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BEARING DETECTION IN THE PRESENCE
OF TWO SOURCES OF VARYING COHERENCE
USING THE COMPLEX CEPSTRUM

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1. SUMMARY

The effect of the presence of two acoustic sources (one, the primary, whose location is to be detected) of varying coherence on a cepstral bearing finding procedure is experimentally studied. The coherence between the acoustic sources was altered by adding random noise of various SNR (signal-to-noise ratio) to the input signal of the primary source; the same base signal being fed to both sources. The results demonstrate that, when block liftering is used, the primary source bearing is reliably estimated for coherences as low as $\gamma^2 \gtrsim 0.5$. The results also imply that background noise (unreflected) of SNR $\gtrsim$ 10 dB will not markedly affect the accuracy of the bearing estimation algorithmn.

2. INTRODUCTION

In a previous study the application of cepstral processing techniques to the determination of acoustic source bearings in the presence of a reflective surface was studied.[1] The results showed that, for a single source positioned near a reflective surface, cepstral processing could successfully correct errors in the bearing estimations due to the echo from the reflective surface. A new block liftering procedure was also developed which, by using coherence testing between the elements of the microphone array, allowed automation of the echo removal procedure.

In practice, however, bearing estimation can occur when there is more than one acoustic source present or reflections occur from many nearby surfaces. A natural progression of the single source, single echo test is to examine the use of cepstral processing techniques when there are two acoustic sources of varying coherence in an echo-free environment.

The purpose of this report is to present the results of a preliminary experimental investigation which was designed to assess the ability of the system described in reference 1 to locate a primary acoustic source in the presence of a second source of varying relative coherence. The same input signal was fed to each source. The coherence between the sound emitted from the sources was varied by adding degrees of random noise to the signal input of one source.

3. EXPERIMENTAL SETUP

The experiment was performed in a 2.3 × 2.6 × 4-m anechoic chamber located at Virginia Tech. Two acoustic sources (primary and secondary) were positioned at different locations in the chamber as shown in figures 1(a) and 1(b). Here primary denotes the source whose bearing is required to be measured. A two-microphone array was positioned in one corner of a chamber in order to determine the primary source bearing in the plane of the source/receiver. Additional microphones were located very close to the outlet of each source (i.e., in the near field) in order to estimate the coherence between the signals radiating from each source. The acoustic sources used were 55-watt University drivers. The array microphones were B & K 1/2-inch microphones, while the "near-field" microphones were Radio Shack 1/2-inch microphones.

3.1 Signal Generation System

The input signals to each source were generated using the system shown in figure 2. The purpose of the signal generation system was to supply the primary and secondary sources with signals of varying coherence. The approach was to use one signal generator as a base input for one source and then mix band-limited white noise with this signal for use as the additional source signal. In this way different source coherence levels could be achieved by mixing more or less noise into the base signal. Ideally, when no noise is mixed into the base signal, the secondary source represents an echo of the primary source. Conversely, as more noise is mixed into the base signal, the sources progressively begin to become of a different nature.

The signal generation system was based around three signal generators: a trigger source which simultaneously activated the signal generation and data acquisition system; a Wavetek arbitrary waveform generator which functioned as the base signal generator for the primary and secondary sources; and a B & K random noise generator which was used to modify the signal from the arbitrary waveform generator. Thus, the modified signal was directed to the primary source while the unmodified signal was directed to the secondary. Random noise was added to the primary signal instead of the secondary source to ensure that the rms level of the primary source was always larger than the rms level of the secondary source (a requirement of the cepstral routine used in the investigation).[2]

The base signal was composed of a swept sine burst which originally was digitally generated on a main-frame IBM computer. The digital representation was down-loaded into the memory of the arbitrary waveform generator which could be subsequently triggered to convert the digital waveform into an analog signal. This process is described in greater detail in reference 2. The test signal had a duration of 30 msec and swept through a frequency range of 0 to 5 kHz. An example of this signal is shown in figure 3. The burst swept sine was then amplified and used directly as the input signal to the secondary source.

