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# ROOM RESPONSE MEASUREMENTS IN A REVERBERATION CHAMBER CONTAINING A ROTATING DIFFUSER

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RÉSUMÉ

L'application de séquences périodiques pseudo-aléatoires à la mesure du comportement d'une pièce a été étendue aux pièces dotées d'un diffuseur rotatif. Les résultats obtenus avec cette nouvelle technique correspondent assez bien à ceux obtenus par la méthode de balayage à fréquence unique. Pourtant, la nouvelle méthode n'exige qu'une fraction du temps requis par l'ancienne pour réaliser le même travail.

# Room response measurements in a reverberation chamber containing a rotating diffuser

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The application of periodic pseudorandom sequences for room response measurements has been extended to chambers containing one rotating diffuser. Results obtained by the new technique compare very well with those measured by the single frequency sweep method. Yet it takes only a small fraction of the time required by the latter method to accomplish the same task.

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## INTRODUCTION

Accurate determinations of room responses in reverberation chambers are required for the qualification test of pure-tone or narrow-band sound power measurements.[1] Conventional single frequency sweep method is very time consuming and new techniques should be developed.

In an earlier paper,[2] it was shown how a periodic pseudorandom sequence (also named a maximum-length sequence) can be used effectively as a mulitone source in a chamber with fixed geometry. The new technique can shorten the testing time by more than one order of magnitude.

In this paper, the extension of this technique to rooms equipped with one rotating diffuser is discusssed. To approximate such a room as a time invariant system, it is necessary to match the period of the sequence with that of the rotating diffuser and perform all analyses over exactly one period. The different frequency components of a room response can be determined by the fast Fourier transform (FFT) technique. However, measurements showed that the room response varied with the phase relationship between the periodic motion of the rotating diffuser and the period of the sequence. Thus, some ensemble averaging is necessary. Very good agreement has been obtained between this new technique and the single frequency sweep method. Yet the new technique takes a much shorter time to achieve the same results.

## I. SINGLE FREQUENCY SWEEP METHOD

Measurements were taken for one fixed microphone and source position in a rectangular model reverberation chamber with dimensions 3.2×2.6×1.96 m. The room is equipped with both fixed diffusers and a rotating diffuser. The latter consists of a 0.76×0.91 m wooden panel mounted at about 45° inclination on a rotating shaft in the middle of the room; it rotates at about 15 rpm.

The room was excited with pure tones generated by a stable frequency synthesizer (HP 3325A) fed through a power amplifier to a speaker placed at a fixed position on the floor of the room. Two hundred frequencies were used starting from 400 Hz with an increment of 1 Hz. At each frequency, the sound pressure at one chosen location in the reverberant sound field about half a meter from the rotating diffuser

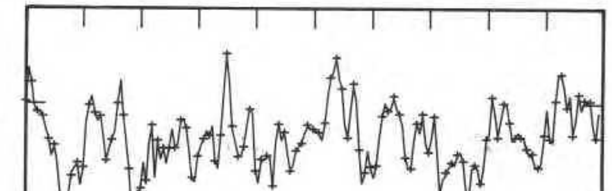


FIG. 1. Repeated measurements of room responses in the 400–600 Hz range by the single frequency sweep method.

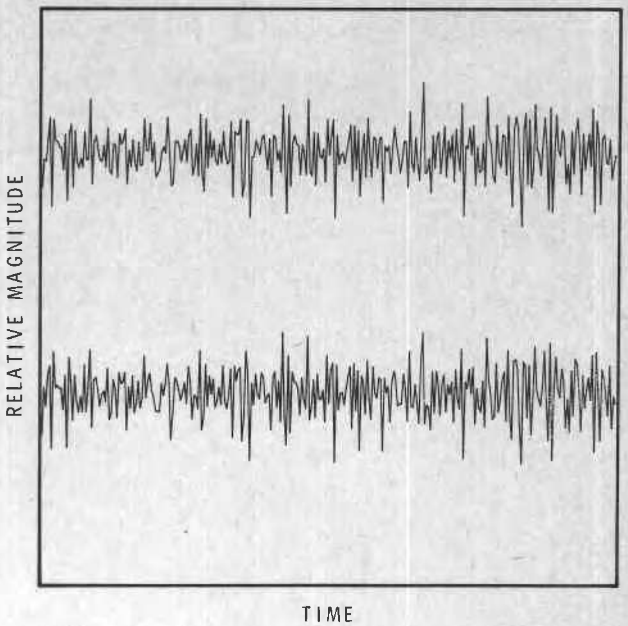


FIG. 2. Initial portion of two separate time traces measured from the same reference position of the rotating diffuser under periodic pseudorandom sequence excitation.

was measured with a B&K 1/2-in. microphone whose output was fed into an Analog Devices 442J true rms-to-dc converter with a time constant of 0.03 s. The output of the rms detector was sampled every 0.1 s. A total of 40 samples were used to compute the averaged mean-square pressure over one period of the rotating diffuser. Results from two repeated runs are plotted in Fig. 1 as sound pressure levels versus frequency. The excellent agreement indicates that the procedure of averaging over one period of the rotating diffuser is correct.

