

## Methods of temperature measurement in a radio-acoustic tropospheric sounder

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**SUMMARY.** — The temperature of the lower troposphere is inferred by measuring with a doppler radar the speed of a powerful acoustic wave, capable of periodically perturbing the index of refraction of air. Three methods for performing these measurements are described.

**RIASSUNTO.** — La temperatura della bassa troposfera viene dedotta da misure della velocità del suono ottenute a mezzo di un radar doppler, utilizzando la perturbazione periodica dell'indice di rifrazione dell'aria, provocata da una potente onda acustica. Vengono descritti tre metodi per ottenere tali misure.

### INTRODUCTION

A radio-acoustic sounder of the vertical temperature distribution in the lower troposphere, inspired by the Stanford RASS<sup>(2,5)</sup>, is in a stage of construction in the premises of the Laboratorio di Ricerche Ambientali dell'Ente Nazionale per l'Energia Elettrica (ENEL) at Trino Vercellese<sup>(3)</sup>.

As it is well known, the system consists, in its essence, of a powerful acoustic generator beaming toward the zenith a short train of

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sinusoidal waves. The local speed of this signal during its rise is controlled by the square root of the air temperature. This speed is continuously monitored from the ground by means of a doppler radar. The echo is due to the change in the refraction index of air caused by the intense pressure of the acoustic wave. The record of the measured sound speed as a function of delay allows the direct plotting of the temperature vertical profile.

In our knowledge, this is the first attempt to build a radio-acoustic sounder after the Stanford experiment. In our design we have made an effort to minimize dimensions and improve mobility of the RASS system. For this purpose, we have adopted a doppler radar having carrier frequency in the 159 MHz band, to which corresponds an acoustic Bragg resonance of circa 360 Hz. Consequently, the areas of both acoustic and radar antennas are reduced compared with the Stanford RASS. Obviously, since the acoustic atmospheric absorption is about tenfold higher at 360 Hz than at 85 Hz, which is the sound frequency used at Stanford, a reduction in thermal sounding range might be expected. However, it is easy to realize that atmospheric absorption brings a negligible contribution to the attenuation loss at heights below 2 km, with respect to the inverse of the squared distance term. Hence, we do not foresee any sizable sounder range reduction as an effect of the increased sound frequency. Besides, we hope to operate in a more favorable region of the atmospheric turbulence spectrum.

#### GENERAL SETTING

Fig. 1 shows a general view of the installation at Trino Vercellese. The photo was taken from the top of the meteorological tower, which is 120 mt. high.

On the roof of the central building one may spot the first installed acoustic cell, a  $\sim 2.2$  mt<sup>2</sup> brick square. The complete acoustic array will include 9 of these cells, with an expected yield of the order of 100 acoustic watts.

The transmitting and receiving antennas of the bistatic doppler radar will be located at the lower left and upper right corners, respectively, of the fenced ground shown in the picture. The shielding effect of the interposed building should hopefully reduce mutual interference between the two antennas. The antenna spacing has been set to leave

