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Scintillations of Acoustic Signals Backscattered by Atmospheric Layers

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1. Introduction.

Many works did appear in the literature concerning the use of monostatic acoustic radars (SODAR) in different meteorological situations; more elaborate systems using Doppler wind effects have been realized and put in operations in the last few years. Such systems permit the measurements of the wind in the atmosphere (e.g. CHONG, 1976; THOMSON, 1975) and many of them are based on the detection of the scattered field in a direction quite different from 180° . A few measurements have also been made using more than one receiver placed nearby or not too distant from the transmitter (MAHONEY *et al.*, 1973). The purpose of the present work is to systematically analyze the field in the vicinity of the transmitter. Indeed, various physically different situations may give rise to different patterns in the acoustic field on the ground. Fig. 1 shows some of these possibilities; in *a*) the scattering layer is homogeneous in space and the received eco in the two antennas on the ground will present the same level; in *b*) the presence of a non uniform scattering layer may cause different signal levels in the two receivers; the situation may be

further complicated by the presence of lens-like structures in the space between ground and reflection level [case *c*) and *d*)]. The situations described in Fig. 1 are static; however, quite often the presence of the wind or of other dynamic processes will modify the time and space behaviour of the acoustic level on the ground.

The field in the vicinity of the transmitting antenna may be analyzed from the point of view of amplitude or of phase coherence; in the present paper only the amplitude coherence will be examined.

2. The measuring system.

The system in use in Torino (G. E. PERONA *et al.*, 1975) is schematically described in Fig. 2; it consists of a 3 m diameter parabolic reflector (*A*) used for transmitting and receiving, and a smaller (1.2 m diameter) parabolic reflector (*B*) used in reception: both antennas are placed inside a concrete shield with inside walls acoustically treated and their centers are 3 m apart. The shield assures an acoustic noise reduction of at least 18 dB at the adopted frequency of 1000 Hz. A third 1.2 m paraboloid (*C*) has been placed at a variable distance from paraboloid *A*: the

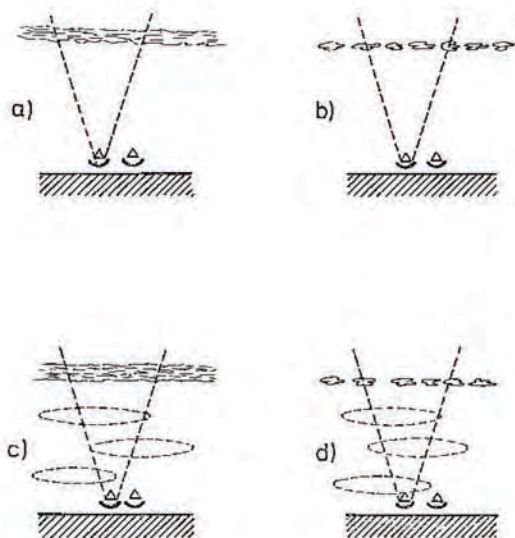


Fig. 1 - Schematic representation of different possible physical situations.

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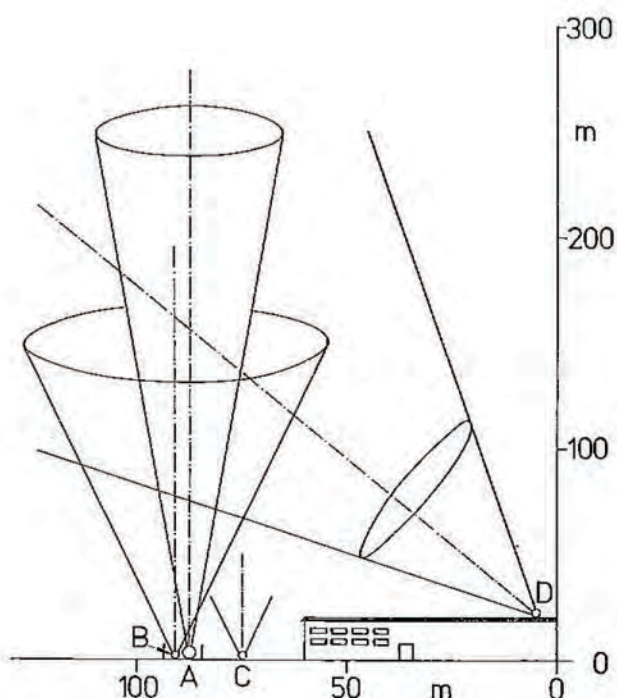


