

## STANDING WAVE TUBE TECHNIQUES FOR MEASURING THE NORMAL INCIDENCE ABSORPTION COEFFICIENT: COMPARISON OF DIFFERENT EXPERIMENTAL SETUPS.

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### INTRODUCTION

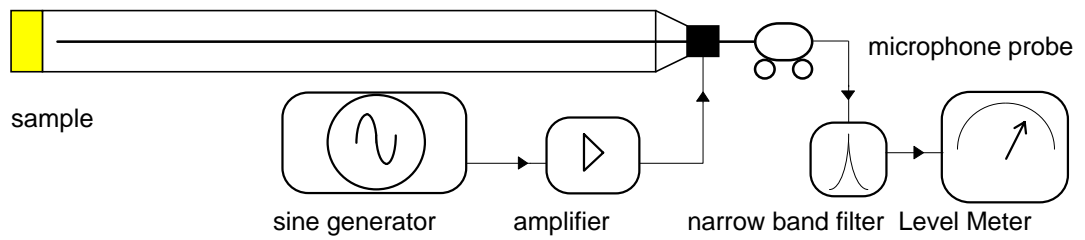
The traditional standing wave tube technique is many years old: nevertheless, it is a current issue, as the I.S.O. is reviewing the test code (ISO/DIS 10354). At the same time, many alternative measuring techniques have been proposed, based on the digital signal processing of the signals coming from a pair of phase-matched microphones, or from a series of subsequent microphone positions. The numerical elaboration can extract either the Transfer Function between these microphones or the Cross Spectrum, and the latter case can be seen as a sound intensity technique. Also the excitation signal can be of different kinds: the original steady sine wave has been substituted by a white noise, by a swept sine and finally by a pseudo-random Maximum Length Sequence (MLS).

In this paper the results of a wide experimental research are presented. The authors employed three different experimental setups, including the traditional one, a multi-point single-microphone arrangement, and a two-microphone tube. The acquisition hardware consist of an analog meter, a two-channel FFT analyzer, a 1/12 octave digital real time analyzer and a MLSSA system. The samples used for these experiments are various kinds of plasters and other mineral materials, avoiding the commonly used soft layers of polyurethane foam or glass wool (with these, in fact, all methods work well!).

Furthermore, a new measurement technique was developed, which combines several distinct measures made with a single, movable microphone. A validation check is used to discard data outside the frequency range valid for the microphone spacing or below a minimum coherence. In this way, accurate measurements can be made also with samples of materials that usually produce poor results with the other measuring techniques.

### MEASUREMENT TECHNIQUES

The first measurement technique is the traditional one, described in the test code ISO/DIS 10534. No further explanation is required, but it must be noted that this “reference” method requires a measurement at each frequency, as it employs pure tone excitation. The following picture shows the apparatus:

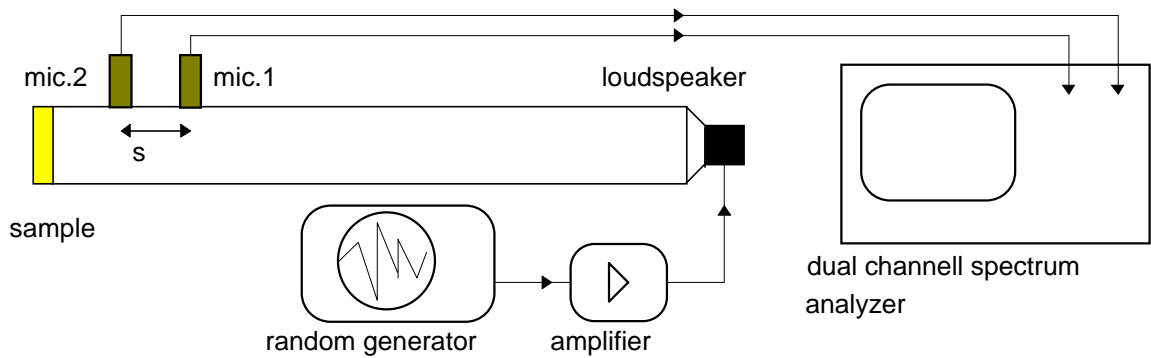


A B&K type 4002 Standing Wave Apparatus has been employed, with a B&K analog generator, filter and Level Meter.

