Doppler Wind Profiler Radar at 50 MHz

Sagar Vijay Mhatre, Ajay Khandare and P.B.Borole

Abstract: This paper presents the design of a 50MHz Wind Profiler with focus on modularity, signal processing needs to be done and the major hardware blocks involved in the signal processing. Wind profiler radars are vertically directed pulsed Doppler radars capable of analyzing the back-scattered signals to determine the velocity of air along the beams. By steering the beams typically 15° from zenith, the horizontal and vertical components of the air motion can be obtained. The bands around 50 MHz are ideally suited for high altitude measurements. In view of the physics involved, for measurements above 20 km, only the 50 MHz band can be used. The paper discusses the issues such as the principle of wind profiler radar, How wind profilers estimate the horizontal wind as a function of altitude in 'clear air', Doppler Beam Swinging (DBS) technique for Wind velocity measurement, Signal processing done on transmitted signal, Signal processing done on received signal, necessity of the signal processing and the hardware used for the signal processing.

Keywords: Coherent integration, Doppler frequency, FFT, Radar, etc

I. INTRODUCTION

Wind profiling radar, also referred to as "radar wind profiler", "wind profiler", and "clear-air Doppler radar", is used to measure height profiles of vertical and horizontal winds in the troposphere. It receives signals scattered by radio refractive index irregularities (clear-air echo) and measures the Doppler shift of the scattered signals. Wind profiling radar measures wind velocities by steering its beam directions or using spaced receiving antennas. The two methods are referred to as the Doppler beam swinging (DBS) technique and spaced antenna (SA) technique, respectively. Owing to its capability to measure wind velocities in the clear air with high height and time resolutions (typically a hundred to several hundreds of meters and less than several minutes, respectively), it is used for atmospheric research such as radio wave scattering, gravity waves, turbulence, temperature and humidity profiling, precipitation system, and stratosphere-troposphere exchange (STE) processes. Wind profiling radar is also utilized for monitoring wind variations routinely [6].

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II. WORKING PRINCIPLE

Wind profiling radars 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 a vertically transmitted electromagnetic wave encounters a refractive index irregularity, a minute amount of energy is scattered in all directions. In clear air the scattering targets are the temperature and humidity fluctuation produced by turbulent eddies. Because the refractive index fluctuations are carried by the wind, they can be used as tracers. Doppler shift in the backscattered signal is used to derive the wind speed and direction as function of height. Using appropriate trigonometry, the three-dimensional meteorological velocity components (u, v, w) and wind speed and wind direction are calculated from the radial velocities with corrections for vertical motions.

When a pulse encounters a target it is scattered in all directions. Out of the total scattered energy, the energy scattered in the direction opposite to the direction of transmission is received by the RADAR. This signal is much weaker than transmitted wave and called as back-scattered wave

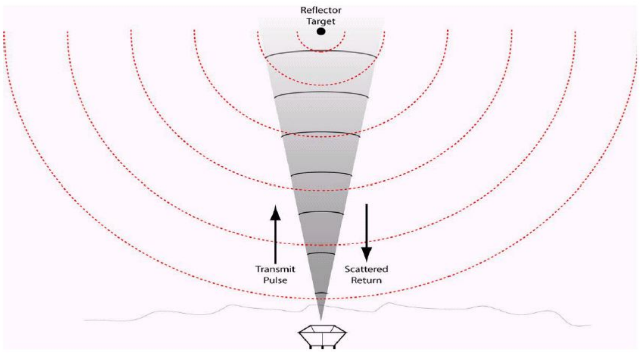

Fig. 1. Scattering mechanism

Scattering of the electromagnetic wave follows the Bragg's principle. Bragg's principle states that, an electromagnetic wave can be scattered by the particles having size half the wavelength of an incident electromagnetic wave. Irregularities exist in a size range of a few centimeters to many meters. For wind profiling radars, frequency range of 30-3000 MHz (i.e., VHF and UHF bands) is generally used because the energy spectrum of atmospheric turbulence falls off rapidly with decreasing eddy size in the inertia sub-range [7], and radar radio waves are scattered only from turbulent eddies at the Bragg scale (i.e., half the radar wavelength).Wind profiling radars operated at approximately 50 MHz frequency are not sensitive for small-sized cloud particles. Therefore 50-MHz wind profiling radars are able to measure vertical and horizontal wind velocities in both the clear air and cloudy regions.

