Wind measurements with one switched-beam digital acoustic radar using independent control on the array antennae's transducers.

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Abstract: - A modular switched beam digital acoustic radar system (titled SBEDAR), developed from our research group in the Department of Informatics, is being used for sounding experiments in the Atmospheric Boundary Layer. The system is operating using independent control on every transducer of the antenna. Single-pulse raw data have been recorded, while the radar was operating in monostatic mode. Profiles of vertical wind velocity have been calculated from these raw data. These first sets of measurements and the resulting wind velocity profiles are presented here. IMACS/IEEE CSCC'99 Proceedings, Pages:4741-4745

Key-Words: acoustic radar, digital, switched beam, independent control, vertical wind velocity, measurements.

1 Introduction

Systems based on acoustic remote sensing have been used for measuring parameters of the Atmospheric Boundary Layer (ABL). The first device of this kind was presented by McAllister on 1969 ([12]) and was used to get clear images due to inversions and presence of internal waves. The scientists' interest for devices of such type and the technological progress effected the development of a variety of devices better known as acoustic radars or sodars ([12], [13] and [14]).

A comprehensive historical evolution of the acoustic radars from a designer's point of view, ranging from early pioneer efforts to latest works, in conjunction with the technological progress, is presented in [9]. The technological progress mainly concerns improvement of features like maximum sounding height, range resolution, reliability, expansion of the set of measured parameters etc. A current trend in sodar development is towards high frequency compact systems ([1], [2], [4], [5]) and usage of phased-array technologies ([3], [6], [11]). Inspite of the technological improvements, devices resulted were "dedicated", in the sense that they cannot be reused in different system or experiment configurations. Generally, considerable effort is required in redesign and reconstruction processes of an existing system (in both the software and mainly the hardware level) in occasions like using a monostatic system as a tristatic one or operating a switched-beam system in a different set of beam directions than the ones it was made for.

To solve the problem, a modular, switched-beam digital acoustic radar system (titled SBEDAR) has been developed. This system ([8], [9], [11]) offers the following advantages:

- Menu driven system set-up and configuration of the required parameters
- Flexibility on: the number (up to 961) of elements constructing the array antenna
- Integration of data acquisition, storage, on-line processing and results presentation processes
- Independent control on every transducer of the antenna, offering 1000's of directions to switch the beam