The primary source signal was created by mixing the base signal with band-limited random noise, generated by band-pass filtering the output of a white noise generator. The frequency range of the band-pass filter was set from 10 Hz to 5 kHz. The mixing process was done using a Sure sound mixer with variable inputs. The amount of noise mixed with base signal was monitored using an rms voltmeter.

3.2 Data Acquisition System

The data acquisition system is shown in figure 4. Two data flow paths are given: one for the microphone array measurements which were used to calculate the source bearing, and a second for the source near-field measurements which were used to monitor the coherence between the sources.

The two signals from the microphone array were preconditioned using microphone preamplifiers and high-pass filters. The high-pass filters were used to eliminate low-frequency transmission noise into the anechoic chamber. Once the array signals were preconditioned, digital sampling and further preprocessing were performed by a Dual-channel Zonic signal analyzer. The analyzer was set up to simultaneously acquire a single set of 1024-point time records from the array microphone signals. The analyzer's data sampling rate was set to 10 kHz, and a 3 kHz low-pass filter was used to reject alias signals.

Triggering of the analyzer was remotely controlled by the main trigger signal which was also used to start the swept sine burst. The analyzer sampling was pre-triggered to ensure that a full time history of the microphone signal was located between 10 and 50 percent of the time record. The second 50 percent of the time record was artificially set to zero. This procedure, called "zero padding," was used to minimize cepstrum aliasing in the later data reduction.[3] When the data acquisition system had finished sampling the required number of data sets, the time records were up-loaded and stored, via a modem, to a mainframe IBM computer where the cepstral processing and bearing calculations were performed.

The signals from the microphones in the near-fields were sampled using a second Zonic signal analyzer. High pass and anti-aliasing filters were used as previously. This analyzer was triggered using the same trigger signal as the array microphone data acquisition system. Frequency domain processing was used to calculate the average coherence between the signals emitted by each source. At the completion of the averaging process, the coherence estimate was displayed and recorded on a hard-copy device.

4. EXPERIMENTAL PROCEDURE

The test procedure started by setting up the primary and secondary source geometries. The two arrangements used are shown in figures 1(a) and 1(b).

Before data acquisition commenced, the source signal amplitudes had to be set. The objective of presetting the source signals was to achieve a particular coherence between the sources. Three average coherence levels were studied: 1.0, 0.9 and 0.5. These also corresponded to signal-to-noise ratios (SNR) for the primary source of ∞, 20 and 10 dB. These coherence levels were achieved through a trial and error method of mixing random noise with the base signal and measuring the coherence between the near-field microphone signals.

Similarly, the rms value of the primary source signal was maintained to be just above the secondary source rms value as seen by the near-field microphones. This adjustment maximizes the height of the delta functions in the cepstrums of the microphone signals.

The acquisition of the data was controlled using a separate trigger source, as previously described. The rate of the trigger source was set so that only one full transient time history was acquired per time record. The time records were then subsequently transferred and stored on the mainframe computer via a modem link.

This data acquisition procedure was repeated for each of the three coherence levels. Three paired sets of time histories were recorded for each coherence level as required by the bearing calculation algorithm.

5. DATA ANALYSIS

The purpose of the data analysis phase of this work was to extract the bearing information of the primary source from the combined primary plus secondary source time histories. The process to perform the wavelet deconvolution and bearing calculation is detailed in reference 2. A flow chart of the algorithm used to extract the primary signal and perform the bearing calculation is shown in figure 5. As can be seen in the figure, the two microphone signals of the array are initially acquired. The next step of the procedure is to calculate the complex cepstrum of each microphone signal. The cepstrum is then block liftered, as described in reference 2. Liftering is traditionally used to remove echo information from the direct signal. In this investigation a similar block liftering technique is used in an attempt to eliminate the contribution of the second source. For a reflecting surface, the echo is coherent with the direct signal and for a signal with a reasonable bandwith (as here) the echo signal information is compressed into delta functions or rahmonics which appear at periodic times in the cepstrum. These can then be removed by liftering. The success of the liftering procedure for this experiment is thus likely to be dependent upon the coherence levels between the primary and secondary sources.

