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ABSTRACT

Presented are the results of the continuing study of the statistical properties of the envelope functions of narrowband reverberation. Included are some initial estimations of the intensity spectrum of the reverberation envelope processes generated by scattering 1.0 msec cw signals from the rough, moving surface of a fresh water lake. In addition the intensity spectrum of the time-averaged envelope is estimated. These experimental estimates are compared to the corresponding theoretical quantities derived in earlier research.

EXPERIMENTAL ESTIMATES OF THE INTENSITY SPECTRA
OF THE REVERBERATION ENVELOPE AND ITS TIME AVERAGE

by

T. D. Plemons

TABLE OF CONTENTS

I. INTRODUCTION

Two previous progress reports[1,2] in this series present the theoretical results obtained in the study of the statistical properties of the envelope functions of narrowband reverberation processes. In this report the first experimental results of this study are presented with comparisons with the corresponding theoretical expressions. Before proceeding with the discussion of the experimental data, a review of the theory will be given.

II. REVIEW OF THEORY

The narrowband reverberation process $X(t)$ is of the form

$$X(t) = E(t) \cos\left[2\pi f_o t + \phi(t)\right] \quad , \tag{1}$$

where f_o, $\phi(t)$, and $E(t)$ are, respectively, the center frequency, the phase, and envelope of $X(t)$. The first- and second-order statistics of the envelope $E(t)$ are the subject of this study; in particular, the covariance and spectra of $E(t)$ are the desired quantities. Actually it is the fluctuating component,

$$y(t) \equiv E(t) - \langle E(t) \rangle \quad , \tag{2}$$

that is of interest. Here $\langle E(t) \rangle$ is the expected value (mean) of $E(t)$. The covariance of $y(t)$ is (Eq. (3.9), Ref. 1)

$$\begin{aligned} K_y(t_1,t_2) &\equiv \langle y(t_1) y(t_2) \rangle \\ &= \frac{\pi}{8} \Psi \, k_o^{\,2}(\tau) \quad , \quad \tau = t_2 - t_1 \quad , \end{aligned} \tag{3}$$

where Ψ is the mean intensity of the narrowband reverberation $X(t)$ and $k_o(\tau)$ is the envelope of the normalized covariance of $X(t)$.

Applying the Wiener-Khintchine theorem the dependence of the associated intensity spectrum of $y(t)$ on the frequency f was derived (Eq. (4.1), Ref. 1):

$$W_y(f) = \frac{\Psi\pi}{2} \int_0^\infty k_o^2(\tau) \cos \omega\tau d\tau \tag{4}$$

with $\omega = 2\pi f$.

The next assumption was that the covariance of the reverberation $X(t)$ is equivalent to the autocorrelation of the transmitted signal, $S(t)$. This assumption allowed us to write

$$k_o(\tau) = C_o(\tau) \quad , \tag{5}$$

where $C_o(\tau)$ is the envelope of the correlation function of $S(t)$. Substituting this expression in Eq. (4) gave

$$W_y(f) = \frac{\Psi\pi}{2} \int_0^\infty C_o^2(\tau) \cos \omega\tau d\tau \quad . \tag{6}$$

Specifying a transmitted signal waveform determines $C_o(\tau)$. There are two cases of interest in this study: frequency modulated (FM) signals and pulsed cw signals. The calculated intensity spectra of $y(t)$ corresponding to these signals are[2]

$$\left.\begin{aligned} W_y(f)_{cw} &= T\Psi_{cw} \frac{\pi}{(\omega T)^2} \left[1 - \frac{\sin \omega T}{\omega T}\right] \quad , \qquad \omega \ge 0 \quad , \\ &= 0 \quad , \qquad \text{elsewhere.} \end{aligned}\right\} \tag{7}$$

and

$$\left.\begin{aligned} W_y(f)_{FM} &= \frac{\pi\Psi_{FM}}{4W} (1 - f/W) \quad , \qquad 0 \le f \le W \\ &= 0 \quad , \qquad \text{elsewhere.} \end{aligned}\right\} \tag{8}$$