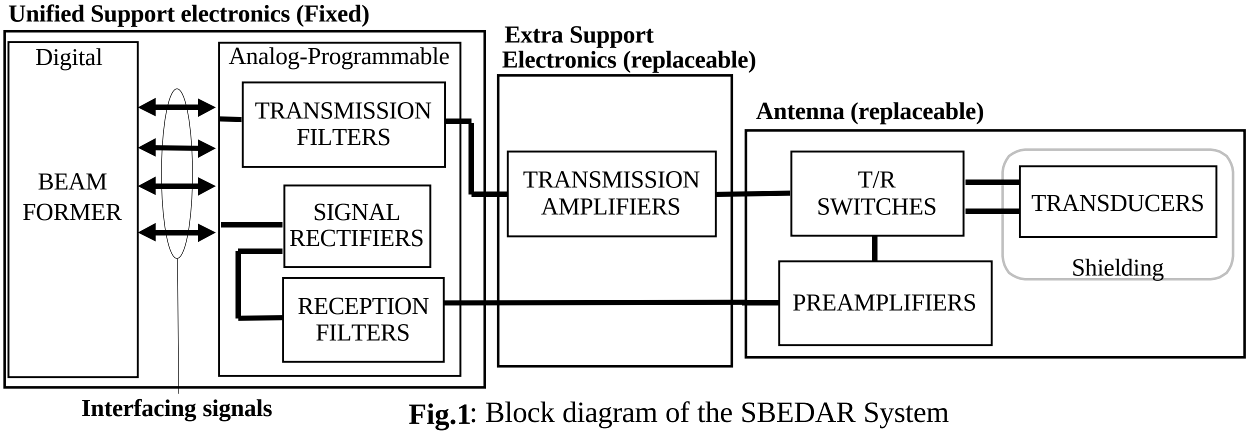

Fig.1: Block diagram of the SBEDAR System

TABLE 1: General and implemented features of the SBEDAR System

SYSTEM	GENERAL ARCHITECTURE FEATURES	IMPLEMENTED FEATURES
Antenna	Independent control on up to 31 individual elements or up to 31 groups of elements (maximum 31x31=961 elements in a row-column mode)	25 Motorola KSN1078 tweeters, placed as a planar 5x5 array Individual element control
	Amplitude tapering on elements	Natural tapering
	Element's phase error corrections	Cancellation of measured differences
	Acoustical Screening	Screened with sound absorbing material
	1000s of beam switching directions to select from ([7])	Beams tilted up to 30º from vertical, for the selected screening.
	Beamwidth depending on beam direction and configuration	Vertical Beam: 18º Beam tilted at 23º from vertical: 20º
	Maximum Power transmitted (electric)	25W
Support Electronics	Programmable Transmit Duration	t_t= from 9.6ms to 154ms in steps of 9.6ms
	Programmable Receive Duration	t_r=from 0.3s to 4.5s in steps of 0.3s
	Programmable recovery time after transmission	t_d=30ms
	Programmable frequency of operation f_{op}	f_{op}=3.4KHz
	Programmable Receiver's Bandwidth	BW=200 Hz
Data Processing	Selectable type of timing window	5 types of time windows (Rectangular, Triangular, Han, Tuckey, Cooley)
	Selectable Doppler shift extraction Method	2 Methods: FFT and SHCC ([6])
	Mean values calculated for time or height integration	User Selected, experiment depended
Results Presentation	On line presentation on Screen or Printer	Colour Screen Graphs or Simulation of usual Facsimile records on printer's paper

A block diagram of the device is presented in Fig.1. The computer (not shown in Fig.1), a crucial part of the system needed for programming it, is connected to the beamformer through a standard parallel port. The whole sodar system, which is in the experimental prototype stage, was successfully tested in the laboratory. It has performed the first measurements in the University campus, urban Athens area. The data collected during the sounding experiments were processed for extracting wind velocity estimates. Both data and estimated wind velocity profiles are presented in this paper.

2 System Description

The SBEDAR system is able to operate in one of the following modes: monostatic, switched beam