Once liftering has been performed, the cepstrum process is reversed and the time history of the primary source is recovered. The next step is to calculate the cross spectrum of the signals between each element of the detection array. The bearing of the primary source can then be calculated from the cross-spectrum phase, as explained in reference 2. Bearing angles for each frequency bin were calculated. The coherence between the recovered signals between each element of the array was also estimated. The coherence was used as a criterion to reject possible faulty primary source bearings due to the block liftering procedure. All bearing angles whose corresponding coherence at the same bin point were less than 0.98 were rejected. Frequencies above which spatial aliasing occurred and below which phase errors were significant were also rejected. Finally, the overall bearing angle was computed from the average of the individual bin angles.

6. RESULTS

6.1 Configuration 1

The following results are for the configuration shown in figure 1(a). For the first test no random noise was mixed with the base signal. The corresponding coherence between the near-field microphone signals is given in figure 6 and can be seen to be close to unity up to approximately 3.5 kHz where the anti-aliasing filters take effect. The very low frequency dropouts were due to the high-pass filters used to remove background noise.

Figure 7 gives the time histories of the signals acquired at both microphones of the bearing array. The secondary source signal amplitude, acquired at the array microphones, was separately measured to be approximately two-fifths of the primary source signal. This characteristic is due to spherical spreading, the path difference between the secondary and primary sources being 2.26 m. Figure 7 also shows the swept-sine nature of the signal. However, the speaker output is not as flat as the test signal, due to the response of the speaker varying with frequency.

Figures 8 and 9 present the complex cepstrum and power cepstrum, respectively, of one channel of the microphone array. In the complex cepstrum the first and last five points are not plotted in order to expand the vertical range of the results. A definite peak (or rahmonic) can be seen close to 6.6 msec in both figures corresponding to the 2.26 m path difference between the sources.

The complex cepstrum of figure 8 was block liftered from points 60 to 992 by zeroing, as described in reference 2, and the cepstrum reversed to recover the primary time history. This was done for the three individual sets of data on each channel. Coherence between the frequency domain averaged signals of both channels was then calculated and is shown in figure 10. The coherence is close to unity but has oscillations due to signal noise ratio problems at frequencies where destructive interference occurs between the primary and secondary sources at the array microphone locations.

The average bearing for the primary source was then calculated as 100.8 degrees compared to the actual source bearing of 96 degrees.

For the next test, random noise was mixed with the base signal and fed to the primary source as described previously. The magnitude of the noise was adjusted until a coherence (averaged across the frequency range of 0 to 3.5 kHz) of close to 0.9 was obtained between the source near fields, as shown in figure 11. The signals acquired at the microphones are plotted in figure 12 where the presence of the noise can clearly be seen. The complex and power cepstrums of channel 1 are given in figures 13 and 14, respectively. Although the effect of the secondary source is not apparent in the complex cepstrum (compare fig. 13 with fig. 8), it can be clearly seen in the power cepstrum. On liftering, and then applying the inverse cepstrum, the average source bearing was estimated to be 97.5 degrees, as opposed to the true bearing of 96 degrees.

For the next test the added noise was increased until an (averaged) coherence between the two sources of 0.5 was obtained. Again the complex cepstrum did not reveal the effect of additional source by presence of delta functions, etc., while the power cepstrum did. On liftering and implementation of the bearing finding algorithm the source bearing was estimated to be 97.2 degrees.

The results for the tests using configuration 1 are summarized in table 1. Also shown is the signal-to-noise ratio (SNR) for the added random noise to the input signal of the primary source. It is not clear why improved bearing estimation occurred as the signal-to-noise ratio decreased.

