the central point of the template. This template will move from the peak to the either side of the spectrum to find the lower and upper point of Doppler index from the maximum peak. The running average of seven points is checked against a threshold. The threshold is kept 3dB above the mean noise level. The Doppler point is considered till the template average is above the threshold. Remaining part of the moments calculation is same as that of the calculation for the single peak Doppler spectrum.

RESULTS:



CONCLUSSIONS:

An Matlab code has been stated to calculate zeroth,first and second Moments of MST Radar ,same code with slight corrections is used to calculate three moments of wind profiler data.

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