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The Measurement of Absorption Coefficient using a Correlation Technique

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Introduction

Correlation provides a quantitative measure of the degree of causality between two functions $f_x(t)$ and $f_y(t)$. The correlation function is expressed as:

$$\psi_{xy}(\tau) = \lim_{T \to \infty} \frac{1}{T} \int_0^T f_x(t) \cdot f_y(t+\tau) \cdot dt$$

The variable τ represents a time delay imposed on $f_x(t)$ before it is multiplied by $f_y(t)$.

Correlation is readily applied to acoustical signals. Given a random noise signal $f_x(t)$ emitted from a loudspeaker, the signal $f_y(t)$ received by a microphone from that loudspeaker will correlate with $f_x(t)$ to produce a peak in the function $\psi_{xy}(\tau)$ when τ is equal to the transit time of sound from speaker to microphone. The sound pressure amplitude at the microphone due to sound which has traversed a particular path can thus be determined from the magnitude of $\psi_{xy}(\tau)$

The specific application of correlation to be considered here is the direct measurement of absorption coefficient by using a correlator to select the reflection from the sample in question and measure its amplitude.

Correlation was first applied to acoustical measurements by Goff in 1955[1] and again by Burd in 1964[2]. In the work described here we have concentrated on using correlation with standard Brüel and Kjaer filters and level recorder so that results may be readily compared with those obtained by more standard acoustical techniques.

When random noise of limited bandwidth is used for correlation, the peaks become broader than when white noise is used. This fact introduces a complication into the experimental work because there must be a sufficient time interval between successive sound paths to avoid overlapping of peaks. The autocorrelation function of a signal is the Fourier transform of the power spectrum. Thus an ideal filter with a rectangular pass band gives rise to an autocorrelation function of the form $\frac{\sin x}{x}$ multiplied by a sinusoidal function of the same frequency as the centre frequency of the band.

In practice an octave band of noise of 1 k H z centre frequency produces an autocorrelation function approximately 3 m.sec. wide. As the bandwidth is narrowed, so the function broadens; i.e. as the frequency information is increased, the time scale resolution is reduced.

The analogue correlator

Fig (1) shows the basic elements of the analogue correlator. The time delay is produced by a magnetic tape recorder specially adapted with one replay head mounted on a micrometer screw sliding track to provide a variable time delay. Owing to the physical size of the heads, a single channel system cannot provide a time delay variable through zero. Hence a fixed time delay is used in channel A and the variable time delay in channel B, the net time delay τ being the difference between the two delays.

The B & K 2305 level recorder drive shaft is mechanically linked to the scanning replay head so that a chart is obtained of correlation function $\psi_{xy}(\tau)$ against time delay τ. The estimated maximum error in correlation peak height is $\pm$ 3.5%, of which $\pm$ 2% is contributed by the level recorder quantization error.

Absorption coefficient measurements

Fig (2) is a schematic diagram of the layout for absorption measurement. The correlator selects the peaks in the correlation function corresponding to the path traversed by sound from the speaker reflected from the sample back to the microphone. The height of this peak is directly proportional to the modulus of the sound pressure reflected from the sample, averaged over the frequency band in use. The modulus of the normal incidence reflection coefficient is found by covering the absorbent specimen with a 100% reflector of the same size and comparing the two correlation peaks thus obtained. In the laboratory tests a sheet of 32 oz. glass was used for this purpose (dimensions 2' x 2'). If h_s = correlation peak height due to sample

h_g = correlation peak height due to glass.

then reflection coefficient $|r| = \frac{h_s}{h_g}$

$\therefore$ absorption coefficient $\alpha = 1 - |r|^2$

$$= 1 - \left(\frac{\lambda_s}{\lambda_g}\right)^2$$

The most interesting application of correlation to absorption measurement is measurement "in situ" on an existing wall. The two signals to be correlated are recorded on a twin-channel portable recorder and taken back to the laboratory, where a tape loop is made and the signals fed into the correlator for as long as necessary. In these measurements, where the absorbent area may be very large, glass cannot conveniently be used as the reference 100% reflector. Instead, a hard plastered brick wall (dimensions 11' x 20') is compared with the unknown sample by first standardising the "direct" sound levels which should be the same in both cases, all distances having been made the same.

Results of absorption coefficient measurements

In general the results of normal incidence absorption measurements made using correlation have been in close agreement with results from the B & K standing wave tube. Fig (3) shows normal incidence absorption coefficient plotted against frequency for polyurethane foam of 3" thickness. The results obtained by correlation (continuous line) are compared with results from the standing wave tube (dotted line).

Fig (4) shows similar graphs for 1" foam. The discrepancy at 500 Hz is due to the fact that the correlation result is averaged over the octave band whilst the tube result is for a single frequency. Where absorption coefficient is changing rapidly with frequency, the two methods produce different results each of which, however, is valid in its own way.

Fig (5) shows results for 1" perforated fibre acoustic tile. The solid line refers to results obtained from correlation in the laboratory and the dotted line to the standing wave tube. The dashed line shows results obtained "in situ" in a small recording studio. It is interesting to note that the standing wave tube gives a much higher result at 2 kHz and 4 kHz than correlation. This discrepancy could be due to the fact that the impedance tube uses a very small sample (1" diameter) which may not be representative of the properties of a large area. There was also some uncertainty in the high frequency results in the impedance tube due to cross-modes. The "in situ" correlation results are in reasonable agreement with the laboratory results. The small size of the room unfortunately prevented a result from being obtained at 500 Hz, reflections from the floor merging with the wall reflection.