6.2 Configuration 2

The following results are for the configuration shown in figure 1(b). As for the previous configuration, three tests for three average coherences of 1.0, 0.9 and 0.5 were performed. The results of all the tests are summarized in table 2. Only the results for a coherence of 0.5 will be expanded upon for conciseness.

Figure 15 gives the coherence between the near fields of the primary and secondary sources. Averaged from 0 to 3.5 kHz, the coherence can be seen to be close to 0.5. Figure 16 presents the time histories of the signals acquired at the microphones. The secondary source signal amplitude at the microphone bearing array was measured to be approximately three-fifths of the primary source amplitude. This increase in relative amplitude of the secondary source is due to the reduced path difference of configuration 2, leading to a smaller relative change in amplitude due to the spherical spreading effect. The random noise can also be seen to be significantly larger than in the previous figures, giving rise to the lower source coherence and SNR.

Figures 17 and 18 give the corresponding complex and power ceptrums of channel 1. A marked peak (rahmonic) can be seen in the power ceptrum at close to 5.2 msec corresponding to the path difference of 1.78 m for configuration 2. The complex cepstrum was liftered from points 50 to 990 and the process reversed. On recovery of the time history of the primary signal, the bearing angle code gave a source angle of 96.5 degrees to be compared with the actual source bearing of 97 degrees. The coherence of the recovered signals at the microphones is plotted in figure 19. It is apparent that the range of frequencies that satisfy the criterion of $\gamma^2 \gtrsim 0.98$ is significantly reduced when compared to the results of figure 10. Thus, it can be seen that the process appears to work well for signals from two acoustic sources of low coherence ($\gamma^2 \gtrsim 0.5$) due to the use of the coherence test in rejecting bearing angle information from the recovered signals at the microphones.

Similarly, it can be shown that the energy due to the swept sine burst and its echo will be compressed near a quefrency of zero and at the location of the rahmonics due to the wide bandwidth of the test signal. The added noise however, being uncorrelated, is distributed over the whole cepstral domain, as can be seen in the cepstrum plots of figures 13 and 17. Thus, block liftering will remove most of the uncorrelated signal as well as the secondary source signal and leave behind most of the primary source information. Thus, the method described here (i.e., using block liftering) is very successful for a secondary source signal which has a large amplitude of noise added relative to the base signal and thus a low relative coherence.

7. CONCLUSIONS

The use of cepstral processing in determining the bearing angle of an acoustic source in the presence of a secondary acoustic source of varying coherence has been experimentally studied. The results demonstrate that for a test signal of wide bandwidth, the method satisfactorily estimates the source bearing for coherences of greater than 0.5. The success of the method for signals of relatively low coherence has been shown to be due to the nature of block liftering procedure and coherence rejection testing used in the bearing finding algorithm.

8. ACKNOWLEDGEMENT

The authors are grateful to S. Tavakkoli for help with data processing using the bearing finding algorithm.

9. REFERENCES

1. Fuller, C. R.; Tavakkoli, S.; Elliott, K. B.; Hurst, C. J.; and O'Brien, W. F.: Application of the Complex Cepstrum to the Location of Acoustic Sources Near Reflective Surfaces. AIAA Paper 87-0014, 1987.
2. Tavakkoli, S.: Application of the Cepstrum Technique to Location of Acoustic Sources in the Presence of Reflective Surfaces. M.S. Thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA, 1986.
3. Bolton, J. S.; and Gold, E.: The Application of Cepstral Techniques to the Measurement of Transfer Functions and Acoustical Reflection Coefficients. Journal of Sound and Vibration, Vol. 93(2), pp. 217-233, 1984.