The absorption coefficient is then computed from the SPL difference between a pressure maximum and minimum,  $\Delta L$ :

$$\alpha = \frac{4 \cdot 10^{\Delta L/20}}{\left(10^{\Delta L/20} + 1\right)^2} \quad (1)$$

The second technique is that described in the test code ASTM E-1050 (85): this is substantially the same technique suggested by Chung and Blaser [1], based on the measurement of the transfer function  $H_{12}$  between the microphones:



In the present work, a 1/12 octave real-time analyzer has been employed (B&K 2133), connected with a B&K type 4206 tube. The absorption coefficient is then computed as follows:

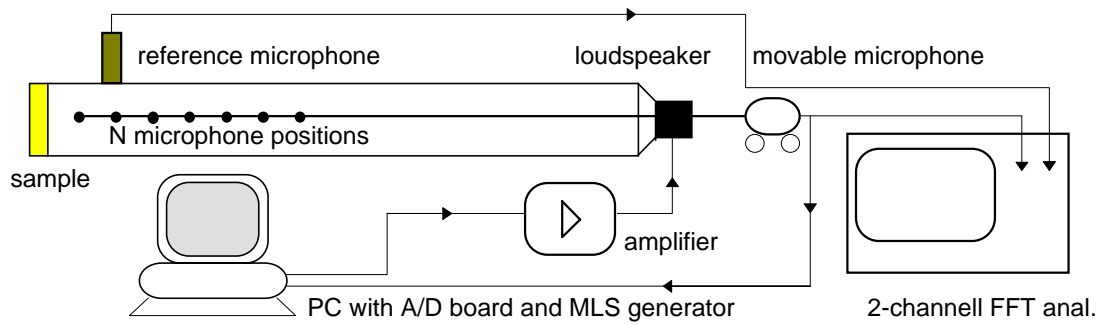
$$\alpha = 1 - \left| \frac{H_{12} - e^{-jks}}{e^{jks} - H_{12}} \right|^2 \quad (2)$$

The same apparatus has been employed also for the third technique; the Sound Intensity software of the analyzer has been used to measure the three basic quantities: Mean Pressure (MP), Particle Velocity (PV) and Active Intensity (AI).

After simple manipulations, from these quantities it can be obtained:

$$\alpha = 1 - \frac{AI_{ref}}{AI_{inc}} = 1 - \frac{\frac{1}{2} \cdot \rho \cdot c_0 \cdot PV^2 + \frac{1}{2} \cdot \frac{MP^2}{\rho \cdot c_0} - AI}{\frac{1}{2} \cdot \rho \cdot c_0 \cdot PV^2 + \frac{1}{2} \cdot \frac{MP^2}{\rho \cdot c_0} + AI} \quad (3)$$

The fourth technique is based on a multi-point transfer function measurement, inside the same apparatus shown for the traditional method.



This system can measure the Transfer Function between loudspeaker and movable microphone through deconvolution of the MLS signal [2] employing a MLSSA A2D-160 PC board, but it can also measure a traditional FFT transfer function between the reference and movable microphones, with an Ono Sokki CF920 analyzer.

In either way, one obtains  $N$  Transfer Functions ( $H_1, H_2, \dots, H_N$ ), and these can be processed as suggested by Fujimori et al. [3] (neglecting the tube attenuation) to give  $\alpha$ :

$$\alpha = 1 - \frac{\left| \sum_N H_i \cdot e^{jkx_i} - \sum_N H_i \cdot e^{-jkx_i} \right|^2}{\left| \sum_N H_i \cdot e^{jkx_i} + \sum_N H_i \cdot e^{-jkx_i} \right|^2} \quad (4)$$

The same apparatus is the one employed for the newly developed technique (the fifth), that consists in a different way of processing the  $N$  measured Transfer Functions.

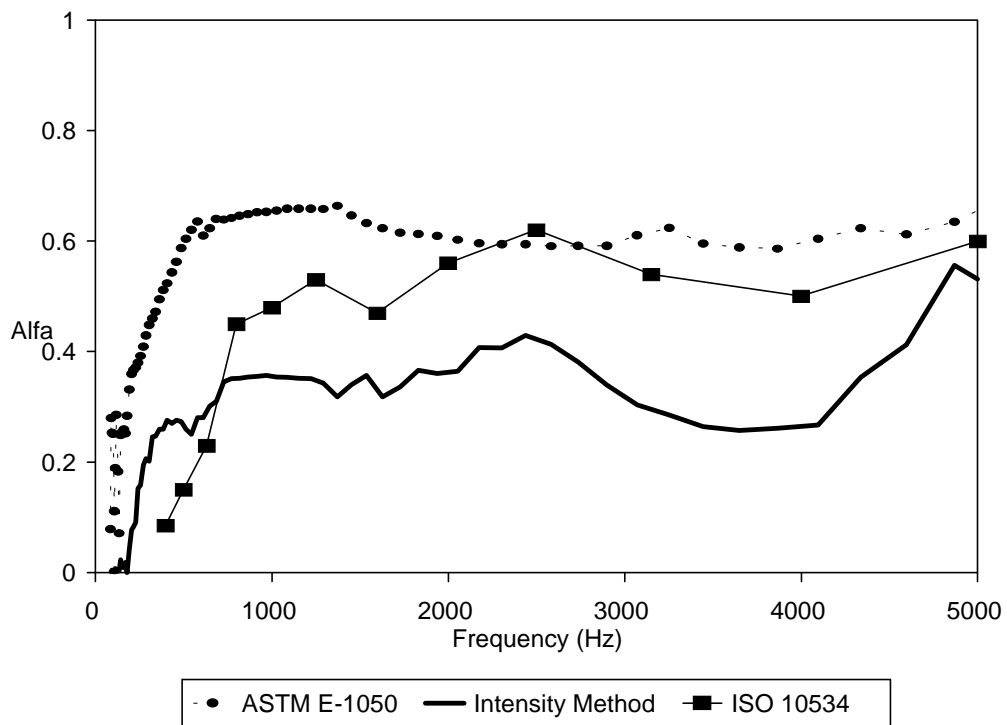
The basic idea of the new method is to consider pairs of microphone positions (not necessarily consecutive): for each pair, the Transfer Functions between position  $i$  and  $j$  and the Coherence function can be obtained.

