UNIVERSITY OF NIŠ
The scientific journal **FACTA UNIVERSITATIS**
Series: **Working and Living Environmental Protection** Vol. 1, No 4, 1999, pp. 55 - 63
Editor of series: Ljiljana Rašković, e-mail: ral@junis.ni.ac.yu
Address: Univerzitetski trg 2, 18000 Niš,YU, Tel. +381 18 547-095, Fax: +381 18 547-950
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IMPROVEMENT OF DYNAMIC RANGE OF SOUND ENERGY DECAY IN ROOM

UDC 534.843

Miroslava A. Milošević, Dejan G. Ćirić

University of Niš, Faculty of Electronic Engineering, Beogradska 14, 18000 Niš
Serbia, Yugoslavia

Abstract. *Dynamic range of sound energy decay in room obtained by integrated impulse method can be often relatively small. The reasons are insufficient energy of impulse and existing background noise. There are several alternatives to circumvent this problem. Using pseudorandom noise as excitation signal makes possible to excite the room by the considerable greater energy and to obtain, in that way, greater dynamic range. Also, methods such as the truncation of the impulse response at the knee and the subtraction of the mean square value of background noise are the potential solutions which are often used. The influences of several factors on obtained dynamic range in integrated impulse method by using the impulse and pseudorandom noise as well as the methods for dynamic range improvement are analysed in this paper.*

Key words: *sound energy decay, dynamic range improvement, integrated-impulse method*

1. INTRODUCTION

The integrated impulse method proposed by Schroeder before more than 30 years, was a good alternative to overcome the disadvantage of interrupted noise method [1-3]. This method can give smooth decay curves in only one measurement. However, obtained dynamic range representing the difference between the initial maximal level and the point where the decay curve intersects the background noise level, can be often relatively small. This a result of the insufficient energy of the excitation impulse.

If the pseudorandom noise is used as the excitation signal, the room is excited by considerably more energy [4]. Usually, the sufficient dynamic range for reliable determination of energy decay characteristic and reverberation time is obtained if appropriate pseudorandom noise is used. However, big background noise comprising both

Received July 26, 1999

the acoustical noise in the room and the electronic noise of measurement system, can reduce this dynamic range [5-7]. Because of that, even with this excitation it is sometimes desirable to use the reducing of the influence of the background noise and improvement of dynamic range.

Various alternatives for dynamic range improvement are analysed in this paper. The truncation of the impulse response in the knee and integration up to this new upper limit as well as subtraction of background noise mean square value from the squared original signal before the integration are the solutions which can be implemented for this purpose [2,6]. Also, pseudorandom noise as excitation signal enables the use of averaging for dynamic range improvement.

2. THE IMPLEMENTATION OF INTEGRATED IMPULSE METHOD

The averaged decay curve of squared sound pressure $s^2(t)$ in the receiving point in the room excited by filtered white noise, can be obtained by the integration of squared impulse response of the room $r^2(t)$. This can be mathematically presented as [1,2]

$$s^2(t) = N\int_t^\infty r^2(\tau)d\tau\,, \tag{1}$$

where N is power spectral density of the noise in the analysed frequency band. In order to reduce the measurement system influence and to obtain real response of the room, the excitation impulse should be very short in duration. Often, such impulse does not have sufficient energy for obtaining of necessary dynamic range.

The room impulse response can be obtained if the room is excited by the pseudorandom noise. In this case, the impulse response is extracted by cross-correlation of the response and excitation signal. The pseudorandom noise has significantly longer duration than an impulse, so the room is excited by significantly greater energy for the same amplitude. As a result, considerable improvement of dynamic range is obtained.

The pseudorandom noise is generated on several ways. The binary maximum length sequences which are easily generated by the feedback shift registers, are the most used for this purpose. The length of this sequence is $2^m - 1$, where m is the order of the sequence and it represents the number of stages of the shift register used for the sequence generation. The most used sequences for measurement are sequences of order of 15, 16 and 17. The pseudorandom noise generated by this sequence is referred as noise of appropriate order.

Besides its advantages, the pseudorandom noise as excitation signal has also the imperfection of complex processing. This problem can be circumvented if the cross-correlation is calculated by fast Hadamard transform, so this calculation even for the longer sequences can be done in a time of order of seconds [4].