The highest altitude from which scattering can be detected depends upon the average power transmitted, the size of the antenna, meteorological conditions, and the frequency (or wavelength). The greater the transmitted power or the larger the antenna, the stronger the returned signal and greater the return signal and greater the height range of detection. Likewise, the more turbulent the atmosphere, the stronger the returned signal and greater the height range of detection. The dependence of scattering upon the wavelength is related to the abundance of scatterers of the appropriate size. The smaller "irregularities" (cm size) are abundant only at the lower heights. The higher frequency waves, therefore, aren't backscattered as effectively at the greater heights, as are those at the lower frequencies.

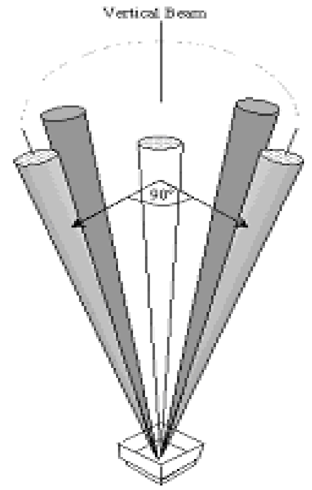

Fig. 2. Dual Beam Swinging

III. DUAL BEAM SWINGING TECHNIQUE

There are three measurement techniques to estimate the horizontal wind speed. Namely, Velocity Azimuth Display-VAD (Steerable Dish), Spaced Antenna-SA (Interferometry) technique and Doppler Beam Swinging-DBS (Phased Array) technique. Of which the paper discusses the DBS technique [1].

Doppler shift obtained from radar is an accurate method of measuring wind velocity along the line of sight of the radar beam. Taking advantage of this, wind profilers have been used to monitor the atmospheric wind field. A pulsed Doppler radar transmits a sequence of electromagnetic pulses and receives the scattered signal in between [2]. A Doppler weather radar is capable of determining component of the wind velocity and direction as function of height by analyzing the Doppler shift in the backscattered signal. The Doppler frequency shift f_d is related to the radial velocity. As,

$$f_d = - 2 * V_r / \lambda$$

Where V_r is the radial velocity and λ is the wavelength of the electromagnetic wave.

Pulsed Doppler radar utilizes the same set of Antennas for the transmission of electromagnetic waves and reception of backscattered wave. Receiver is blanked for specific period of time. In that time period a signal is transmitted using the antennas. A typical DBS wind profiler system uses three or five radar beams pointed in fixed directions. 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) [3]. 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.

IV. WIND VELOCITY MEASUREMENT

While deriving wind velocities it is assumed that the atmosphere is homogeneous across the radar observational volume. Horizontal wind velocity has three components u, v and w in the direction east, north and upward.

In the three-beam configuration, horizontal winds are measured using two orthogonal beams (e.g., east and north) and a zenith beam. Horizontal wind components at any given height are derived from the radial velocities (V_R) (positive away from the radar) measured on each of the three antenna beams. V_Z, V_{RE}, V_{RN} are the vertical, tilted east and tilted north radial velocities with γ as the off-zenith angle.

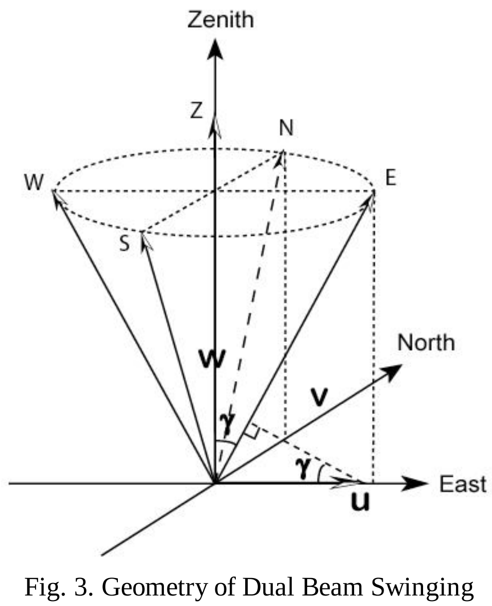

Fig. 3. Geometry of Dual Beam Swinging

In five-beam configuration all four oblique beams (east, west, north and south) and a zenith beam are used. Radial velocities in east (V_{RE}), west (V_{RW}), north (V_{RN}), south (V_{RS}), and zenith (V_{RZ}) directions with γ as the off-zenith angle can be expressed in terms of u, v and w as [4],

$$V_{RE} = u \sin\gamma + w \cos\gamma \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(i)}$$
$$V_{RW} = -u \sin\gamma + w \cos\gamma$$
$$V_{RN} = v \sin\gamma + w \cos\gamma$$