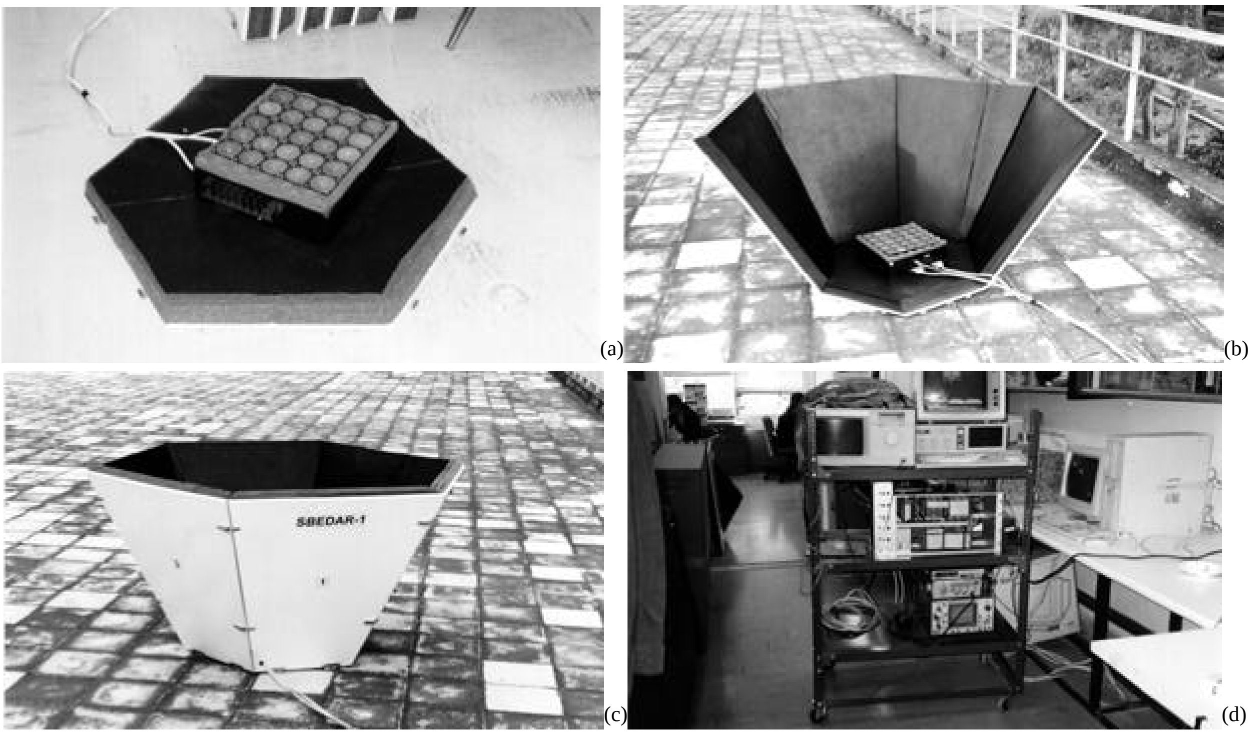

Fig. 2: System photos: (a)Array antenna, (b) antennae's shielding partially & (c)fully assembled, (d)Support electronics

tristatic, and switched beam multistatic. The user may select the set of switching directions and the system will sequentially switch the beam to each of them. The features of the system, grouped in two main sets, the general ones (allowed by the architecture) and the currently selected and implemented, are presented in Table 1. A very important feature of SBEDAR is the independent control on every transducer in the antenna. This feature permits the system to scan in a very different set of directions than these allowed from the usual row-column mode operation ([7]). Few photographs of the SBEDAR system are presented in Fig. 2.

The system in the present stage is an experimental prototype for laboratory uses. It is rack mounted, along with useful electronic instruments. These instruments are not part of the system, they were used for validating its' operation during the testing phase, while these photos were taken. The shielding of the antenna is a hexagonal assemblage, internally covered by 6cm thick sound absorbing material (see Fig.2). This shielding suppresses the side lobes and prevents the environmental noise to enter the system.

3 Experiments and discussion

The first set of measurements was taken with the system operating in a simulated monostatic mode (multistatic mode where all the directions were the same). The raw data collected were stored in sequentially organised files in the hard disc of the system, for off line processing. For every cycle of operation (i.e. transmit/receive/store), a number of integer (16 bit each) values are collected and stored as a block in the received raw DATA file. The length of this block (NOS) depends on the duration of the reception (t_r from Table 1) and the sampling frequency (4 times the operating frequency f_0). A set of values describing the conditions under which each data block was collected, are stored as a record in an accompanying LOG file. The fields of the LOG file record are:

- INDX: Index of record
- φ,θ: beam position (0°,0°:vertical beam)
- Start_time: Start of transmission (real time)
- End_time: End of reception (real time)
- T_{tran}: Duration of transmission
- NOS: Number of samples

The intensity of the collected atmospheric returns is used to construct the echo fax graphs presented in fig. 4 (parts a(I) and b(I)). Because no absolute calibration is done on the sodar, the intensities were normalised to a fixed maximum value. These data are subjected to off line FFT processing for extracting the mean (vertical) wind velocity. Every block of data has been subjected to the processing described in Fig.3. Each block is divided in L packets (sub-blocks) each having a length of R (NOS=L*R). L or R may be selected according to the desired range bean or gating. A real FFT processing is performed for every data sub-block. The FFT results (frequency spectrum) for each sub-block are stored, the one after the other, as chunks of a new block of results. This block (having a size of NOS/2 real numbers) is the record of the RESULTS file. This file is sequentially organised too. All processes regarding data storage, extraction of results and their storage are presented in Fig.3.