## II. PERIODIC PSEUDORANDOM SEQUENCE TECHNIQUE

For comparison purposes, the room response at the same microphone location was measured under identical conditions. The instrumentation setup is similar to that used in Ref. 2. Since it has been established that the spectrum of the source signal is flat,[2] it is only necessary to compute the microphone output spectrum rather than the transfer function.

Matching the period of the sequence with that of the rotating diffuser is important. To measure the period of the rotating diffuser accurately, a small rod, attached to the shaft of the rotating diffuser, interrupted the beam of a light sensor once every revolution. The output from the light sensor was used to trigger a frequency counter. The same signal was also used as a trigger for the A to D converter so that data could be obtained from the same reference position of the rotating diffuser.

In order to meet the requirements imposed by the matching of periods and the frequency range of interest, the length of the sequence $L$ was chosen to be $(2^{17}-1)$ and a clock frequency of 32 998 Hz was used. The sampling frequency was 1/16 of the clock frequency as used in the previous paper. For this case, the total number of data points

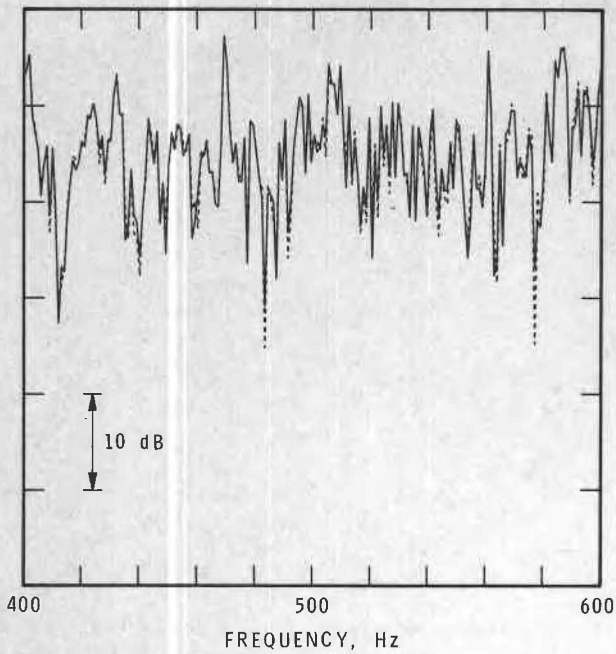


FIG. 3. Comparison of room responses computed from the two time traces shown in Fig. 2 in the 400–600 Hz range.

used became 8192. The Nova 4 minicomputer can handle the 8192 point FFT producing 4096 frequency components of approximately 0.25-Hz spacing. However, only every fourth point (giving approximately 1-Hz resolution) will be used for better graphic presentation of all results reported here. For smaller computers that cannot handle large FFTs, either the method proposed by Chu[3] or the one by Aoshima[4] can be used.

First it will be shown that when the periods of the sequence and the rotating diffuser are matched, the sound field is also periodic and deterministic. This was accomplished by analyzing two separate digitized time records of 8192 points, each taken not necessarily consecutively, but from the same reference position of the rotating diffuser while a fixed phase relationship between the rotating diffuser and the sequence was maintained. Indeed, the two time traces show good repeatability. An initial portion of each of them is shown in Fig. 2. Figure 3 depicts the spectra computed from these time records between 400 and 600 Hz. The two curves are nearly identical.

It is evident from Figs. 1 and 3 that the new technique has not produced a room response equivalent to that obtained by the single frequency sweep method. Further studies showed that the measured room response for the fixed microphone and source position varied with the phase relationship between the periodic motion of the rotating diffuser and the periodic pseudorandom sequence. Figure 4 shows significant differences between two spectra obtained after the sequence had been turned off and on again to alter this phase relationship. Thus ensemble averaging for different phase relationships is necessary.