Here Ψ_{cw} and Ψ_{FM} are the intensities of the narrowband reverberation processes generated by these signals, T the transmitted signal lengths, and W the bandwidth of the FM signal. The corresponding covariance functions are

$$\left.\begin{aligned} K_y(\tau)_{cw} &= \frac{\pi}{8}\Psi_{cw}\left(1 - \frac{|\tau|}{T}\right)^2 \quad , \quad & |\tau| \le T \\ &= 0 \quad , & \text{elsewhere}, \end{aligned}\right\} \tag{9}$$

and

$$\left.\begin{aligned} K_y(\tau)_{FM} &= \frac{\pi}{8}\Psi_{FM}\frac{\sin^2 \pi W\tau}{(\pi W\tau)^2} \quad , \quad & |\tau| \le T \\ &= 0 \quad , & \text{elsewhere}. \end{aligned}\right\} \tag{10}$$

These results were used to determine the covariance and intensity spectrum of the envelope that is subjected to a time averaging ("smoothing"), which is the case of an incoherent detector-averager. The fluctuating component at the output of the detector, with an averaging time T_o, is

$$Y(t) = \frac{1}{T_o}\int_{t-T_o/2}^{t+T_o/2} y(\alpha)d\alpha \quad . \tag{11}$$

The covariance and intensity spectrum of Y(t) are (Eqs. (7.2) and (7.3), Ref. 2)

$$K_Y(\tau) = \frac{1}{T_o}\int_{-T_o}^{T_o}\left(1 - \frac{|\alpha|}{T_o}\right)K_y(\tau-\alpha)d\alpha \tag{12}$$

and

$$W_Y(f) = W_y(f)\,\frac{\sin^2 \pi T_o f}{(\pi T_o f)^2} \quad . \tag{13}$$

III. DESCRIPTION OF THE EXPERIMENTAL DATA

The experimental reverberation data were generated by scattering sound from the rough, moving surface of a fresh water lake. The location of the experiment was at the Lake Travis Test Station of Applied Research Laboratories. The transmitter and receiver were located at approximately the same place 8 ft beneath the scatter surface with their acoustic axes parallel and horizontal; i.e., the grazing angle of each acoustic axis was zero. A reverberation ensemble containing 150 returns was generated by transmitting cw pulses at a rate of 1/sec. The center frequency of the pulse was 110 kHz and the pulse duration was 1 msec.

The data were recorded on analog magnetic tape and later converted to digital samples to be used for computer processing. Thus the quadrature components were sampled directly[3] at a rate of 110 kHz. Figure 1 shows computer plots of the envelopes of the first three reverberation returns. These envelope functions are easily obtained by computing the square root of the sum of the squares of the quadrature components.