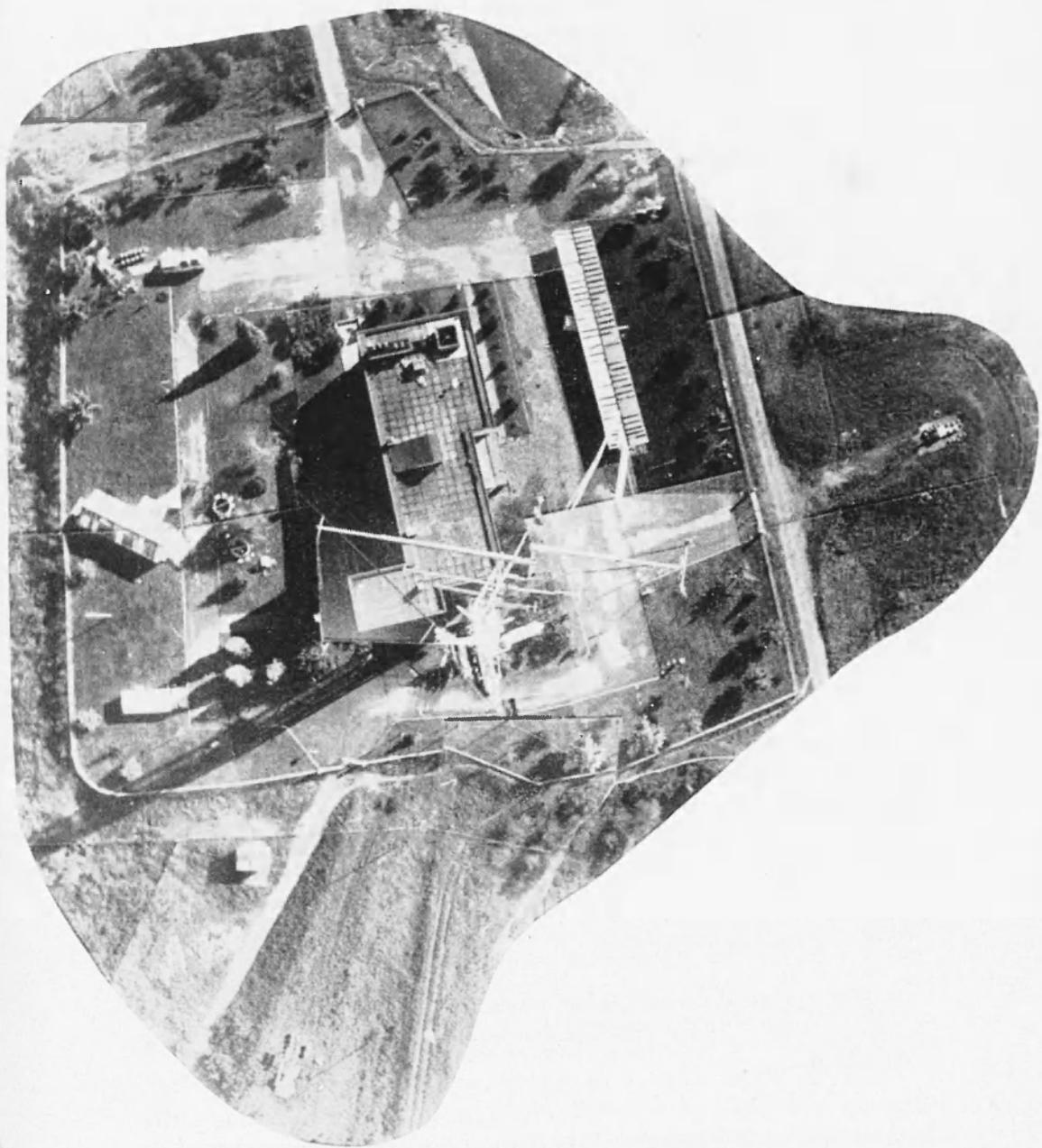


Fig. 1 - General view of the installation site, at Trino Verellese.

the top of the tower out of the main radiation lobes, although soundings above 150 mt are possible. Square arrays composed of 4 identical one-director Yagis will be installed.

#### RADAR EXPERIMENTS

The radar system utilizes a standard quartz-controlled communication transmitter which can yield a maximum of 10 watts C.W. The insidious 7th harmonic ripple of the 50 Hz power line was eliminated from the carrier by carefully stabilizing the transmitter power supply (1).

The autodyne receiver, which includes a RF amplifier, a double-balanced mixer, and a high-gain, LF amplifier with a 335-370 Hz pass-band filter, was assembled in the laboratory.

We have tested the radar system on the ground, using as scatterer a dipole interrupted 360 times per second by means of a reed switch. Clearly, such a dipole, by changing drastically its cross-section at the rate of the doppler frequency expected in the operating sounder, offers sidebands which perfectly fit the receiver. The scattered signal is maximized when the distance between dipole and antennas is an integer number of half-wavelengths.

