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Signal Processing and Data Acquisition for Wind Profiler Using Labview

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ABSTRACT
This paper presents the design of Wind Profiler using LabVIEW. Wind speed is a useful weather parameter to monitor and record for many applications like shipping, aviation, meteorology, construction etc. Wind observations are crucial importance for general (operational) aviation meteorology, and numerical weather prediction. 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. Steering the beams typically 15° from zenith, the horizontal and vertical components of the air moment can be obtained. The extraction of zeroth, first and second moments is the key reason for doing all the signal processing. For measurements above 20 km, the 50 MHz frequency 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. Moment calculation and Signal processing of recoded experimental data is performed by LabVIEW code developed in my project.
***Keywords* -** Radar, Doppler effect, Bragg's scattering, FFT etc

I. INTRODUCTION

Wind profiling radar, also referred to as "wind profiler", used to measure height profiles of vertical and horizontal winds in the atmosphere. Wind profiling radars depend on the scattering of electromagnetic energy by minor irregularities in the index of refraction (Bragg scattering), which is related to the speed at which electromagnetic energy propagates through the atmosphere and measures the Doppler shift of the scattered signals (Gage, 1990). Wind profiling radar measures wind velocities by steering its beam directions or using spaced receiving antennas. The two methods are 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 (Fukao, 2007; Hocking, 2011)[6].

II. WORKING PRINCIPLE

Wind Profiler depends on the scattering of electromagnetic energy with minor irregularities in the index of refraction, which is related to the speed at which electromagnetic energy propagates through the atmosphere. A minute amount of energy is scattered in all directions when a vertically transmitted electromagnetic wave encounters a refractive index irregularity. In clear air the temperature and humidity fluctuation produced by turbulent eddies are the scattering targets. The refractive index fluctuations are carried by the wind so they can be used as tracers. The wind speed and direction as function of height is derived by using Doppler shift in the backscattered signal. The radial velocities with corrections for vertical motions are used to calculate the three-dimensional meteorological velocity components (u, v, w) and wind speed and wind direction, using appropriate trigonometry.

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.

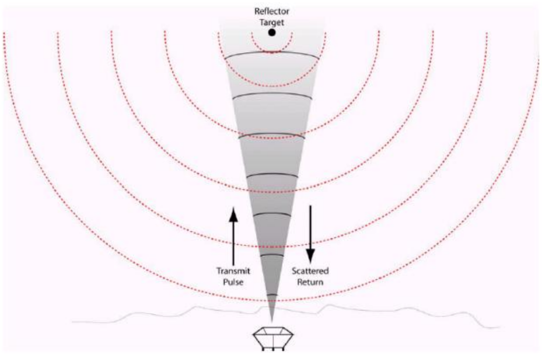

Fig.1 Scattering Mechanism

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

The average power transmitted, the size of the antenna, meteorological conditions, and the frequency (or wavelength) helps us to find the highest altitude from which scattering. The greater the transmitted power or the larger the antenna, the stronger the returned signal and greater the return signal, greater the height range of detection. The more turbulent the atmosphere, the stronger the returned signal and greater the height range of detection. The smaller "irregularities" are abundant only at the lower heights. The higher frequency waves aren't backscattered as effectively at the greater heights, as compare to the lower frequencies.

III. DOPPLER BEAM SWINGING TECHNIQUE

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

Doppler shift obtained from radar is a 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[2]. 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 fd is related to the radial velocity. As,

$$fd = - 2 * Vr / \lambda$$

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

The same set of Antennas for the transmission of electromagnetic waves and reception of backscattered wave utilized by Pulsed Doppler radar. 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 repeated every 1–5 min. 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. Radial velocity estimates can be made with a per-pulse signal-to-noise ratio (SNR) below -40 dB.

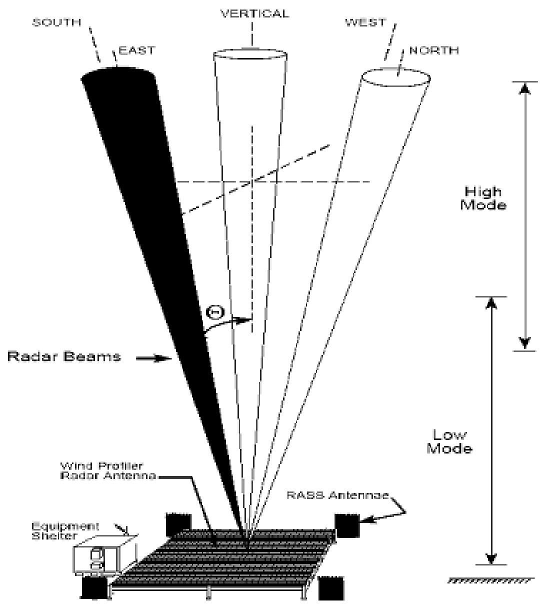

Fig. 2. Dual Beam Swinging

IV. WIND VELOCITY MEASUREMENT

It is assumed that the atmosphere is homogeneous across the radar observational volume.

Horizontal wind velocity has three components that is u, v and w in the direction east, north and upward.

Horizontal winds are measured using two orthogonal beams (e.g., east and north) and a zenith beam, In the three-beam configuration. Horizontal wind components at any 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.