The simple measurement system based on PC as a central unit, is used for the integrated impulse method implementation [6-8]. The measurement is performed in two steps, Fig. 1. Firstly, the room response is recorded, where this response is digitized and stored in the PC memory. Than, the response is processed. The processing includes filtering, squaring and integration. Also, in the case of pseudorandom noise excitation, the cross-correlation is calculated by fast Hadamard transform.

3. INFLUENCE OF MEASUREMENT SYSTEM

The important influence on obtained dynamic range has background noise. Moreover, it is also necessary to take in consideration the influence of measurement system itself for generating as much as possible dynamic range. Namely, even with the implementation of pseudorandom noise as excitation signal which is immune on background noise, it is necessary to optimise the measurement system parameters in order to get optimal dynamic range [5]. First of all, this is referred on the amplification of the excitation signal that is the excitation signal level and on the equalisation of sound source.

Generally, the greater level of excitation impulse would result in the greater dynamic range. However, this is the truth only in the band where there is no distortion of the sound source. The further increasing of excitation signal level in the band where distortions are present would have negative result on the obtained dynamic range.

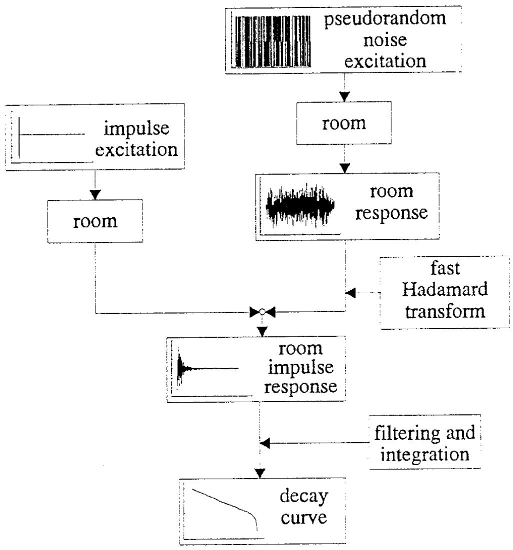

Fig. 1. The measurement procedure

In order to get optimal level of excitation signal for the mentioned measurement system, the several measurements were performed in the particular room. One of the classroom at the Faculty of Electronic Engineering was used for this purpose. As excitation signals, the appropriate impulse and pseudorandom noise of order of 17 were implemented. The room responses for various levels of amplification were recorded. In the reference to the maximal level of amplifier amplification, these levels varied from −35 to −5 dB. The decay curves in 1/3 octave band of central frequency of 4 kHz for the pseudorandom noise excitation are presented in Fig. 2. In order to analysed wider frequency range, the obtained results in 1/3 octave bands from 100 Hz to 8 kHz were averaged and the results for both excitations are presented in Fig. 3. It is obvious that for both excitations there is optimal amplification level that is excitation signal level. However, this optimal level for impulse excitation is obtained almost at maximal amplification.

The generated excitation signals have flat spectrum. However, the loudspeaker output signal often has no flat frequency characteristic. Due to this, it is desirable to reduce the negative influence of the sound source. Unfortunately, it has been shown that equalisation resulting in a flat frequency characteristic usually reduces the obtained dynamic range [5]. Because of that, the equalizer of amplifier is used in order to reduce the decay of the sound source frequency characteristic at low frequencies. The results for the excitation by psedurandom noise of order of 17 are presented in Fig. 4. In the same figure, it is also shown the decay curve at 4 kHz in order to present that this equalization does not affect the results at higher frequencies and that almost equal dynamic range is obtained in this way.