In this way we were able to optimize the amount of injected LO signal, directionally derived from the transmitter. The interrupted dipole was received within a horizontal distance of about 1.5 Km. Taking into account the high level of man-made interference present, and the fact that the two-way raypath was tangent to wind-stirred vegetation, we estimate this result to be highly promising.

#### METHODS OF MEASUREMENT

The temperature-measuring procedure of our system is still in a design stage. Three different methods of measurement have been considered:

- 1) - In method 1, sketched in Fig. 2, a delayed gate chooses the sounding height, where the counting of the doppler frequency of the received echo is performed. Such a counting requires a signal-to-noise ratio of 27 db (2) or better. The actual counting

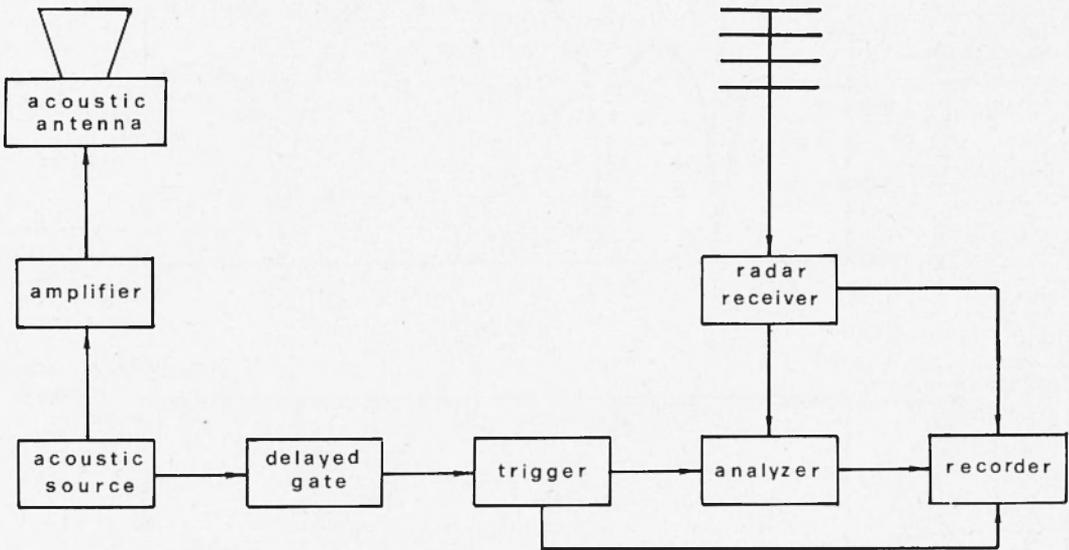


Fig. 2 - Block diagram of Method 1 for the spot measurement of the temperature.

is processed in the Analyzer of Fig. 2, and converted in analogic form. This output, together with the doppler signal, are displayed in a Bryant-Southern's quick-response recorder.

- 2) - Method 2 is based on the Bragg resonance property, for which the RASS echo reaches a maximum when the frequency of the acoustic radiation equates the doppler frequency. The behavior of the echo intensity as a function of the acoustic frequency was studied by Marshall<sup>(4)</sup>, and is plotted in Fig. 3. In the figure, the abscissae are acoustic/doppler frequency ratios, the ordinates are ratios of the echo intensities, in db. Moving from the top to the bottom of the figure the 3 plots indicate a number of periodicities of the acoustic train of 10, 20 and 100, respectively.

With this method, sketched in Fig. 4, the height of operation is selected by a delayed gate, as in Method 1. A succession of soundings is then performed using an acoustic radiation of continuously increasing, or decreasing, frequency. The acoustic frequency and the corresponding echo intensity are both recorded at each sounding. The acoustic frequency at which a maximum of echo intensity occurs is the doppler frequency sought for.

