IJCSE International Journal of Computer Sciences and Engineering Open Access
Research Paper Volume-5, Issue-2 E-ISSN: 2347-2693

PC-Based Real Time Data Processing System for Doppler Sodar Applications

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Available online at: www.ijcseonline.org

Received: 06/Jan/2017 Revised: 13/Jan/2017 Accepted: 10/Feb/2017 Published: 28/Feb/2017

Abstract- **SODAR, an acoustic pulse radar, provides detailed information on dynamic properties of air turbulence in the lower part of the atmosphere. The speed of the transmitted sound wave is responsive to changes in wind swift, due to high rate of susceptibility to temperature variations. The velocity of the transmitted sound wave propagation is much lower when comparing to velocity of electromagnetic waves. Due to this fact the processing of sodar information is significantly simplified and reached better spatial resolution and dead zone. Sophisticated model of tri-static sodar has developed to using general purpose PC to study the properties of sound wave at see breeze.**

Keywords- **Scattering, Turbulence, Facsimile, Echo, SODAR, Homogeneous, Wind profile**

I. INTRODUCTION

The SODAR (SOnic Detection And Ranging) is a remote sensing instrument that to measure the wind profile in the lower atmosphere of the earth. The volume measurement of the wind profile by the remote sensing device, like SODAR, has a great advantage compared to point measurements in one height. In SODAR, acoustic pulses with particular time duration are sent vertically and at a small angle to the vertical. A thus transmitted sound pulse is scattered by the fluctuations and gradients as well as wind shear. A backscattered signal has received by the receiver of the SODAR antenna. Here this backscattered signal may have a probability of mixing with another signal, which has fallen into backscattered signal frequency range. These back scattered signal fed to the computer and later directed to SODAR software [8, 10]. Here the software will take the responsibility to store and plot the graph. Here these graphs are known as facsimiles. So this facsimile is the combination of original backscattered signal and unwanted signal. Generally, this backscattered signal get filtering before fed to the computer but this filters will be designed for a band of frequencies, not restricted for the single frequency. Therefore a band of frequencies will be fed to a computer as backscattered signal. Actually, problems arise here with identifying that original backscattered signal.

The first acoustic sounding system was developed by Tyndall [15] and he observed sound scattering from turbulence while studying the propagation of sound waves through the sea fog. The theoretical problems of sound scattering by turbulence was first formulated and solved by Obukhov [1, 2]. Further, the fundamental theories of sound wave scattering were established many physicists' like Obukhov [1,2] in 1943, Blokhinzev in 1946, Tatarskii [13] in 1961, Monin in 1962 in Russia and kraichan in 1953 in the USA. These new theories stimulated scattering experiments in physicists. An important step towards the modern sodar system was made by McAllister [3] in 1968. McAllister along with his co-scientist, Pollard in 1969, were the first, who recorded the echo intensity as facsimile. This height time cross-section will be referred to as a sodargram. Therefore, it was possible to get a picture of the temporal variation of the atmosphere's acoustic reflectivity. The first Doppler sodar developed by Kelton and Bricout, who have initiated the measurement with high frequency sound wave through the bi-static scattering experiments.

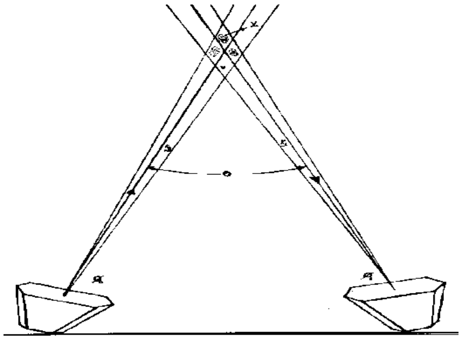

Figure.1: Bi-static sodar configuration.

II. THEORITICAL EVALUATIONS

The sodar system belongs to the group of remote sensing systems, which leads the efficiency of sodar system has been enhanced to measure real time profiles of wind velocities up to several hundred meters above the ground.. The basic design of a sodar system can be monostatic or bistatic. In the phenomenon of the bi-static system, the emitting and the receiving antennas are separated, while in mono-static systems have one antenna with transceivers. This transceivers is a combination of transmitters and receivers, which are switched into receiving mode after the sound pulse is emitted. Here, in this work, a mono-static system configuration is adopted in experiment; further explanations will be limited to mono-static system type of sodar.