The mean vertical wind's velocity is extracted using the mean Doppler frequency shift (taking into account the bandwidth) of the received signal ([10]). The component V (measured in the beam direction, towards the receiver) of the wind velocity is:

$$V = \frac{c}{2}\frac{\Delta f}{f_0}, \qquad [1]$$

where *Äf* is the mean Doppler frequency shift of the return signal, *c* is the sound velocity and f_0 is the frequency of the original signal. From every packet (of size R) of data, one value of the mean wind velocity is extracted. L consecutive values for wind velocity are extracted from the block of data collected during each cycle of operation. These values are used to form the wind profiles.

Two sets of measurements are presented in figures 4a and 4b, corresponding to different atmospheric conditions. For each set, two graphs are

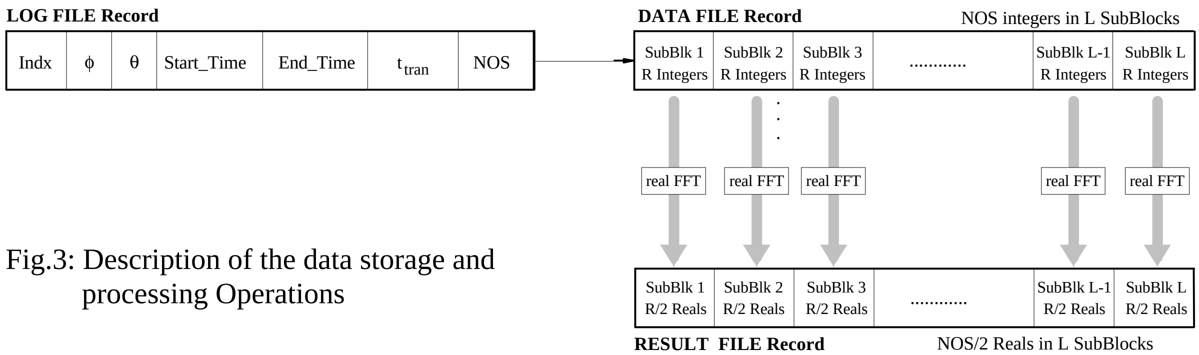

Fig.3: Description of the data storage and processing Operations

included: (I) back scattered signal intensity and (II) corresponding profiles of the extracted vertical wind velocity, represented by vertical bars. The arrowed lines at the right top corner of velocity graphs serve as magnitude units and direction indicators. Velocity values are rejected, whenever the computed signal-to-noise ratio is below the value selected as the threshold. This case is responsible for missing bars (as for the time slice 21:09 to 21:17 in fig. 4a(II)).

These measurements show that the system is capable to grab atmospheric disturbances, in a range of up to 100m, above ground level. This relatively small range is due to the low acoustic power transmitted and the individual element control at reception. The extracted values of vertical wind velocity show consistency with time.

4 Conclusions

The experimental prototype of a modular, switched-beam, digital acoustic radar, developed from our research group, is being used for experiments in Athens area. The system is operating with independent control on every transducer of the antenna and not in a row-column mode as most of the phased array sodars.

These first experiments were done while the system was operating in monostatic mode. The measurements taken and corresponding results for the vertical wind velocity, show that the system is capable to grab atmospheric disturbances, in a range of up to 100m, above ground level. This relatively small range is due to the low acoustic power transmitted and the individual control of the transducers (during the reception). The extracted values of vertical wind velocity show consistency with time. Mean values with time will be extracted and compared with in situ measurements

Measurements while the system is operating in the tristatic and multistatic mode are currently taken and will be presented along with the resulting total wind vector estimates, in a future work.