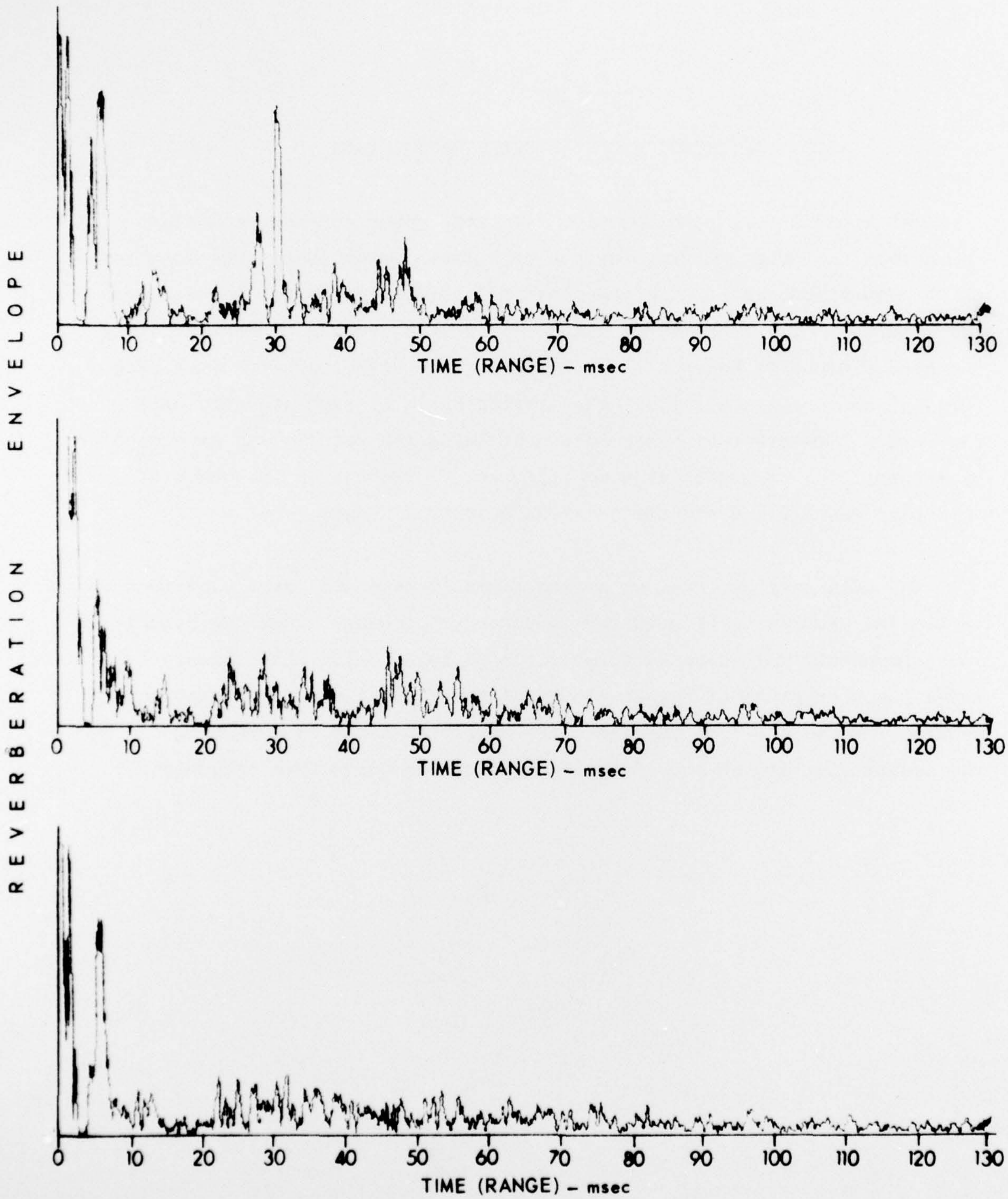

FIGURE 1
THREE SAMPLE ENVELOPE FUNCTIONS OF REVERBERATION
FROM THE SURFACE OF A FRESH WATER LAKE

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IV. THE FLUCTUATING COMPONENT OF THE REVERBERATION ENVELOPE

The fluctuating component is obtained by first computing the ensemble mean of the envelope and then removing, through subtraction, this mean from each envelope function. Thus, we compute

$$\overline{y(t)} = E(t) - \overline{\langle E(t) \rangle} \quad . \qquad (14)$$

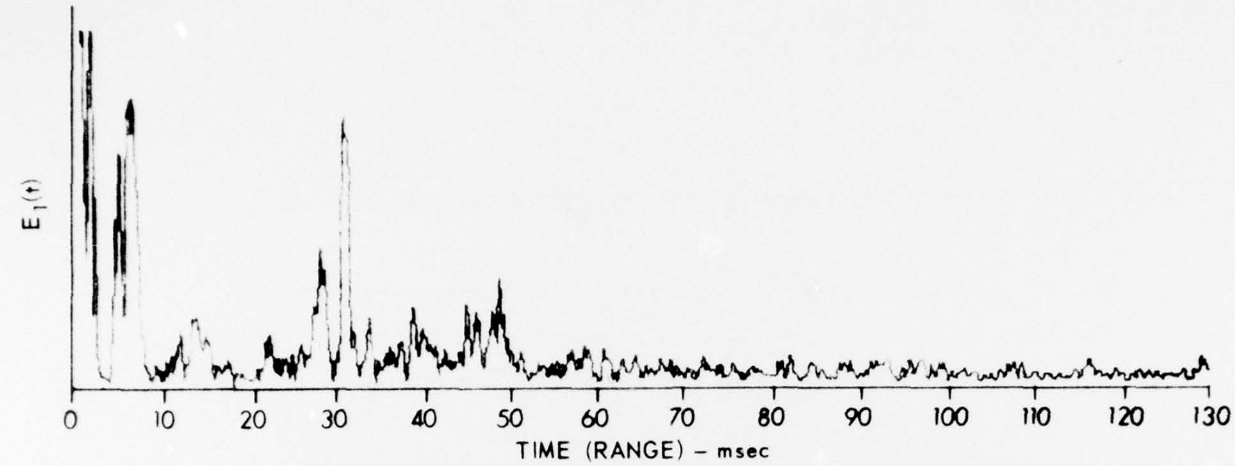
The bar placed over any symbol denotes the experimental estimate of that quantity. This estimate corresponds to Eq. (2). The ensemble mean is estimated according to

$$\overline{\langle E(t) \rangle} = \frac{1}{150} \sum_{i=1}^{150} E_i(t) \quad . \qquad (15)$$