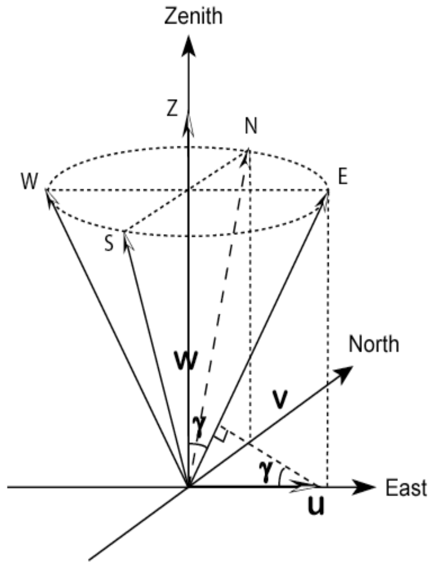

Fig. 3. Geometry of Dual Beam Swinging

In five-beam configuration all four oblique beams (east, west, north and south) and a zenith beam are used and Radial velocities in east (V_{RE}), west (V_{RW}), north (V_{RN}), south (V_{RS}), and zenith (V_{RZ}) directions with the γ as the off-zenith angle[4]. The radial velocity components can be expressed in terms of components of horizontal wind velocity using basic trigonometry formulae as,

$$V_{RE} = u \sin\gamma + w\cos\gamma$$
$$V_{RW} = -u \sin\gamma + w\cos\gamma$$
$$V_{RN} = v \sin\gamma + w\cos\gamma$$
$$V_{RS} = -v \sin\gamma + w\cos\gamma$$
$$V_{RZ} = w$$

From the above equation components of horizontal wind velocity can be derived as,

$$u = (V_{RE} - V_{RW}) /\sin\gamma /2$$
$$v = (V_{RN} - V_{RS}) /\sin\gamma /2$$
$$w = V_{RZ}$$

V. HARDWARE PROFILE

The wind profiler is made up of three basic building blocks which are Trans-receiver system, digital signal processing system and computing and display device.

Trans-receiver system transmits the electromagnetic wave and receives the back-scattered wave. It also consists of RF trans-receiving antennas. The receiver is blanked for some period of time using a blanking pulse. During this period the coded signal is transmitted in the atmosphere. The transmitted signal is complementary coded and complementary coding is done to target the large volume of air keeping the signal to noise.

The digital signal processing system converts the received RF signal into digital domain and then extracts the required signal from the received signal. It also generates the timing and control signals required for the whole system. It also controls the communication between the signal processing unit and the computing and display unit. Two units are communicates with each other using this UART and Ethernet connection.

Computing and display device can be a computer, which will analyze the signal and display the required parameters using GUI. The same GUI can also be used to set parameters for the whole process.

VI. SIGNAL PROCESSING

The classical signal processing is mainly divided in two stages. The time-domain stage and the frequency-domain stage. The fundamental base parameters of the atmospheric signal are the reflected power, the radial velocity and the velocity variance. Signal processing is then performed to finally determine the wind and other meteorological parameters using measurement from all radar beams

vi.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.

vi.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.

vi.iii Coherent Integration:

The detected quadrature signals (I and Q) 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

vi.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 □ sec, the implementation would be difficult in software. Hence coherent Integration is applied first and then the decoding follows.

vi.v. Fourier Analysis:

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. MOMENT ESTIMATION

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

Step 1.

Reorder the spectrum to its correct index of frequency (ie. -fmaximum to +fmaximum) in the following manner.

0	1
ambiguous freq.	–fmaximum
N/2	N-1
Zero freq.	+fmaximum

Step 2:

Subtract noise level L from spectrum.

Step 3:

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

$$i.e., \quad \tilde{P}_1 \geq \tilde{P}_i \quad for\ all\ i = 0, \cdots\cdots N-1$$

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

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

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

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

Step 4:

The moment are computed as

$$i) \quad M_0 = \sum_{i=m}^{n} \tilde{p}_{iz}$$

The moments are computed as represents zeroth moment or Total Power in the Doppler spectrum

$$ii) \quad M_1 = \frac{1}{M_0} \sum_{i=m}^{n} \tilde{p}_i f_i \qquad where\ f_i = \frac{(i - N/2)}{(IPP * n * N)}$$

Represents the first moment or mean Doppler in Hz

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

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

Here

$$iv) \quad Doppler\ width\,(full) = 2\sqrt{M_2} \quad Hz$$

$$v) \quad Signal\ to\ Noise\ Ratio\,(SNR) = 10 \log \left[\frac{M_0}{(N * L)} \right] \quad dB$$

Here

IPP - is the inter-pulse period in microseconds.

N- is the number of FFT points.

L-Noise level calculated from spectrum

VIII. RESULT

Figure 4 shows the front panel of LabVIEW in which zeroth, first and second moment is calculated with signal to noise ratio, experimental input data and Doppler.

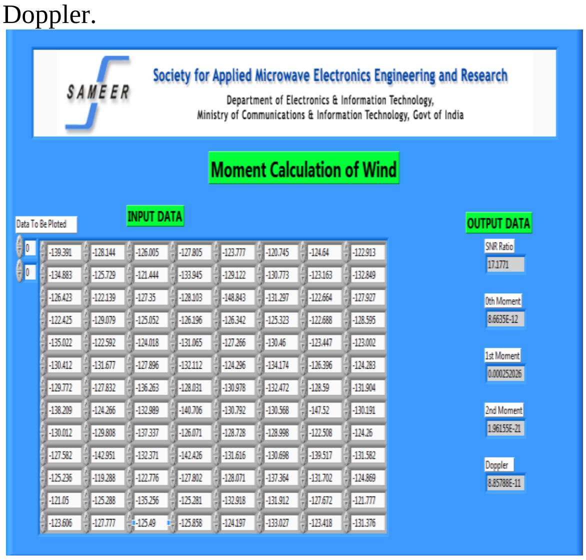

Fig. 4. Front panel of LabVIEW

IX. CONCLUSION

In this paper, we presented the wind velocity measurement is an important part of weather monitoring. A LabVIEW code has been design to calculate zeroth, first and second Moments, same code with few corrections is used to calculate three moments of wind profiler data.

X. ACKNOWLEDGMENT

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