The concept of beam steering of a mono-static sodar system [9, 10, 11], in older design, consists of one separate antenna for each beam, which means, such a sodar has at least three transducer tubes for three beams. The newer design consists of a phased array of transducers, in which, the beam steering is electronically controlled by applying a distinct phase shift from one row to the next when emitting a sound pulse. Due to the interference of sound wave; the beam is titled against the zenith over the edge of the mount. If there is no phase between the rows of the transducers, the pulse is emitted vertically. The beam angle against zenith depends on air temperature and the acoustic frequency. It increases with decreasing air temperature and decreasing frequency.

Sound energy propagates in the atmosphere as a longitudinal pressure wave. The attenuation of the sound wave as it propagates is frequency dependent. Since the variations of attenuation with frequency is a smooth step less continues curves, the decrease in intensity of a plane sound wave in small frequency interval can be expressed as an exponential decay function

$$I = I_o e^{-\alpha l}$$

Here I is the distance (m) andα, the atmospheric attenuation coefficient composed of three components (m-1):

$$\alpha = \alpha c + \alpha m + \alpha s$$

Here αc is the classical attenuation due to dissipation of energy resulting from the viscosity of the air, radiation and heat conduction. Under normal atmospheric conditions αc is very much smaller than αm and αs and is dependent on the frequency f:

$$\alpha c = 4.24\ f210\text{-}11m\text{-}1$$

The molecular attenuation αm decreases with decreasing temperature. The attenuation component αs is due to scattering of sound by temperature structures and turbulence. This component is very large with respect to the other components. However, the sound waves propagating in a perfectly homogeneous and continuous medium are not scattered. Scattering requires an inhomogeneity of the refractive index.

The speed of sound in the atmosphere depends on the wind speed component, on the temperature, and on the chemical composition of atmosphere [8]. Water vapor is the constituent most likely to fluctuate. As a guide to the change in refractive index, Table 1.1 shows the relative change in wavelength per Kelvin of temperature change, per m/s of change in wind speed, and per hPa of change in water vapor pressure.

$\frac{\Delta\lambda}{\lambda}\ in\ K^{-1}$	$\frac{\Delta\lambda}{\lambda}\ in\ (m/s)^{-1}$	$\frac{\Delta\lambda}{\lambda}\ in\ hPa^{-1}$
$1800\ 10^{-6}$	300010^{-6}	160.10^{-16}

Table.1.1: Change of wavelength of sound waves in the atmosphere as a function of changes in temperature, wind speed and water vapor content.

For the energy σ (θ) scattered from unit volume from unit flow at angle "θ", the following can be derived:

$$\sigma(\theta) = \frac{32\pi^5 \cos^2\theta}{\lambda^4}\left[\frac{\Phi(V)\left(\frac{4\pi}{\lambda}\sin\frac{\theta}{2}\right)\cos^2\frac{\theta}{2}}{C_o^2} + \frac{\Phi(T)\left(\frac{4\pi}{\gamma}\sin\frac{\theta}{2}\right)}{4T^2}\right]$$

Where:

λ-Sound wavelength at mean temperature T (m).

θ-Scatter angle in relation to the incident wave (°).

Φ(V) - 3D spectral density of wind velocity.

Φ(T) - 3D spectral density of temperature.

The functions Φ(V) and Φ(T) relate to the spatial region " λ' ":

$$\lambda' = \frac{\lambda}{2\sin\frac{\theta}{2}}$$

Assuming a Kolmogorov turbulence spectrum, the following can be written:

$$\sigma(\theta) = 0.005\lambda^{-1}\cos^2\theta\left[\frac{C_V^2}{C^2}\cos^2\frac{\theta}{2} + 0.13\frac{C_T^2}{T^2}\right]\left(\sin\frac{\theta}{2}\right)^{-\frac{11}{3}}$$

The structure parameters C_V^2 and C_T^2 are defined as follows:

$$C_V^2 = \left[\frac{u(x) - u(x+r)}{r^{\frac{1}{3}}}\right]^2$$

$$C_T^2 = \left[\frac{T(x)-T(x+r)}{r^{\frac{1}{3}}}\right]^2$$

Here u and T are the wind speed and temperature at location x and r. Not only random fluctuations of air temperature but also uniform temperature gradients contribute to the scattering [12,13 &14]. This is so only in the case of marked change in refractive index.