The absorption coefficient  $\alpha$  is then computed, at each frequency, as the average of all the **valid**  $\alpha$  values calculated through eqn. 2) from all the possible pairs: a particular value of  $\alpha$  is considered valid only if the Coherence is greater than 0.85 and the microphone separation is comprised between 0.088 and 0.353 times the wavelength.

In this way the data affected from poor measurement conditions (signal-to-noise ratio, tube resonances, microphones too far or too close for the wavelength) are automatically discarded, and the averaged value is computed only on unbiased data.

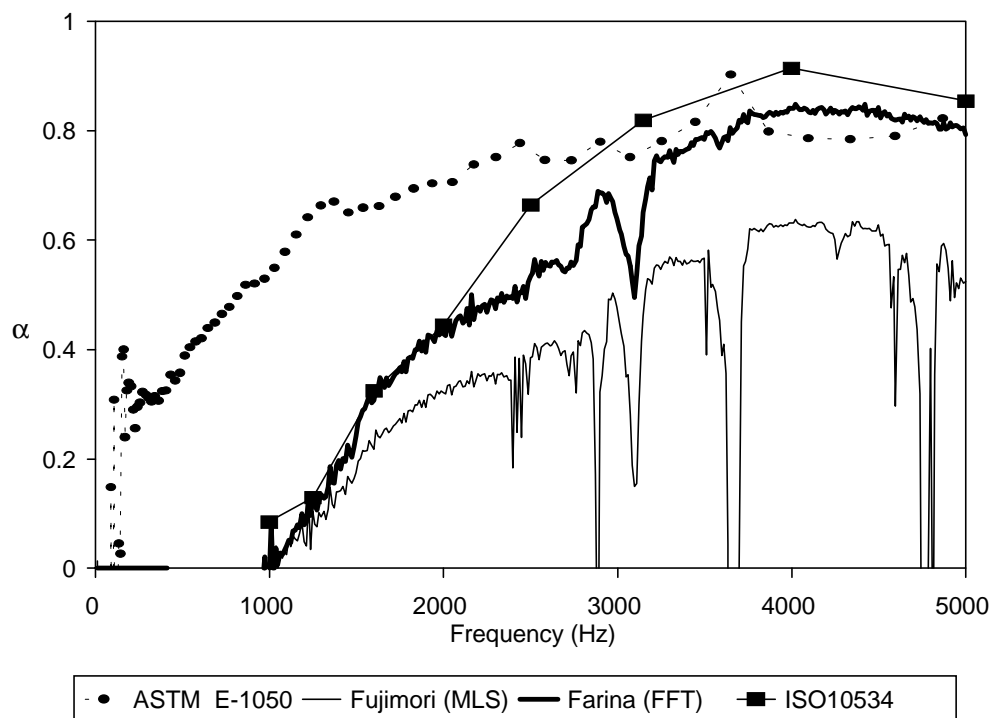
## EXPERIMENTAL RESULTS

The first picture shows the comparison between the ISO 10534 traditional technique, the 2-microphone technique according to ASTM E-1050 and the Intensity technique:



It can be seen that the 2-microphone technique is similar to the traditional one, but much faster. On the other hand, the Intensity technique shows significant errors, probably because the gain and phase correction procedure implemented in the Intensity mode are not so effective in removing these effects as the Chung and Blaser microphone switching method.

The second picture shows the multi-microphone results both with the Fujimori formulas and with the new data-discarding method; these are compared with the traditional pure tone method and with the 2-microphones technique:



It can be seen that the FFT analysis based on a reference microphone gives better results than the MLS deconvolution of the speaker-to-microphone response, and this is due to a higher coherence in the measured transfer functions. Furthermore, it can be

seen that the new data-discarding technique greatly reduce the spikiness of the measured absorption curve around tube resonances and in the high frequency region.

## CONCLUSION

After a wide comparison between available measuring techniques, a new processing algorithm has been developed, which makes it possible to measure the absorption coefficient of very reactive materials, following the formulation required for compatibility with ASTM E-1050. The new technique only requires that the measurement is repeated a few times (typically 7), and so it is only slightly slower than the original 2-microphone method.

The comparison with the other measurement techniques shows that also with the original ASTM method, and with a properly designed tube and a powerful analyzer, reasonably good results can be achieved. However the new method is more versatile, as it can be used with the old moving-microphone tubes, and it can be implemented with a low-cost PC and an MLS board.

## BIBLIOGRAPHY

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