TABLE I. Standard deviations computed from the different ensemble averaged spectra between 400 and 600 Hz for one fixed source and receiver configuration.

| Number of averages | Standard deviation (dB) |
|---|---|
| 1 | 5.86 |
| 2 | 4.58 |
| 3 | 3.97 |
| 4 | 3.76 |
| 5 | 3.60 |
| 6 | 3.63 |
| 7 | 3.64 |
| 8 | 3.59 |

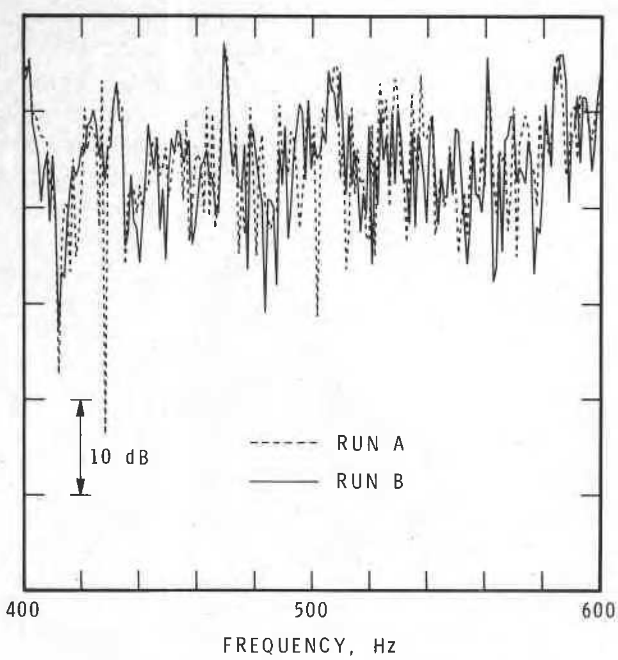


FIG. 4. Comparison of room responses obtained under different phase relationships between the periodic motion of the rotating diffuser and the periodic pseudorandom sequence in the 400–600 Hz range.

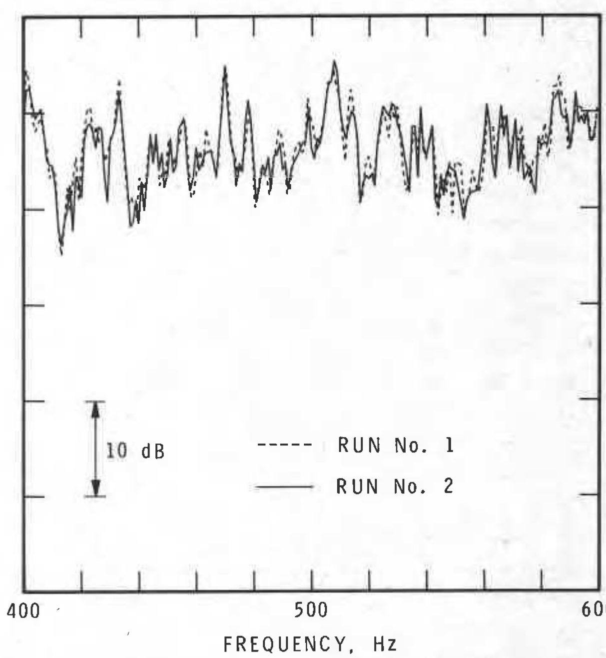


FIG. 5. Repeated measurements of the averaged room response in the 400–600 Hz range obtained under periodic pseudorandom sequence excitation.

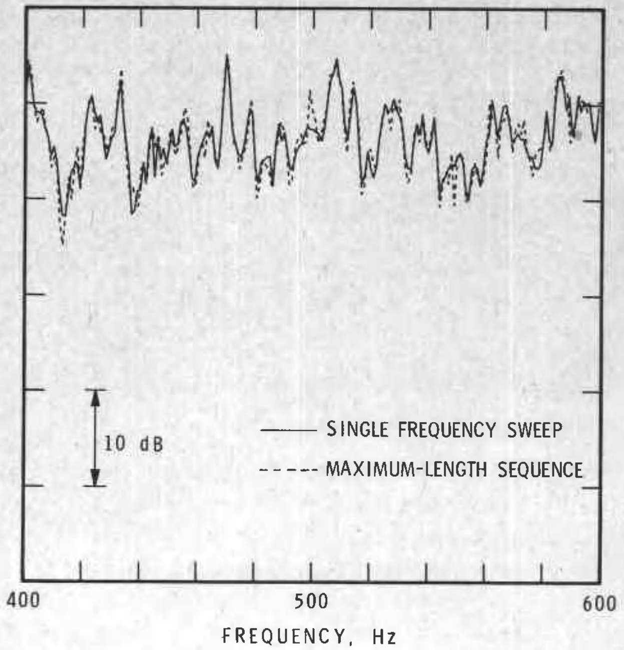


FIG. 6. Comparison of room responses in the 400–600 Hz range obtained by two different methods.