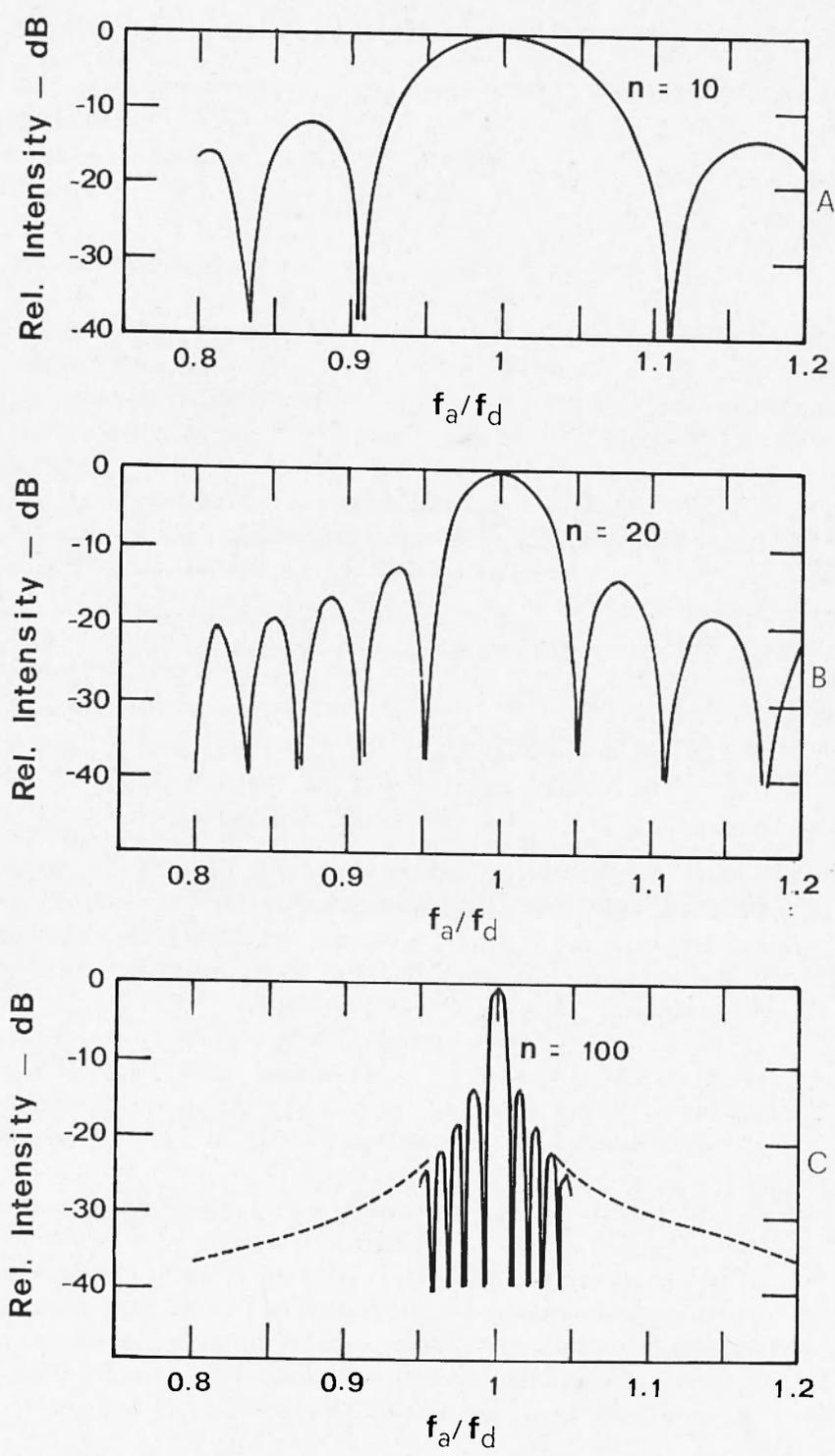


Fig. 3 - The relative echo intensity as a function of the acoustic doppler frequency ratio;  $n$ , number of periodicities in an acoustic train.