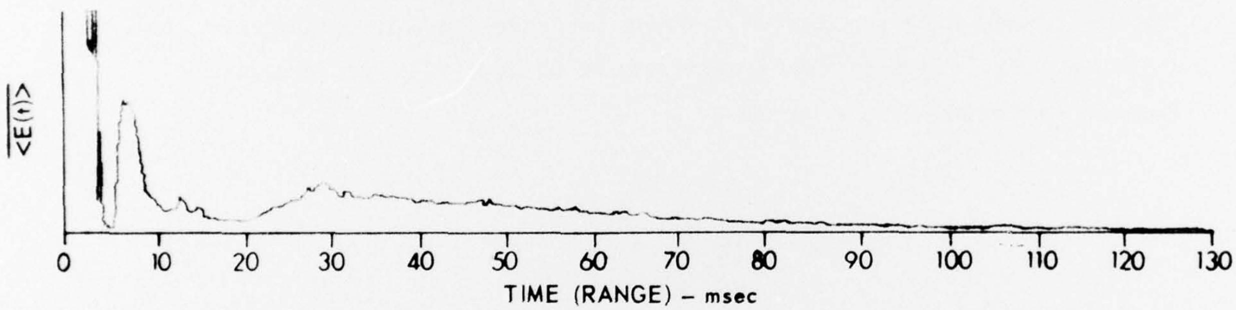
Thus, $\overline{E(t)}$ is the average, at a given time (range) t, of 150 envelope samples.

In Fig. 2(c) the fluctuating component of the first envelope function can be seen. It was obtained by subtracting the envelope mean (average of 150 returns), Fig. 2(b), from the envelope function, Fig. 2(a). It is interesting to note that two types of nonstationarity are observable in this example. First, there is the variation, with respect to range, of the mean of the envelope and, second, there is the variation in the intensity of the fluctuating component.

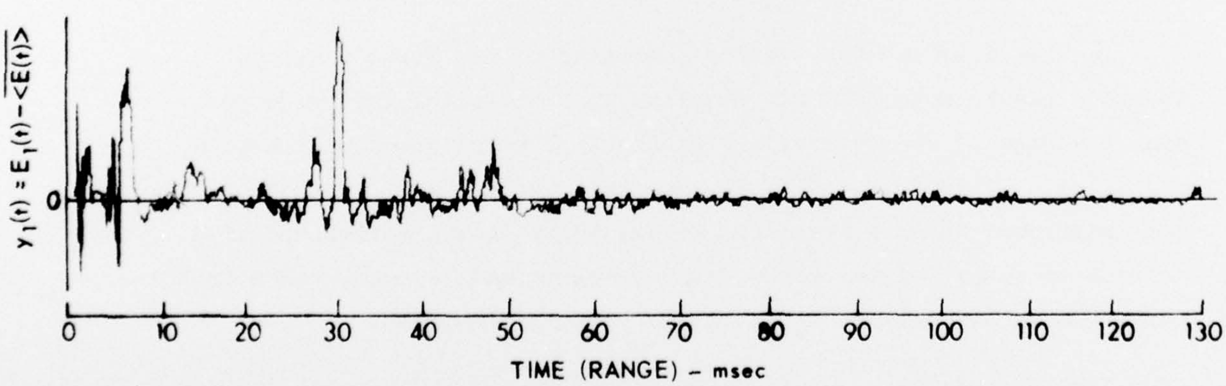
The fluctuating component in Fig. 2(c) represents the first of a 150-member ensemble that contains the second-order statistics of interest.