The relationship between transmitted and received acoustic power Pt and Pr from scattering volume for the mono static Sodar is described by Equation 1 (Neff, 1975; Hall and Wescott, 1974):

$$P_r = P_t \eta_t \eta_r \sigma(\pi) C \tau_l A_r G \frac{\exp(-2\alpha z)}{2z} \quad \text{……… (1)}$$

Where: σ (π)	Acoustic backscatter cross section per unit volume.
ηt	Efficiency of transmitter.
ηr	Efficiency of receiver.
C	Speed of sound.
τ1	Pulse length.
Ar	Antenna effective aperture.
G	Directivity compensation factor.
	Acoustic attenuation coefficient.
Z	Range to scattering region.

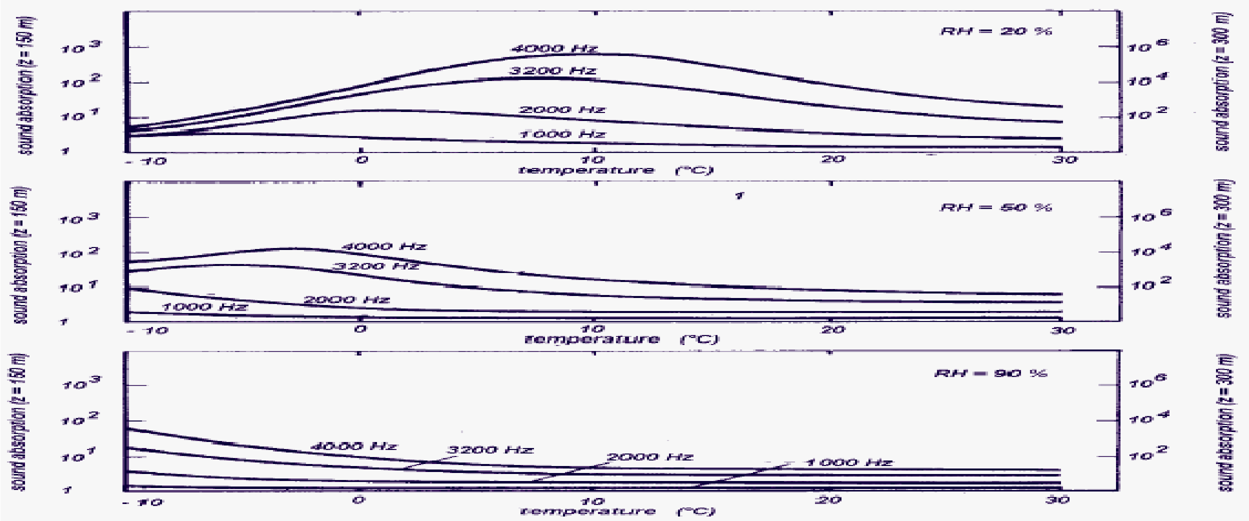

Figure.2: Dependence of sound absorption on temperature and humidity.

σ (π) is related to the turbulent state of air temperature represented by the structure constant for air temperature C_T^2 as follows:

$$\sigma(\pi) = 0.0039 K^{\frac{1}{3}} C_T^2 / T^2$$

Where: K The wave number (m-1).

T Air temperature of scattering volume (K).

Figure.2 shows the variation of the absorption with temperature and relative humidity [8] while Fig 1.2 shows how the coefficient of molecular attenuation αm varies as a function of humidity and frequency.

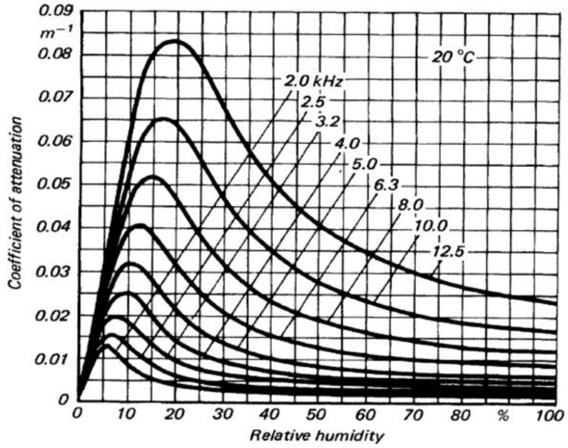

Figure.3: Attenuation of sound waves as a function of humidity at various frequencies.