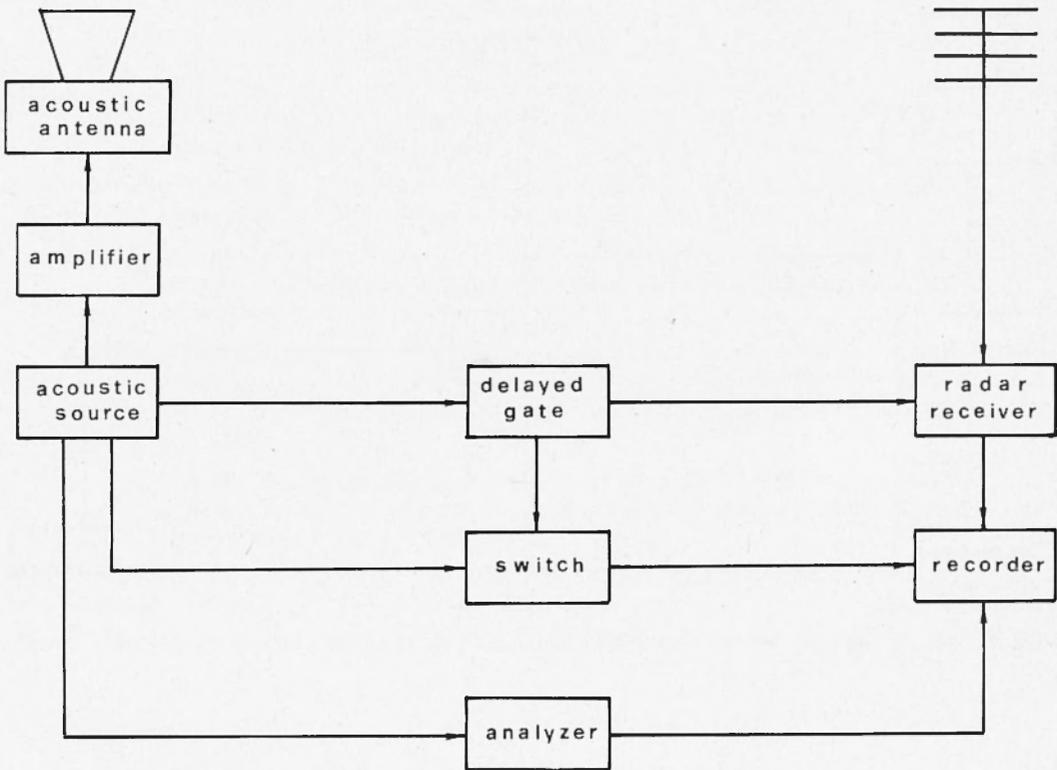


Fig. 4 - Block diagram of Method 2 for the spot measurement of the temperature.

Examining the plots of Fig. 3 it may be observed that this method can probably work even when the signal-to-noise ratio is well below 10 db.

- 3) - Method 3 (see Fig. 5) is a rather faithful reproduction of the scheme devised by Stanford for the systematic sounding of the vertical temperature profile. Here the delay of the gate increases automatically by preassigned steps of about 10 mt until a height span of circa 1500 mt is uniformly covered. This operation is performed in the Analyzer, which basically consists of a quartzed clock, a counter, and a set of memories. The frequency is measured by counting the number of clock oscillations contained in a given number of periodicities of the sampled signal. This measurement can be repeated after a pause of 2 clock cycles,