Fig. 2 - Scheme of the experimental set-up.

data presented refers to a fixed position of paraboloid C, that has been placed at 15 m from A. Furthermore, a fourth receiver (D) has been placed on the roof of a nearby building. The data collected from D are used for Doppler measurements, but will not be presented in this paper.

Fig. 3 shows an approximate view of the system and of the 3 dB antenna lobes. Antennas A, B and C have been placed near each other in order that all of them receive signals only reflected from thermally-driven turbulence (antenna D, instead, gets contributions from wind-driven turbulence).

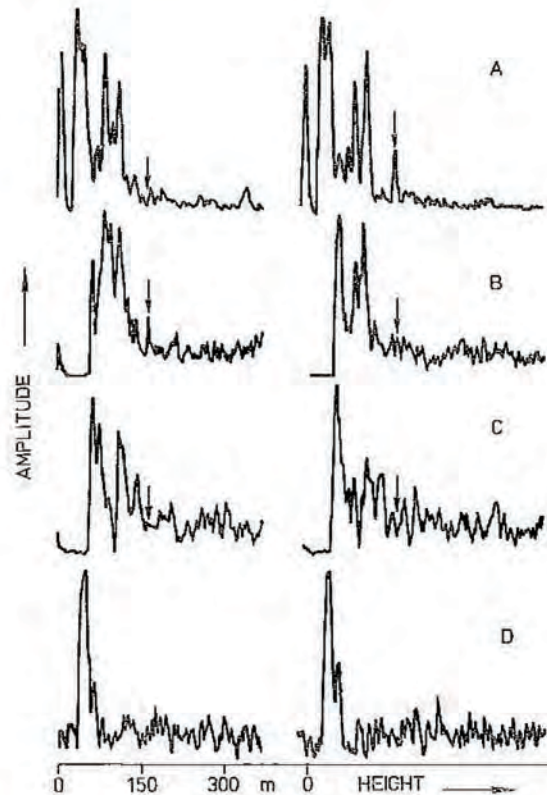


Fig. 3 - An example of signals received in the four channels A, B, C and D.

Fig. 3 shows an example of signals received in the four channels, corresponding to two consecutive transmitted pulses. The arrows in the figure indicate the position of an echo that appears and disappears from one channel to the other and from one pulse to the following: the aim of the present paper is to study the statistical properties of such amplitude scintillations both in time and space. In the experiment performed, 50 msec pulses at 1000 Hz were transmitted with a repetition rate of 5 sec.

3. Signal analysis.

The data considered have been collected in Torino, at 0700 a.m. of the 27th of August 1976, during a clear day without appreciable wind at ground level.

In order to put in evidence the presence of back-scattering layers, 32 consecutive echoes have been averaged in the three channels examined, A, B and C, corresponding to a total time length of 160 sec. The left hand side of Fig. 4 shows the averaged signals A_m , B_m and C_m , computed with the following formula:

$$A_m = \frac{\sum_{i=1}^{32} A_i}{32}, \quad B_m = \frac{\sum_{i=1}^{32} B_i}{32}, \quad C_m = \frac{\sum_{i=1}^{32} C_i}{32},$$