III.EXPERIMENTAL EVALUATIONS

Here, we utilized all three configurations of the Doppler sodar systems, i.e., Mono-static, Bi-static and Tri-static to measure atmospheric parameters.

Mono-static configuration

Out of the three, the simplest system configuration is a mono static Sodar system

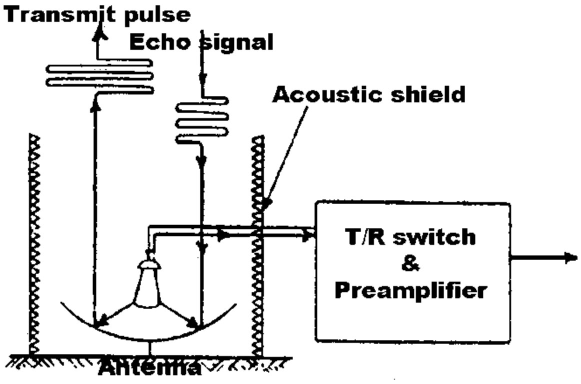

Figure.4: Mono-static single-axis Doppler sodar configuration.

In monostatic mode, the same reversible electro-acoustic transducer serves to radiate a sound pulse and to receive the echo signal scattered at (θ=180°) the scattering volume v, bounded by both. The beam width and the pulse duration move away from the source at sound speed. Time changes in the intensity of echo signal give information on the change in the intensity of temperature and humidity fluctuations as a function of distance [8,9,10 & 11].

The monostatic system can also be operated by tilting the parabolic dish at some prescribed angle, as shown in the Figure 2.2, for wind measurements.

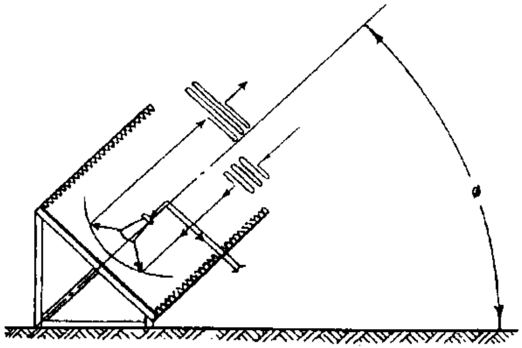

Figure.5: Mono-static configuration with titled.

For a vertical pointing monostatic sodar, the power PR scattered back from the atmosphere is given by the sodar equation:

$$P_{\mathbf{R}} = \left[P_{\mathbf{T}}\eta_{\mathbf{T}}\eta_{\mathbf{R}}\right]\left[e^{-4\alpha\mathbf{R}}\right]\left[\sigma_0(R,f).\left(\frac{c\tau}{2}\right).\left(\frac{A}{R^2}.G\right)\right]$$

Where:

PR= Received power or measured electrical power.

η_R = Efficiency of conversion from acoustic to electrical power.

PTη_T = Radiated power.

PT= Electrical power applied to the transducer.

η_T = Efficiency of conversion to radiated acoustic power.

$e^{-4\alpha R}$ = Round trip loss of power resulting from attenuation by air.

α = Average attenuation to the scattering volume at range R.

$\sigma_0(R,f)$ = Scattering cross section per unit volume (i.e., fraction of incident power backscattered per unit distance unit solid angle at frequency f).

$\frac{c\tau}{2}$ = Maximum effective scattering volume thickness.

C = Local speed of sound.

τ = Pulse length.

$\frac{A}{R^2}.G$ = Solid angle subtended by the antenna aperture A (m) at range R (m) from the scattering volume, modified by an effective aperture factor G, arising from antenna's directivity.

$G = \frac{G(0)\lambda^4 L^2(\theta_0)}{4\pi^2\theta_0^2 A^2} =$ Beam shape compensation factor.

Since for a mono static Sodar, only backscatter is involved, the scattering equation is written as:

$$\sigma(\pi) = (0.03k^{1/3})\left(0.13\frac{c_{\mathbf{T}}^2}{T^2}\right) = 0.0039k^{1/3}\,\frac{c_{\mathbf{T}}^2}{T^2}$$

Through this equation we obtain a volume-averaged measure of C_T^2 from each Sodar range gate. The equations yield a discrete time series of volume averaged C_T^2 values for any selected sodar range gate.