TABLE 1.- GEOMETRY ONE--ACTUAL PRIMARY SOURCE BEARING, 96 DEGREES

Primary Source SNR (dB)	Source Coherence	Block Liftering	Coherence Rejection	Estimated Bearing Angle
∞	1.0	60-992	0.98	100.8
20	0.9	60-992	0.98	97.45
10	0.5	60-992	0.98	97.18

TABLE 2.- GEOMETRY TWO--ACTUAL PRIMARY SOURCE BEARING, 97 DEGREES

Primary Source SNR (dB)	Source Coherence	Block Liftering	Coherence Rejection	Estimated Bearing Angle
∞	1.0	50-990	0.98	114.2
20	0.9	50-990	0.98	96.71
10	0.5	50-990	0.98	96.50

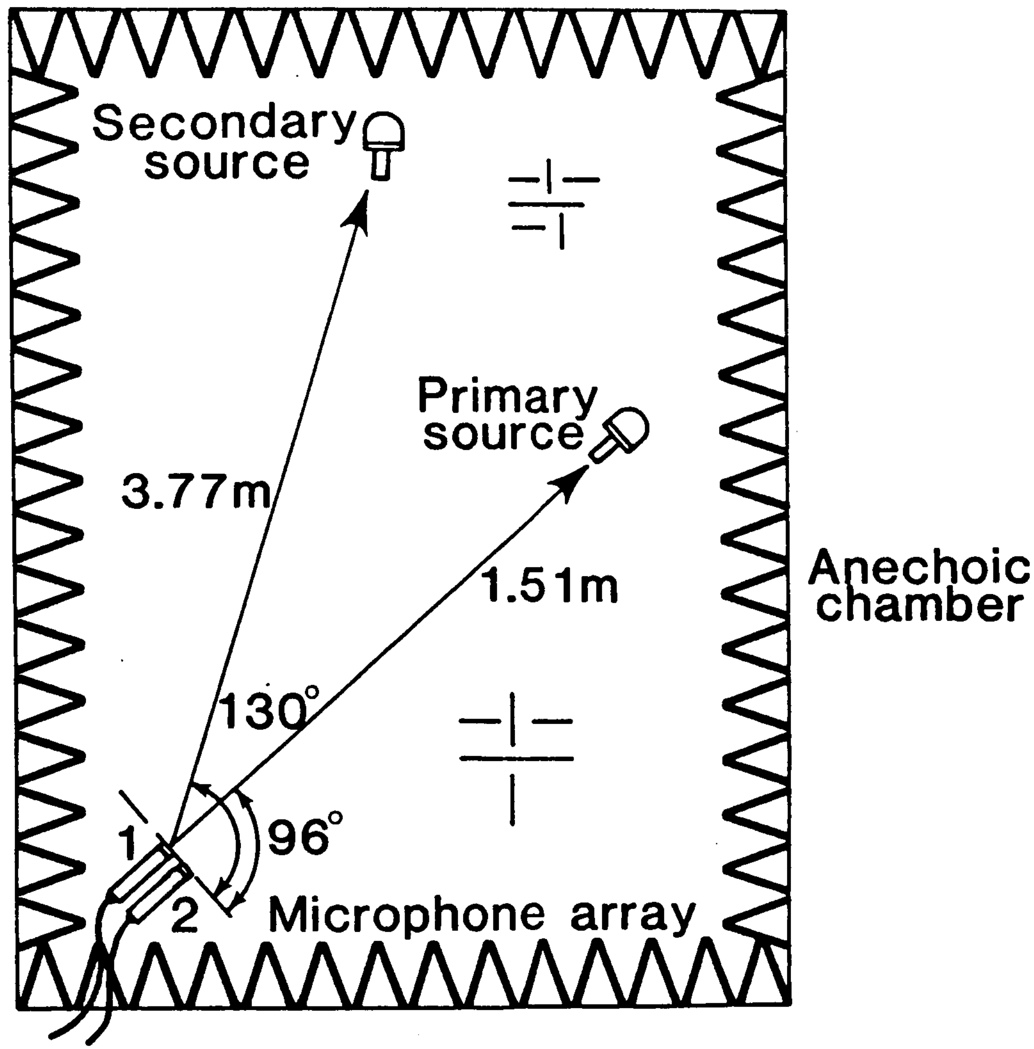

Figure 1(a).- Geometry of configuration 1.