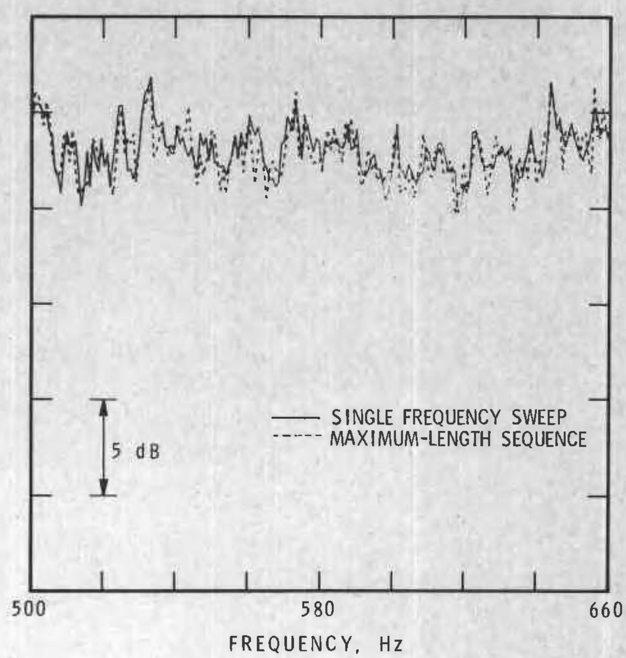


FIG. 7. Comparison of room responses in the 500–660 Hz range obtained by two different methods in a full scale reverberation chamber.

The number of ensemble averages required was determined by comparing the standard deviations computed from the different averaged responses between 400 and 600 Hz. Table I indicates that the standard deviations varied from 5.86 dB for a single observation to a final value of 3.60 dB after six or more ensemble averages. At least for the present room condition and the frequency range of interest, it seems that six to eight averages are adequate, but eight were used for the results presented here. Figure 5 shows that the averaged room response is quite repeatable. This also compares well with the response obtained by the single frequency sweep method, as depicted in Fig. 6. The standard deviation of the single frequency sweep curve is 3.30 dB.

## III. DISCUSSION

A single measurement of the room response using the periodic pseudorandom sequence showed no effect of the rotating diffuser. The measured standard deviation was 5.86 dB, which seems to correspond to the value of 5.57 dB for no rotating diffuser. A possible explanation can be presented based on the modulation theory[5,6] of a rotating diffuser.

In the single frequency sweep method, each frequency point of the measured response function is effectively an average over several frequency components, due to the modulation effect of the rotating diffuser and the way the mean-square values are obtained by including the contributions from all the sidebands. No such summation or averaging exists, however, in the case of the pseudorandom sequence excitation, where the response function was obtained by the FFT procedure. In addition, the redistribution of energy of any frequency into sidebands might be different because the sideband frequencies coincide with the existing driving frequencies of the pseudorandom noise source.

Since the number and relative magnitudes of the sidebands cannot be predicted for each frequency, it is not possible to perform any frequency averaging of the measured response function. Other averaging techniques must be used to reveal the effect of the rotating diffuser. The ensemble averaging chosen for the present investigation works well for a rotating diffuser with a relatively low figure of merit (about 1.5 in the 400–600 Hz range). For a more effective rotating diffuser, the number of ensemble averages required should be increased.

Further experiments carried out in a full scale reverberation chamber of 255 $m^3$ equipped with a larger rotating diffuser (see Ref. 7 for detailed description) confirmed the validity of the present technique. As shown in Fig. 7, the averaged response curve compared reasonably well with that obtained by the single frequency sweep method. For this case, 40 ensemble averages were required to bring the standard deviation to its final value of 1.35 dB. The figure of merit of this diffuser is about 4.1 in the 500–600 Hz range. The corresponding value for the single frequency sweep curve is 1.24 dB.

## IV. CONCLUSION

It has been demonstrated that the periodic pseudorandom sequence can also be used as a multitone source for rooms equipped with a rotating diffuser. Ensemble averaging is required, however, to eliminate variations caused by the phase relationship between the periodic motion of the rotating diffuser and the sequence. The new technique significantly reduces the testing time compared to the single frequency sweep method. Coupled with the nearfield and farfield transfer function technique as suggested by Chu,[8] future qualification tests for sound power measurements can be performed more efficiently.

## ACKNOWLEDGMENTS

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