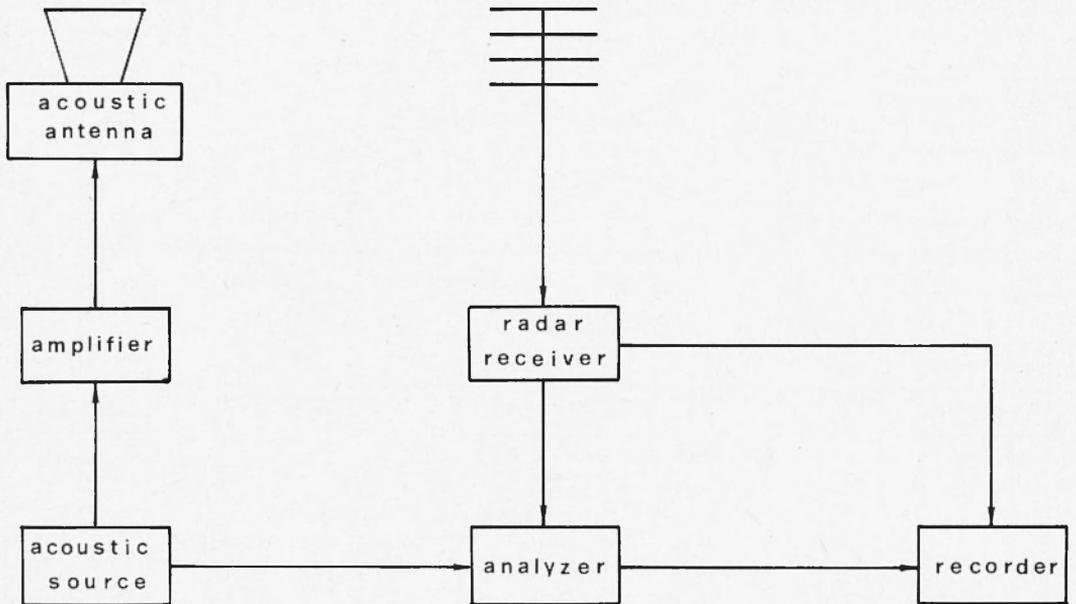


Fig. 5 - Block diagram of Method 3 for the measurement of the vertical temperature profile.

and the number of repetitions may be chosen in binary succession up to 128 times, to which corresponds a height of about 1500 mt. Since the doppler frequency is expected to vary by only few Hz in the height span considered, the digital-to-analog conversion is limited to the last 8 bits of the counter output. This allows a better reading resolution of the vertical thermal profile.

When the radio-acoustic sounder operates at a constant repetition rate, the analyzer memorizes the temperature readings taken at each height, and draws for the recorder the profile of the averages at every 16 soundings. We are planning to make use of all the 3 methods listed.

Method 1 seems ideal in the initial adjustment stage. Method 3 was conceived for the systematic acquisition of meteorological data. Finally, method 2 represents a new approach which offers interesting possibilities, especially in view of increasing the limit height of thermal sounding.

## REFERENCES

- (<sup>1</sup>) ACKER A. E., 1975. - *Eliminating transmitter clutter in doppler radar systems*. "Microwave Journal", **18**, November, pp. 47-50.
  - (<sup>2</sup>) FRANKEL M. S., PETERSON A. M., 1976. - *Remote temperature in the lower troposphere*. "Radio Science", **11**, pp. 157-166.
  - (<sup>3</sup>) LOMBARDINI P. P., BONINO G., 1975. - *Metodo radioacustico per la misura del profilo termico verticale della bassa troposfera*. "Rivista Italiana di Geofisica", **2**, pp. 23-26.
  - (<sup>4</sup>) MARSHALL J. M., 1972. - *A radio acoustic sounding system for the remote measurement of atmospheric parameters*. "Sci. Rep. No. 39, SU-SEL-72-003 Stanford Electronics Laboratories", Stanford, California, pp. 152.
  - (<sup>5</sup>) NORTH E. M., PETERSON A. M., PARRY H. D., 1973. - *RASS, a remote sensing system for measuring low-level temperature profiles*. "Bull. Amer. Meteor. Soc.", **54**, pp. 821-825.
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