Conclusions

Correlation has been found to be a useful method for measuring absorption coefficient "in situ" without the need for cutting a sample of the material.

Disadvantages of the method are:

(i) Frequency information is limited by the need to use bands of noise rather than pure tones.

(ii) The method is slow, taking typically ten minutes to scan through one peak in the function because of the long integration time required for accuracy. A hybrid analogue-digital instrument could work faster by correlating simultaneously at a large number of different time delays instead of simply scanning through the range.

It is interesting to note that accurate measurements can even be made under conditions of high background noise level because the method rejects all signals except the one correlating with the output of the random noise generator.

Although results have so far only been taken at normal incidence, it is hoped to extend the technique to oblique incidence measurements. In principle there is no difficulty in this, provided a large sample of absorbent is available, but results near grazing incidence may be difficult when the path difference between direct and reflected sound is small.

References

1. K.W. Goff, "The Application of Correlation Techniques to some Acoustical Measurements". J.Acoust. Soc. Am. (1955) 27, pp 236-246.
2. A.N. Burd, "Correlation Techniques in Studio Testing" Radio and Electron Engr., (1964), 27, (5), pp 387-395.

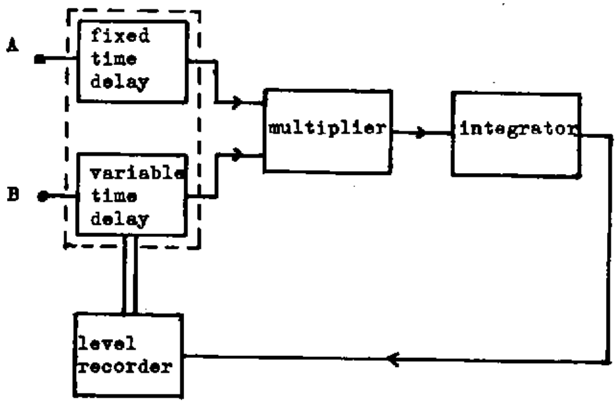

Fig (1) Schematic of Analogue Correlator

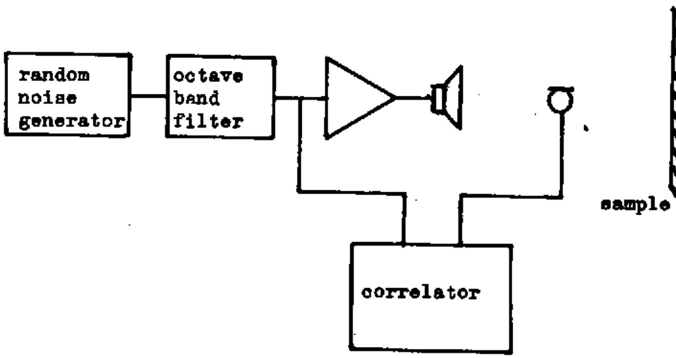

Fig (2) Absorption Measurement by Correlation

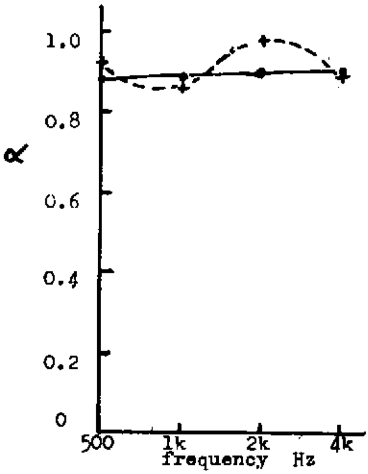

Fig (3) 3" thick polyurethane foam type VRT300

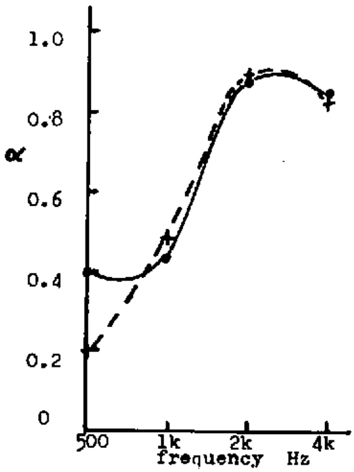

Fig (4) 1" thick polyurethane foam type VRT300

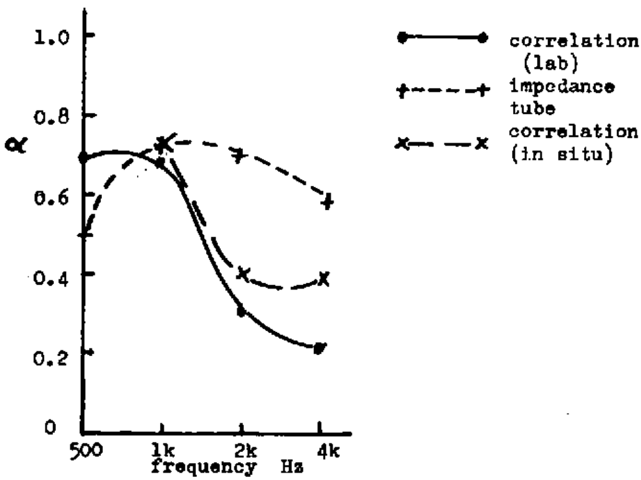

Fig (5) 1" thick perforated wood-fibre tile