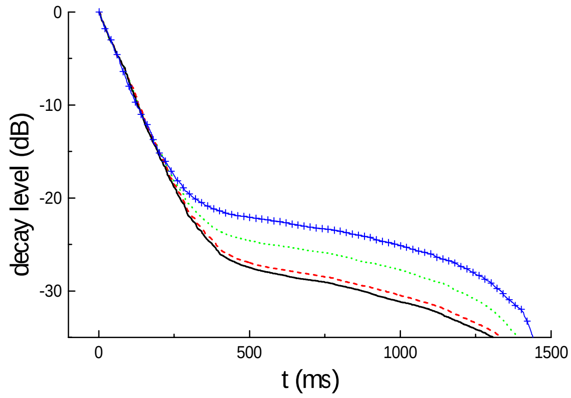

Fig. 2. The decay curves in 1/3 octave band at 4 kHz obtained by pseudorandom noise of order of 17 by using various amplification levels: (- + -) -30 dB, (· · ·) -20 dB, (—) −10 dB and (- - -) −5 dB

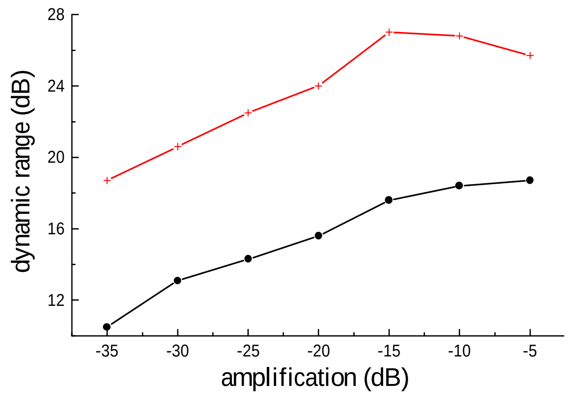

Fig. 3. The averaged results of dynamic range from 100 Hz to 8 kHz obtained by (- + -) pseudorandom noise and (- • -) impulse excitation

4. ALTERNATIVE WAYS FOR DYNAMIC RANGE IMPROVEMENT

Due to the longer duration of pseudorandom noise and the excitation of the room by more energy on this way, this excitation signal enables obtaining of greater dynamic range in reference to the impulse excitation. The binary maximum length sequences which is used for pseudorandom noise generation can be of different duration. This influences the obtained dynamic range.

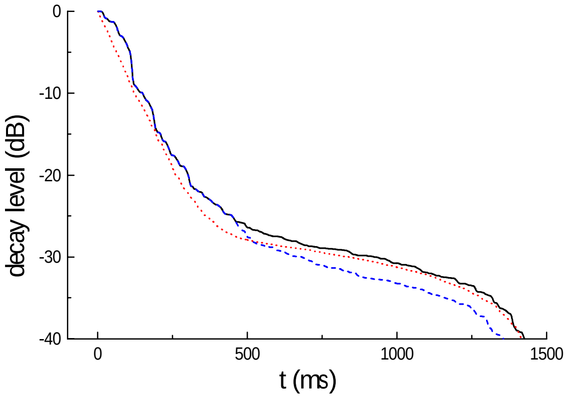

Fig. 4. The decay curves in 1/3 octave band at 200 Hz obtained by pseudorandom noise of order of 17 (—) without equalisation, (- - -) with equalisation and (· · ·) the decay curve at 4 kHz

The examination of this influence was performed by the analysis of the decay curves obtained by excitation sequences of different duration. The obtained curves in 1/3 octave band at 4 kHz are presented in Fig. 5, and the averaged results from 100 Hz to 8 kHz in Fig. 6. The longer sequences resulted in greater ranges. The obtained dynamic range especially for pesudorandom noise excitation is considerably reduced in reference to the range that this excitation makes possible. This is mostly the consequence of relative high background noise. So, it is desirable to use some other methods for dynamic range improvement.

In order to compare the dynamic ranges obtained by the pseudorandom noise and by impulse, the measurements using the impulse excitation were also performed. In these measurements, the optimal levels of amplification for corresponding excitation were used. The dynamic range obtained by impulse excitation is almost equal to that one obtained by pseudorandom noise of order of 15.

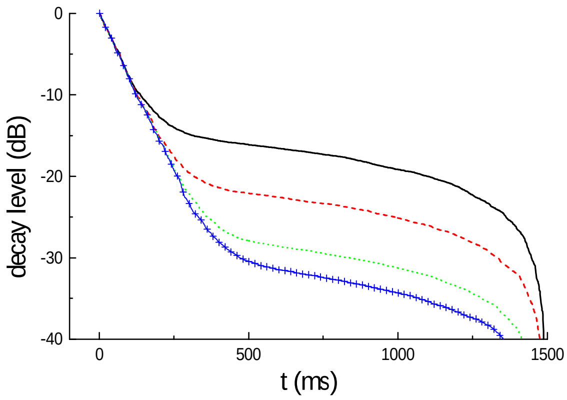

Fig. 5. The decay curves in 1/3 octave band at 4 kHz obtained by pseudorandom noise order of (—) 15, (- - -) 16, (· · ·) 17 and (-+-) 18