Bi-static configuration

Bistatic Sodars are systems in which the transmitting and receiving antennas are separated in space but are aimed at a common volume. This configuration will yield a higher signal to noise ratio, since returns from both temperature and wind fluctuations contribute to the scattering. Wind profiles can be obtained by moving the common volume up and down or by steering one of beams mechanically or electrically.

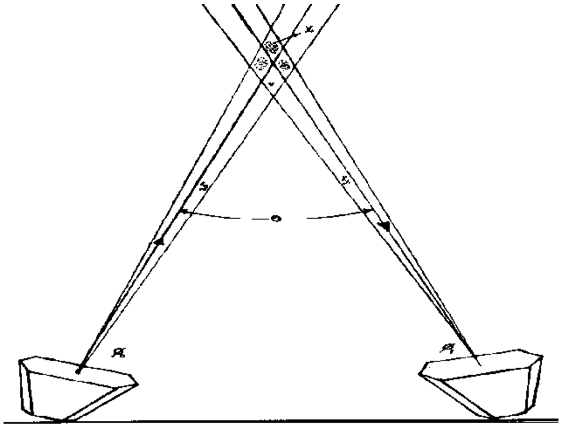

Figure.6: .Bi-static sodar configuration.

Tri-static configuration

A simplified Doppler sodar can be built around an existing vertically pointed receiver system. This instrument consists of two-fan beam transmitters and a pencil beam receiver in an orthogonal configuration.

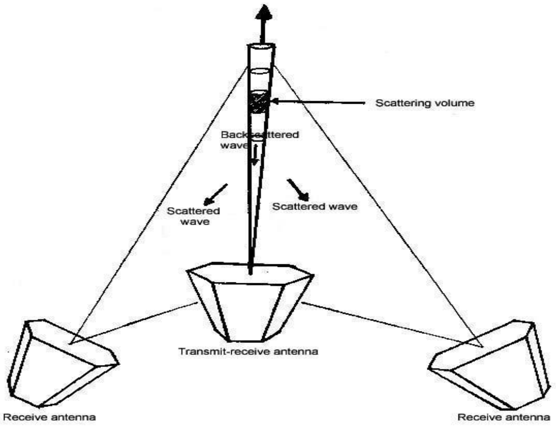

Figure.7: Three-axis bi-static Doppler Sodar configuration for total wind profile.

The system consists of a vertical transmit-receive antenna in the monostatic configuration, and two orthogonal bistatic receive antennas. The vertical monostatic antenna is used to obtain vertical components of the wind (w), and the two bistatic receivers, each consisting of a fan beam horn of sufficient width to illuminate the scattering volume over the desired altitude range, are used to obtain the two horizontal components of the wind (u and v). The total wind vector can be determined using these values for different range gates, and, thus, a wind profile is obtained. The relevant formulae are given below:

$$w = \frac{c\Delta f}{2f}$$ (Vertical component = Vz)

$$u = \left[\frac{c}{f\cos\theta}\right]\Delta f_{\mathbf{xz}} + V_{\mathbf{z}}\left[\frac{1+\sin\theta}{\cos\theta}\right]$$

(X component)

$$v = \left[\frac{c}{f\cos\theta}\right]\Delta f_{\mathbf{yz}} + V_{\mathbf{z}}\left[\frac{1+\sin\theta}{\cos\theta}\right]$$

(Y component)

Where;

f = Transmitted frequency.

c = Speed of sound.

fxz = Doppler frequency shift in XZ plane.

fyz = Doppler frequency shift in YZ plane.

The wind velocity, U, and the wind direction, D, are calculated using the following two formulae:

$$U = \sqrt{u^2 + v^2}$$

$$D = \tan^{-1} \frac{u}{v}$$

IV.EXPERIMENTAL RESULT:

DOPPLER SODAR SYSTEM

A Doppler sodar system is designed, fabricated and installed in the Department of Systems Design of Andhra University. The system operates in the tri-axial monostatic mode. The block diagram of the system is shown in Figure.8. The system is designed to simultaneously radiate tone bursts at 1750, 2000 and 2250 Hz [10]. The pulse repetition frequency is set at 0.25 Hz.

The crystal oscillator generates 1 MHz stable TTL output. The timing circuit is a cascaded section of TTL dividers, which converts the 1 MHz signal down to 2 KHz [10] TTL signal. The 2 KHz TTL square waves should be filtered to produce pure sinusoidal signal, which is required for transmission. Active filter is used to filter the 2 KHz TTL signal with notch filter in the feedback network. The output of the filter bank is a pure sinusoidal wave of 2 KHz.