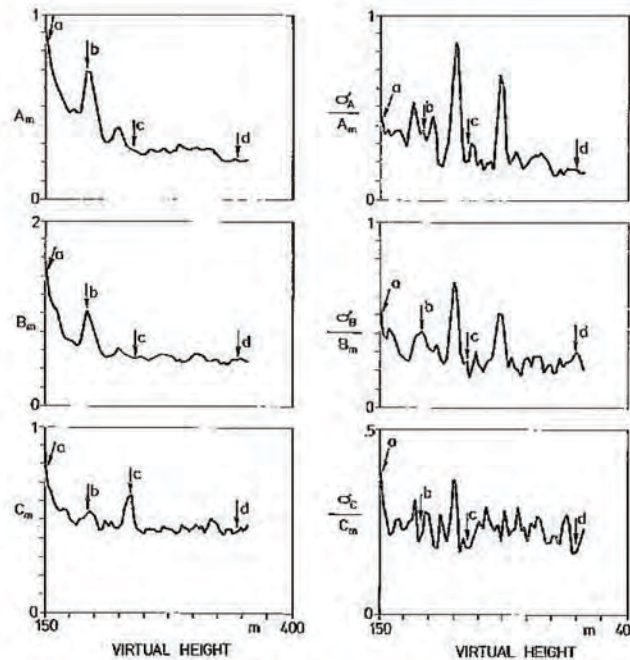


Fig. 4 - Average and normalized standard deviation for the three channels A, B and C.

where A_i , B_i and C_i represent sampled values of the received signals. Since the transmitting pulse length was 50 msec, the sampling frequency of the signal level was chosen equal to 51.2 Hz. Only the height levels between approximately 150 m and 400 m will be represented in the following (*). The right hand side of Fig. 4 shows the standard deviation normalized with respect to the average value as a function of altitude for the three channels; σ_A , σ_B and σ_C have been computed with the usual formula:

$$\sigma_A = \sqrt{\frac{\sum_{i=1}^{32} (A_i - A_m)^2}{32}}, \quad \sigma_B = \sqrt{\frac{\sum_{i=1}^{32} (B_i - B_m)^2}{32}},$$

$$\sigma_C = \sqrt{\frac{\sum_{i=1}^{32} (C_i - C_m)^2}{32}}.$$

(*) It is to be noted that the height of the reflecting layers is evaluated by multiplying half the time delay of the signals for the sound speed, assumed equal to 342 m/sec (changes of the sound speed with temperature may cause only minor errors, much smaller than the total length of the pulses used in the experiment).

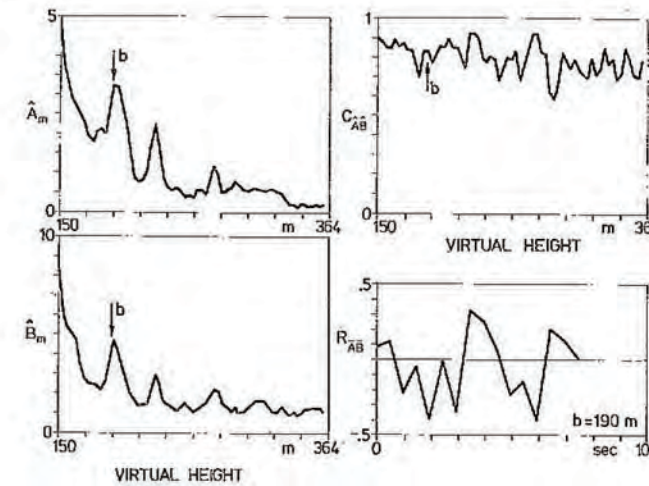


Fig. 5 - Average values and correlation factor for channel A and B as a function of height, and cross-correlation of the scintillation signals for the same channels as a function of time for a specified height.

As one can see from the figure, 3 levels seem particularly interesting in the height considered, namely, level a) at 150 m, level b) at 190 m, and level c) at 240 m; level d) has been examined for reference, since at such level no appreciable echo appears in the records. At these levels, the standard deviation is relatively smaller than the average value.

Note, though, that at the c) level, no echo appears in A and B; however, on this channels, a relatively strong echo appears at a slightly lower level: such echo is characterized by a larger standard deviation.