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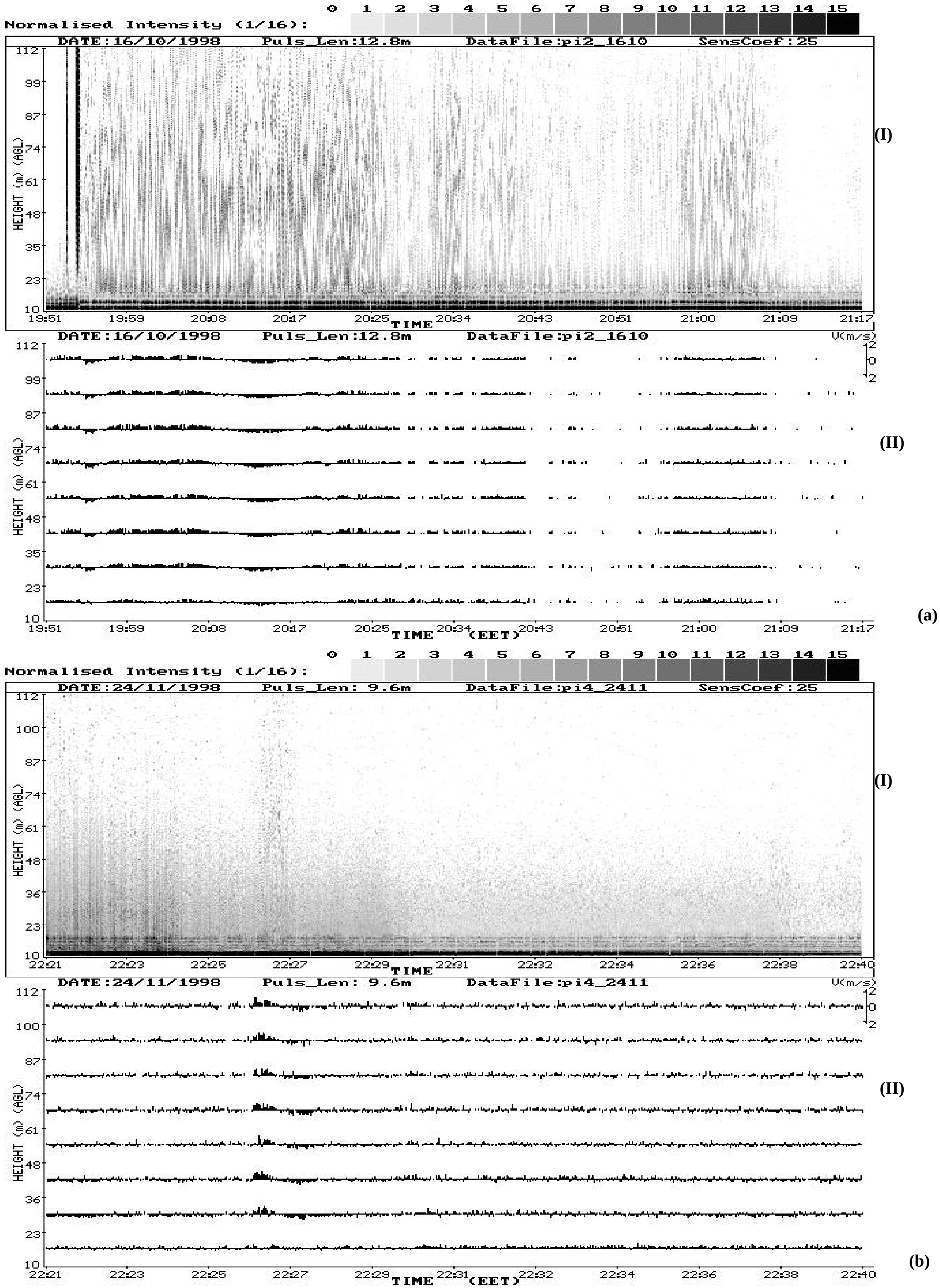

Fig.4: Time-height series of (I)normalized sodar backscattered signal and (II)extracted vertical wind velocity for two experiments (a) and (b), in Athens-University campus area.