(a) SAMPLE REVERBERATION ENVELOPE



(b) ENSEMBLE AVERAGE OF 150 REVERBERATION ENVELOPE FUNCTIONS



(c) FLUCTUATING COMPONENT IS THE SAMPLE REVERBERATION ENVELOPE WITH ENSEMBLE AVERAGE REMOVED

FIGURE 2
AN EXAMPLE OF THE FLUCTUATING COMPONENT OF THE REVERBERATION ENVELOPE

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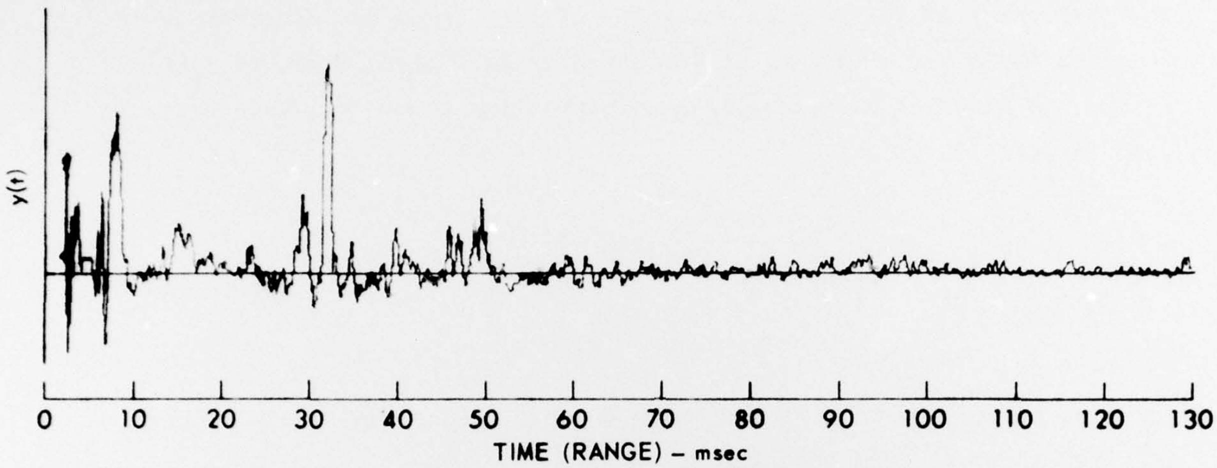
The next phase of the problem consisted of subjecting the fluctuating component to a time average, as indicated by Eq. (11). Thus, if $y_i(t)$ is the ith function representing the fluctuating component, then the time averaged output is

$$Y_i(t) = \frac{1}{T_o} \int_{t-T_o/2}^{t+T_o/2} y_i(\alpha) d\alpha \quad . \tag{16}$$

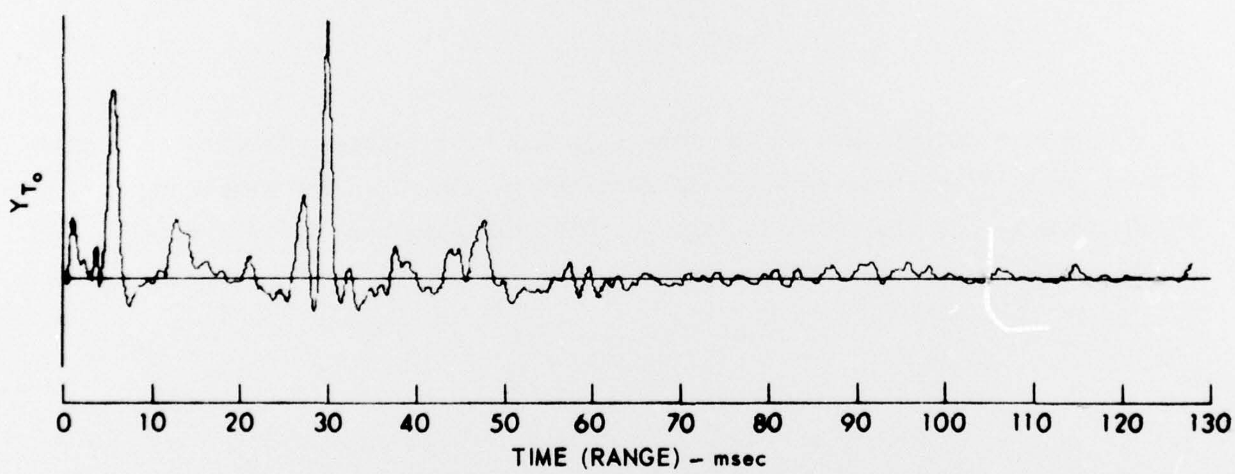
However, since y(t) is represented by digital samples uniformly spaced in time, the output of the time averager is

$$Y_i(n) = \frac{1}{N_o} \sum_{m=n-N_o/2}^{m=n+N_o/2} y_i(m) \quad . \tag{17}$$

The variable n corresponds to the time t in Eq. (16), whereas the number of samples N_o is associated with the integration time T_o. An example of the time average is shown in Fig. 3. The averaging time T_o is 1 msec, which is the transmitted signal length.