$V_{RS} = -v \sin\gamma + w \cos\gamma$

$V_{RZ} = w$

Then the components of horizontal wind velocity will be given by the equations,

$u = (V_{RE} - V_{RW}) / \sin\gamma / 2$…………………… (ii)

$v = (V_{RN} - V_{RS}) / \sin\gamma / 2$

$w = V_{RZ}$

V. PROFILER HARDWARE

The wind profiler has three basic building blocks which take care of RF transmission, Digital signal processing block and Computation and display device. The first block is RF antenna section which is used to transmit and receive electromagnetic wave. The second block will be used for signal processing. All the signal processing devices will be implemented using FPGAs. The third block is Computation and display device, which is a personal computer. Personal computer will analyze the received signal and determine the required parameters. The result will be displayed using the GUI developed for the application.

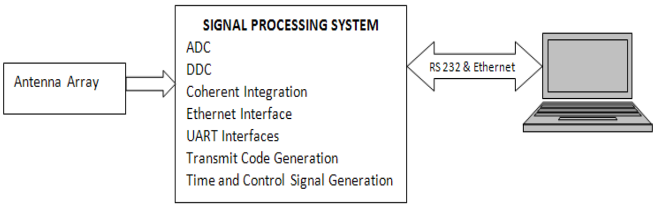

Fig. 4. Wind Profiler hardware schematic

VI. SIGNAL PROCESSING

i. ADC (Analog to Digital Converter):

The transmitted signal is an analog signal at the frequency 50 MHz The signal first needs to be converted into digital data. The incoming RF signal between 1 MHz to 50 MHz is connected at ADC input. These signals must be sampled at high speed. The captured data from the ADCs is forwarded to the next module.

ii. DDC (Digital down Converter):

The signal of interest in the sampled signal is of narrow bandwidth, the bandwidth of interest is very small. Therefore the sampled data from the ADC must be brought to baseband so as to use it for further processing. A DDC allows the frequency band of interest to be moved down the spectrum so the sample rate can be reduced. The required down sampling can be achieved by using multiple stages of CIC filter and polyphase FIR filter.

iii. Coherent Integration:

Coherent integration has been used in matched filter radar signal processing to increase target signal to noise ratios and to reduce the volume of data to be processed.

iv. Decoding:

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 or transversal filter. Since decoding would normally require several tens of operations per μsec, the implementation would be difficult in software. Hence coherent Integration is applied first and then the decoding follows.

v. Fourier Analysis:

Fourier proposed that any finite duration signal, even a signal with discontinuities, can be expressed as an infinite summation of harmonically related sinusoidal components. FFT is applied to complex time series to obtain complex frequency domain spectrum.

vi. Power spectral computation:

Power spectrum is calculated from the complex spectrum.

VII. ANALYSIS AND PARAMETER EXTRACTION

Wind profiler radar echoes are produced by turbulence-induced fluctuations in the index of refraction of the atmosphere. 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. 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. Following procedure is followed for the parameter extraction.

i. Estimation of Noise level:

There are many methods adapted to find out the noise level estimation. The method implemented here is based on the variance decided by a threshold criterion [5].

$$\frac{Variance(S)}{mean(S)^2} \leq 1$$

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.

ii. Computation of Moments:

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.

iii. Computation of absolute Wind velocity vectors (UVW):

After computing the radial velocity for different beam positions, the absolute velocity (UVW) can be calculated. To compute the UVW, at least three non-coplanar beam radial velocity data is required. If higher numbers of different beam data are available, then the computation will give an optimum result in the least square method. The UVW components can be calculated by using the set of equations (ii).

VIII. CONCLUSION

Wind velocity measurement is an important function of weather monitoring. By performing different experiments at different locations with different operating frequencies of radar, it has been clearly established that the Doppler shift obtained from radar is an accurate method of measuring wind velocity along the line of sight of the radar beam. The proposed system can be very useful tool in the wind velocity measurement.

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