The transmit pulse is of 100 ms duration [10]. The duration controlled by an analog gate of type CD4016 .Each analog gate has two inputs and one output.

The transmit signal is fed to one input and a pulse of 100 ms duration with a pulse repetition frequency of 0.25 Hz is applied to sync input of the gate. Under these conditions, output of the gate produces a short burst at the required frequency at the required pulse repetition frequency.

The output of the analog switch is fed to high power audio power amplifier of about 120 W. The power amplifier output is fed to a preamplifier cum T/R switch placed close to the antennae assembly.

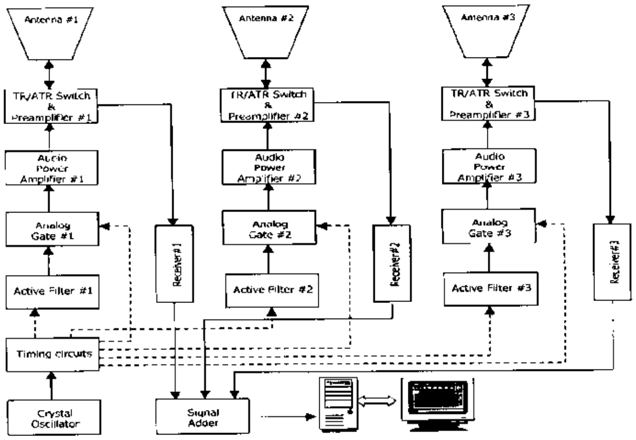

Figure.8: Block diagram of the tri-axial Doppler sodar at Andhra University.

OBSERVATIONS OF SEA BREEZE

Sea breeze is a dynamical response to the differential heating of land and sea by the Sun. It illustrates the principles, which are involved in the change of the radiant energy received from the sun into the kinetic energy of atmospheric motion [8 & 12]. Naturally, the sea breeze is strongest on clear and hot summer days.

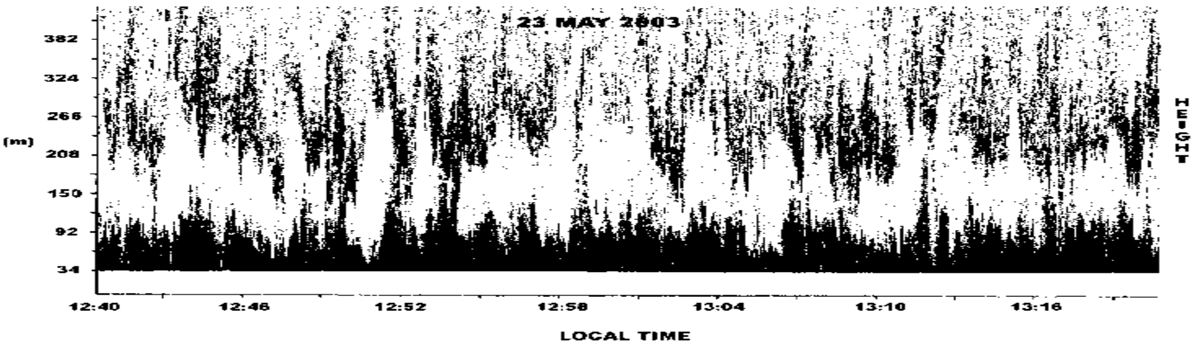

Figure.9: Sodar facsimile record showing sea breeze structure.

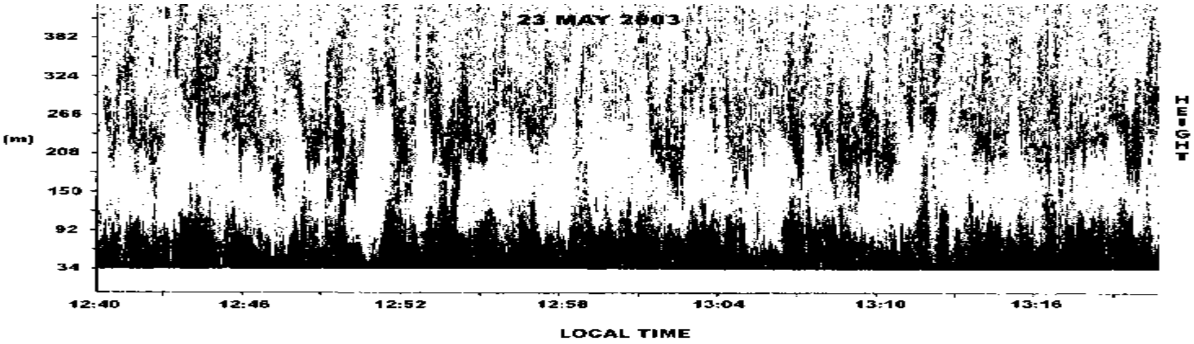

Figure.10: Sodar facsimile record showing sea breeze structure at different system.