(a) FLUCTUATING COMPONENT OF ENVELOPE OF SAMPLE REVERBERATION FUNCTION



(b) TIME AVERAGE OF FLUCTUATING COMPONENT

FIGURE 3
EXAMPLE OF THE TIME AVERAGE OF THE FLUCTUATING COMPONENT OF THE ENVELOPE FUNCTION OF REVERBERATION

$$Y_{T_o}(t) = \frac{1}{T_o}\int_t^{t+T_o} y(\tau)d\tau$$

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V. ESTIMATION OF THE INTENSITY SPECTRUM

The data analyzed in this study are necessarily of finite duration and, therefore, we do not have an infinitely long, stationary random process available for the estimation of the intensity spectrum. Thus, we begin by assuming that a finite sized ensemble of functions representative of the stochastic process (in this case the fluctuating component of the envelope) is available with each function defined over the interval (t_1,t_2). The total time span of our digital data is the interval (0, 130) msec, as Fig. 1 indicates.

The first step in the estimation of the intensity spectrum is the computation of the Fourier transform of each digital record. This gives

$$\mathcal{F}\left\{y_i(t)\right\}_{t_1,t_2} = \int_{t_1}^{t_2} y_i(t)e^{-i\omega t}dt \quad , \quad \omega = 2\pi f \quad , \qquad (18)$$

where the index i varies from 1 to 150, and (t_1,t_2) is the interval chosen for the analysis. Although Eq. (18) represents the transform of a continuous function, the computation is performed with digital samples resulting in a discrete Fourier transform. The computation tool is the Fast Fourier Transform.[5]

The estimate of the intensity spectrum is an ensemble average,

$$W_y(f) = \frac{1}{150}\sum_{i=1}^{150}\frac{1}{(t_2-t_1)}\left|\mathcal{F}\left\{y_i(t)\right\}_{t_1,t_2}\right|^2 \quad , \qquad (19)$$

where (t_1,t_2) = (39, 65) msec (see Fig. 1).

The spectral estimates of both the fluctuating component and its time average (Eq. (11)) are shown in Fig. 4. The estimates, which are compared to the appropriate theoretical expressions (Eq. (7) and Eq. (11)), are plotted in decibels as a function of frequency over the interval (0.0, 2.0) kHz. To allow a comparison of the shapes of these curves, the maximum values of the experimental estimates were normalized. Over the interval (0.2, 2.0) kHz the experimental spectra agree quite well with the theoretically predicted values. Disagreement, however, is noticeable in the interval (0.0, 0.2) kHz. Here the experimental spectra are approximately 2 or 3 dB greater than predicted. The reason for this lack of symmetry is not presently known, but other data, generated independently of the data analyzed here, will be studied in a similar manner to determine if this disagreement still exists at the lower frequencies.