4. Signal fluctuations.

In order to decrease the effects of noise, the signal received from each pulse in the three channels has been decreased of the minimum value of the signal itself; the new values obtained in this way, have been denoted by a letter capped with half a diamond:

$$\hat{A}_i = A_i - A_{i,min}, \quad \hat{B}_i = B_i - B_{i,min},$$

$$\hat{C}_i = C_i - C_{i,min}.$$

With these new quantities, the average values $\hat{A}_m$, $\hat{B}_m$ and $\hat{C}_m$, and standard deviations, σ_A , σ_B and σ_C , may be re-evaluated using the equivalent of eq. (1) and eq. (2). The left hand side of Fig. 5 shows the new average values $\hat{A}_m$ and $\hat{B}_m$ as a function of height. In the same figure, in the upper part of the right hand side, the correlation factor C_{AB} between the two channels has been represented, according to the formula:

$$C_{AB} = \frac{\sum_{i=1}^{32} \hat{A}_i \hat{B}_i}{\sqrt{\sum_{i=1}^{32} \hat{A}_i^2} \cdot \sqrt{\sum_{i=1}^{32} \hat{B}_i^2}}.$$

As it appears from this figure, the levels where the echoes are present [e.g. level b)], do not show correlation factors significantly different from the levels where external noise is predominant. For this reason, it has been thought more significant to examine auto and cross-correlations of the signal scintillations only, that is the signals decreased of their average values and normalized with respect to the standard deviations, namely:

$$\bar{A}_i = \frac{\hat{A}_i}{\sigma_A}, \quad \bar{B}_i = \frac{\hat{B}_i}{\sigma_B}, \quad \bar{C}_i = \frac{\hat{C}_i}{\sigma_C}.$$

The auto and cross-correlations relative to a fixed height h have been computed according to the following formulae:

$$R_{AA}(h, r) = \frac{\sum_{i=1}^{32} \bar{A}_i(h) \bar{A}_{i+r}(h)}{32 - r}$$

$$R_{AB}(h, r) = \frac{\sum_{i=1}^{32} \bar{A}_i(h) \bar{B}_{i+r}(h)}{\sqrt{\sum_{i=1}^{32} \bar{A}_i(h) \bar{A}_{i+r}(h)} \sqrt{\sum_{i=1}^{32} \bar{B}_i(h) \bar{B}_{i+r}(h)}}.$$

As an example, the lower right hand side of Fig. 5 shows the cross-correlation between the channels A and B and relative to the level b).

In Fig. 6 the autocorrelation of the normalized fluctuations of channel A have been plotted for the 4 levels indicated before.

The «roughness» of the plots is mainly due to the limited number of points used (only 32 successive echoes have been considered). However, it is interesting to note the slow decrease in the correlation of the scintillations at level a).

This result is even more striking if it is compared with the result relative to the other levels where the correlation falls to low values just after 5 sec. This implies that different atmospheric processes are at work in the two levels a) and b) for example, notwithstanding their proximity.

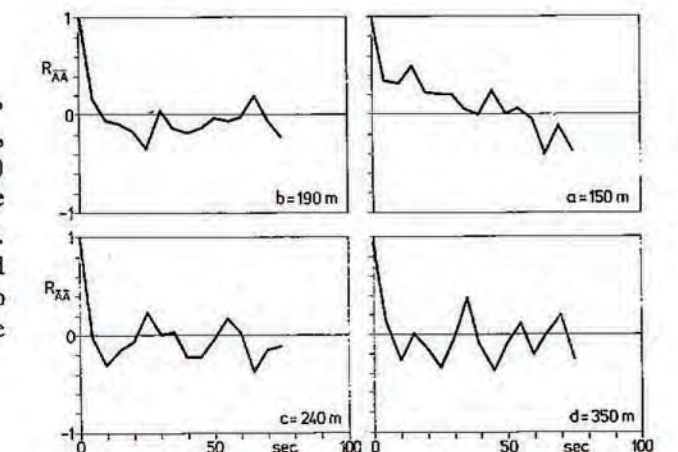


Fig. 6 - Auto-correlations of the scintillation signals for channel A as a function of time at the specified heights.