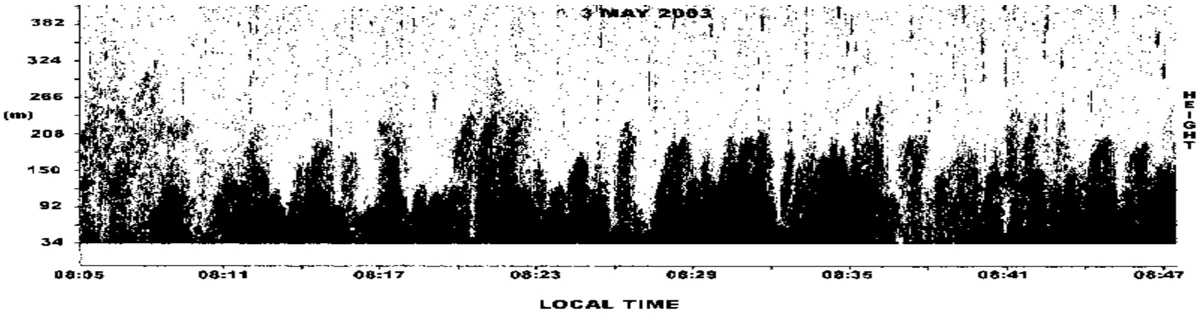

Figure.11: Sodar facsimile record showing the structure of thermal plumes.

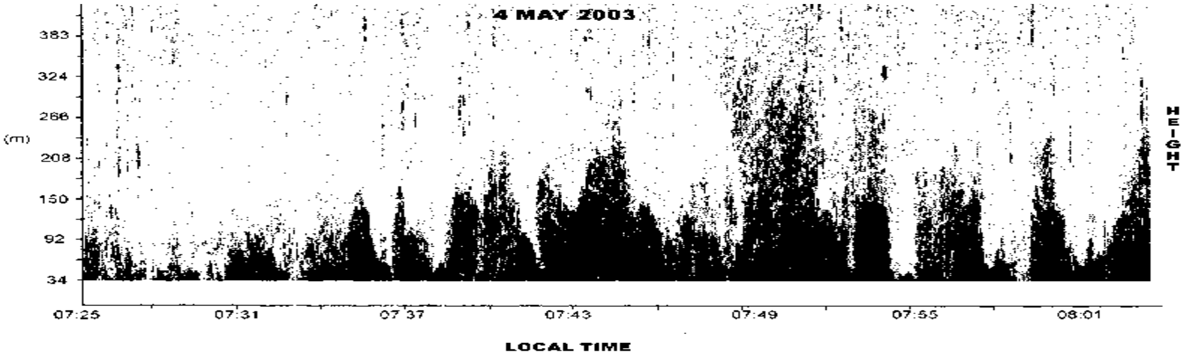

Figure.12: Another example of thermal plume structures before sea breeze.

V. CONCLUSIONS.

A Doppler Sodar system is established in Department of Systems Design of Andhra University, Visakhapatnam, which operates in the tri-axial mono-static mode. This system is operated with the pulse repetition frequency at 0.25 Hz. to radiate tone bursts at 1750, 2000 and 2250 Hz frequency. The output ofthe analog switch is fed to high power audio power amplifier of about 120 W. Later the power amplifier output is fed to a preamplifier cum T/R switch placed close to the antennae assembly and finally reached to PC to store the data as facsimile, which is a combination of original backscattered signal and unwanted signal. Through this setup the experiment is done at Visakhapatnam beach and recorded the back scattered sound signal in the form of facsimile. Analysis of the facsimile will be discussed in further.

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Research Work: Has a 6 years of experience in the field of SODAR and its applications and MATLAB scientific software and published 15 international journals.

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