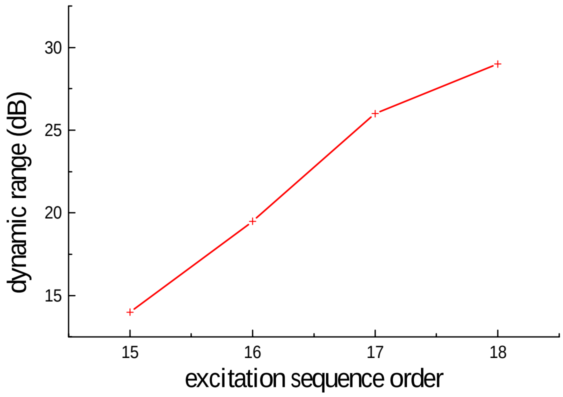

Fig. 6. The averaged results of dynamic range from 100 Hz to 8 kHz versus the pseudorandom noise order

The impulse response truncation in appropriate point and the integration of squared response up to this new upper limit is one of the methods for the background noise reducing and for the dynamic range improvement. By optimisation of various parameters, it is obtained that optimal truncation point is the point where the decay curve intersects the background noise level [5]. Besides other aims of optimisation, this truncation point is determined on this way that sensitivity on uncertainty of this point setting is as small as possible. However, if the truncation point is set before or after the optimal point, this will result in the curve with the bigger or smaller decay than the real one. Due to that, it is important to carefully set the truncation point. One of the possible solution to this problem is to set several truncation points around the knee. Then, the decay curves should be compared to the initial one, obtained without truncation, or to the corresponding one with greater dynamic range, obtained by other alternative method for background noise influence reducing. The curve which is in best agreement with the compared curve in a range of main decay gives the optimal truncation point. The results of this alternative method in 1/3 octave band at 4 kHz are shown in Fig. 7. It is obvious that the decay curve obtained by truncation of the impulse response at the knee is in good agreement with initial curve in the range of main decay. In the same figure, it is also presented the effect of the truncation point setting before the knee, so such decay curve has bigger decay than the initial one and this results in error. The adequate implementation of this method enabled the dynamic range improvement more than 10 dB, where this improvement was somewhat smaller at the lower frequencies.

The method also implemented for the dynamic range improvement is the subtraction of the mean square value of the background noise from the squared impulse response before the integration [2]. The effect of the mentioned method can be mathematically presented like following. If the impulse response $r(t)$ in eq. (1) is changed by the addition of the background noise $n(t)$ to this response, it results in

$$s^2(t) = N\int_t^{\infty}[r^2(\tau) + 2r(\tau)n(\tau) + n^2(\tau)]\,d\tau\,. \tag{2}$$

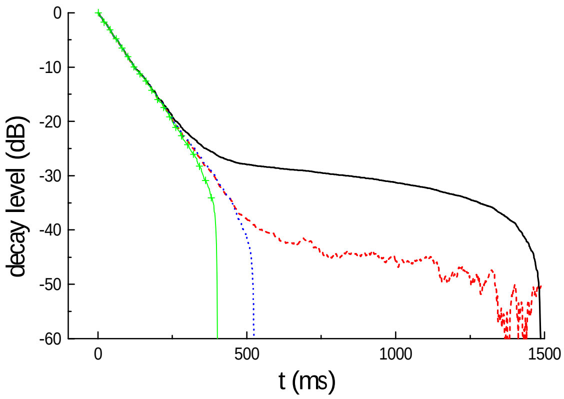

Fig. 7. The decay curves in 1/3 octave band at 4 kHz obtained by pseudorandom noise of order of 17 (—) without the background noise influence reducing, (- - -) by the subtraction of mean square value of background noise and by the impulse response truncation (· · ·) at the knee and (- + -) before the knee