Fig. 7 shows the cross-correlation between the scintillation signals of the channels A and B : again, the correlation decreases slowly in time at level a) following the same time behaviour of the auto-correlation; viceversa, at level b) the cross-correlation oscillates between positive and negative values. This fact confirms the different nature of the two atmospheric levels considered.

Fig. 8 shows similar data for channels A and C with qualitative results similar to those described for the previous figure. It is to be noted that, at level b), the cross-correlation R_{AC} has opposite signature with respect to R_{AB} .

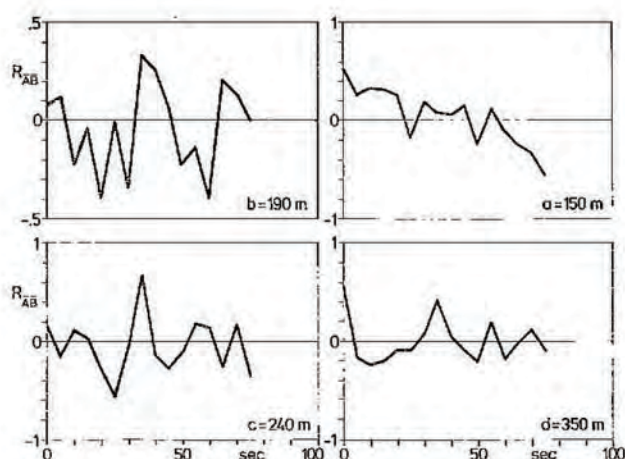


Fig. 7 - Cross-correlations of the scintillation signals for channels A and B as a function of time at the specified heights.

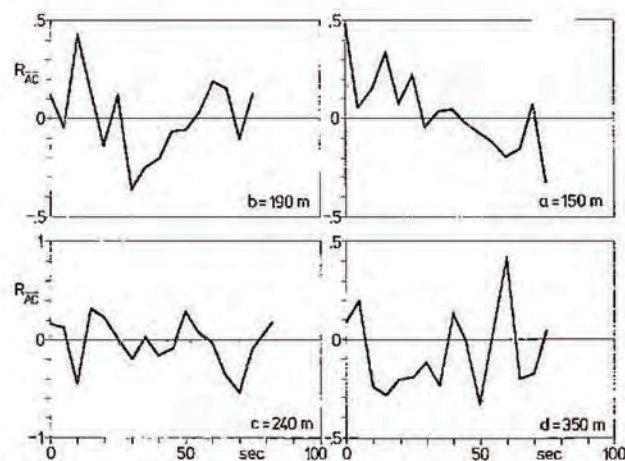


Fig. 8 - Cross-correlations of the scintillation signals for channels A and C as a function of time at the specified height.

5. Conclusions.

The «scintillations» in the signals reflected from different atmospheric layers have been analyzed numerically.

While the method seems able to give interesting results, the data presented here are just preliminary. However, even at this point, some useful conclusions may be drawn. First of all, let us point out that the two levels studied more thoroughly in the present paper, namely level a (150 m) and level b (190 m) do not give a different signature on the usual «facsimile» records, normally adopted with acoustic sounder. In this way, the striking different behaviour in the large scale «turbulence» responsible for the scintillations would be lost. From this point of view, only a numerical analysis of the records as performed here, seem able to characterize the two different layers in a straight-forward way. However, for the moment even with this method, it is not possible to decide the nature of the large scale «turbulence» by examining the data presented. A much more complete analysis of the experimental data, that have been recorded on magnetic tapes, may give in the near future a better understanding of the physical phenomena. It is tempting, even though premature at this point, to suggest that differences in the scintillations behaviour may characterize reflecting strata in the neighbourhood of the top of the inversion layer: if this were the case, an immediate way to characterize the height of the inversion layer would be available.

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Summary — The amplitude scintillations of acoustic signals, backscattered by atmospheric layers and received by four acoustic antennas, have been numerically examined. It is shown that two neighbouring reflecting layers may present strong differences in the characteristic of the scintillations, suggesting an intrinsic different nature of the layers themselves notwithstanding their apparently similar behaviour for what concern the average acoustic reflectivity.