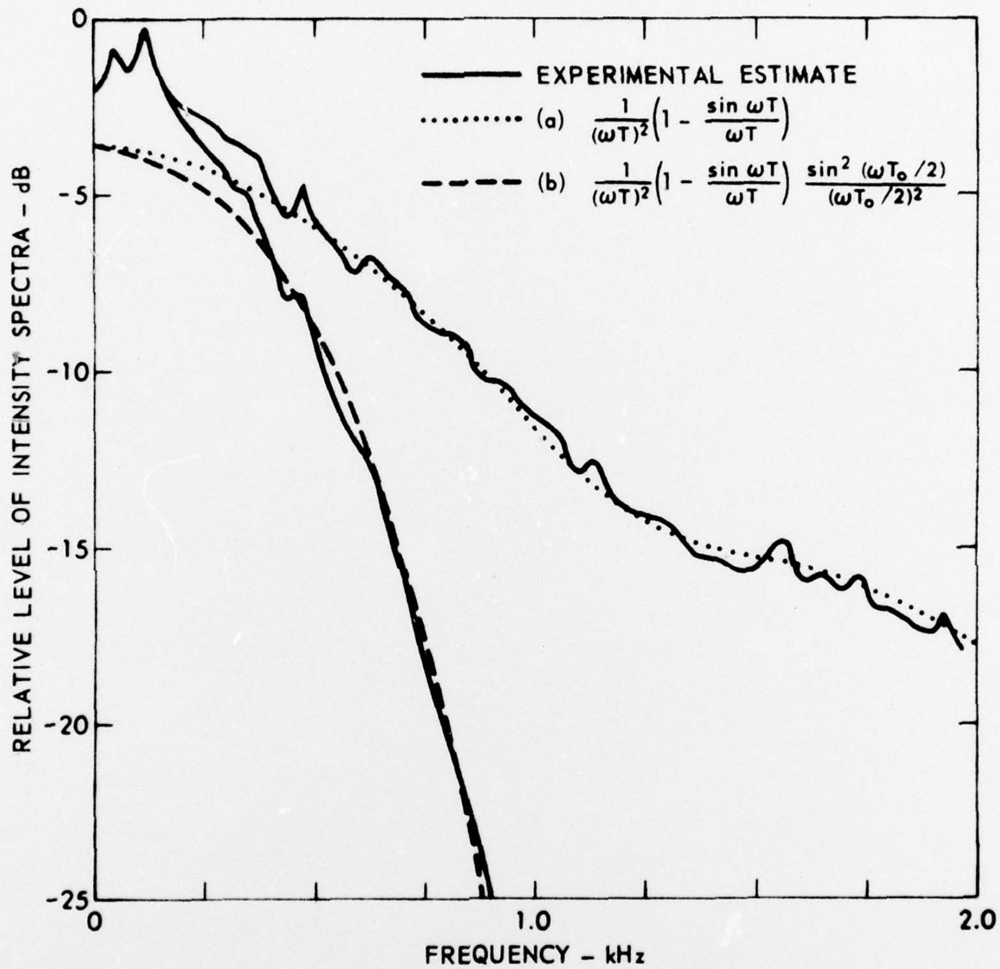

FIGURE 4
INTENSITY SPECTRA OF FLUCTUATING COMPONENT OF REVERBERATION ENVELOPE (a).
TIME AVERAGE ("SMOOTHED") OF FLUCTUATING COMPONENT OF REVERBERATION ENVELOPE (b).

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VI. RESEARCH PLANNED FOR THE NEXT QUARTER

Other statistical properties of the reverberation envelope will be investigated. For example, an important assumption in the theoretical development is made in Eq. (3), which relates the covariance of the narrowband reverberation to the covariance of the envelope. This assumption will be tested with the experimental data, and the results will likely appear in the next progress report.

Additional reverberation data have been generated at Lake Travis and recorded on magnetic tape. These new data, which contain FM in addition to cw reverberation, will be digitized and analyzed to determine their covariance and spectral structure. Hopefully the first results of the effects of time averaging deterministic signals corrupted by the additive reverberation will be reported.

REFERENCES

1. Quarterly Progress Report No. 7 under Contract N00024-70-C-1184, 5 July - 5 October 1971, Applied Research Laboratories, The University of Texas at Austin.

2. Quarterly Progress Report No. 8 under Contract N00024-70-C-1184, 5 October 1971 - 5 January 1972, Applied Research Laboratories, The University of Texas at Austin.

3. O. D. Grace and S. P. Pitt, "Sampling and Interpolation of Bandlimited Signals by Quadrature Methods," J. Acoust. Soc. Amer. 48, 1311-1318 (December 1970).

4. T. D. Plemons, "Spectra, Covariance Functions, and Associated Statistics of Underwater Acoustic Scattering from Lake Surfaces," Applied Research Laboratories Technical Report No. 71-17 (ARL-TR-71-17), Applied Research Laboratories, The University of Texas at Austin (June 1971). (Also doctoral dissertation presented to Department of Physics, The University of Texas at Austin).

5. J. K. Beard, "Interval Reordering and Multivariate Indexing with the Fast Fourier Transform," Applied Research Laboratories Technical Report No. 71-24 (ARL-TR-71-24), Applied Research Laboratories, The University of Texas at Austin (June 1971).

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