The background noise influence becomes bigger as $r(t)$ vanishes. So, in the part where there is practically no $r(t)$, only $n(t)$ affects the value obtained by the integration. If the mean square value of background noise $\overline{n^2}$ is extracted from this part of the impulse response and subtracted from the squared impulse response

$$s^2(t) = N\int_t^\infty [r^2(\tau) + 2r(\tau)n(\tau) + (n^2(\tau) - \overline{n^2})]\, d\tau\,, \tag{3}$$

then the influence of the rest of background noise $n^2(t) - \overline{n^2}$ is much smaller than that one of the noise $n^2(t)$. The dynamic range improvement in the 1/3 octave band at 4 kHz obtained by implementation of this method is presented in Fig. 7, together with the decay curves obtained by the implementation of previous mentioned method. It is noticed that both methods give the similar results and that the decay curves are in good agreement in the range of the main decay which is analysed.

The results obtained by the implementation of the mentioned two methods are presented only for pseudorandom noise excitation. These methods give similar dynamic range improvement in the case of using of impulse excitation.

The pseudorandom noise as excitation signal enables the using of averaging in order to improve the dynamic range. Namely, although this excitation signal has characteristics as the white noise, it represents the deterministic signal which can be repeated with the absolute accuracy. So, the differences in the responses obtained in successively measurements are only the consequence of the background noise which is not correlated with the excitation signal. In that way, the background noise influence can be reduced by averaging. So, doubling the number of averages can improve the dynamic range by 3 dB [4]. The effect of averaging of 10 successively measurements is shown in Fig. 8 in 1/3 octave band at 4 kHz. In averaging is, also noticed the tendency that the dynamic range improvement is slightly smaller at low frequencies.

6. CONCLUSION

The background noise can negatively influence the dynamic range of the decay curve obtained by the integrated impulse method even with using of the pseudorandom noise as excitation signal. Due to that, it is desirable to perform the optimisation of the measurement system parameters and to use appropriate excitation signal that can result in necessary dynamic range.

If such approach can not ensure necessary range, the alternative methods for dynamic range improvement can be used. The methods analysed in this paper such as the truncation of the impulse response in the knee and the subtraction of the mean square value of the background noise from the original squared response, result in the improvement of 10 dB. The similar improvement is obtained by the averaging of results of 10 measurements in which the pseudorandom noise is used as the excitation signal.

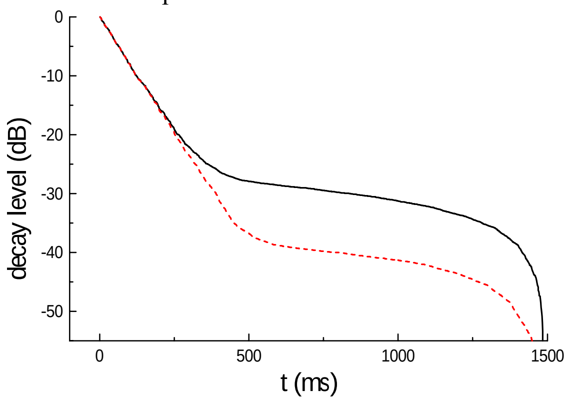

Fig. 8. The decay curves in 1/3 octave band at 4 kHz obtained by pseudorandom noise of order of 17 (—) in one measurement and (- - -) by averaging of results of 10 measurements

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POVEĆANJE DINAMIČKOG OPSEGA OPADANJA ZVUČNE ENERGIJE U PROSTORIJI

Miroslava A. Milošević, Dejan G. Ćirić

Dinamički opseg krive opadanja zvučne energije u prostoriji dobijene metodom impulsnog odziva može često biti relativno mali. Razlozi su mala energija pobude koju nosi impuls i postojeći pozadinski šum. Postoji više alternativa za rešavanje ovog problema. Korišćenje pseudoslučajnog šuma kao pobudnog signala omogućava da se prostorija pobudi znatno većom energijom i time dobije veći dinamički opseg. Takođe, metodi poput odsecanja impulsnog odziva u kolenu i oduzimanja srednje kvadratne vrednosti pozadinskog šuma predstavljaju rešenja koja se često koriste. Uticaji pojedinih faktora na dobijeni dinamički opseg u metodu impulsnog odziva korišćenjem impulsa i pseudoslučajnog šuma, kao i metoda za povećanje ovog opsega, su analizirani u ovom radu.