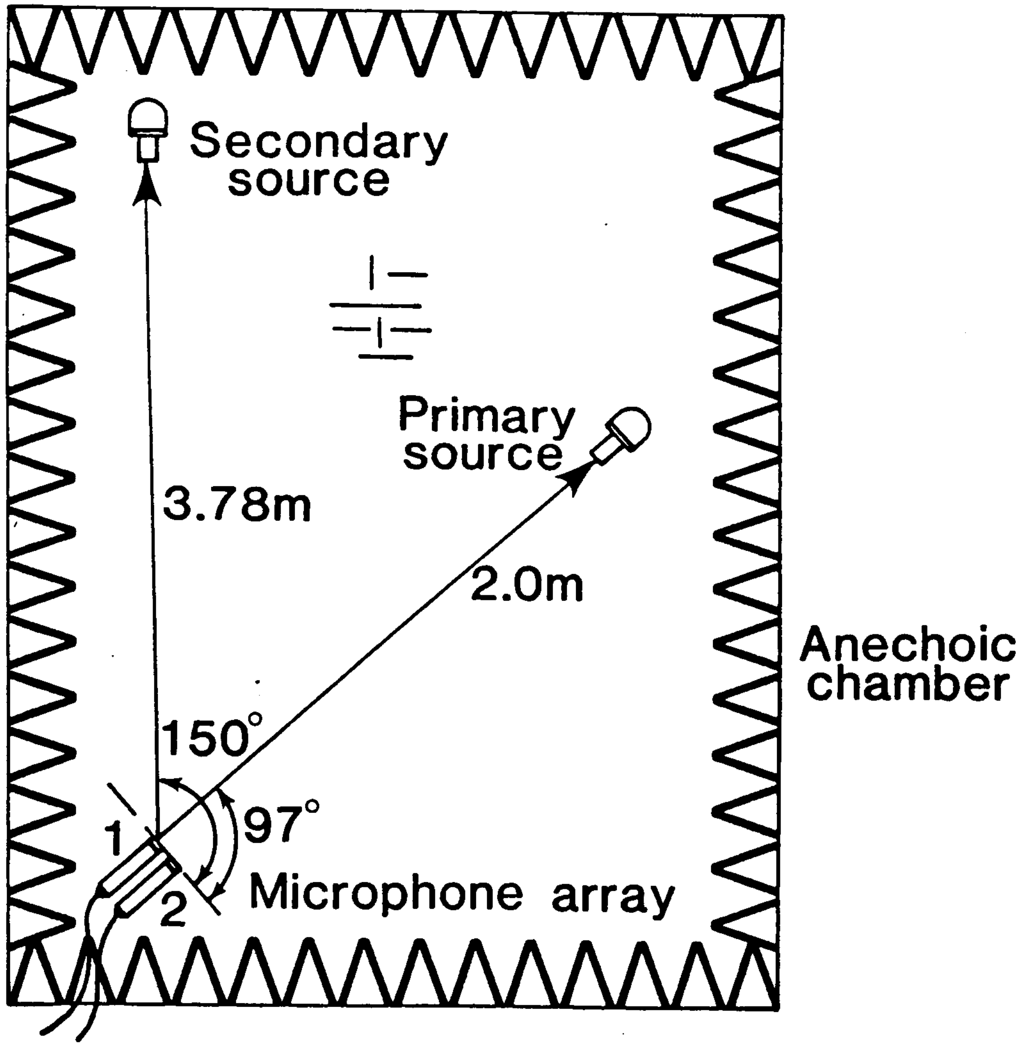

Figure 1(b).- Geometry of configuration 2.

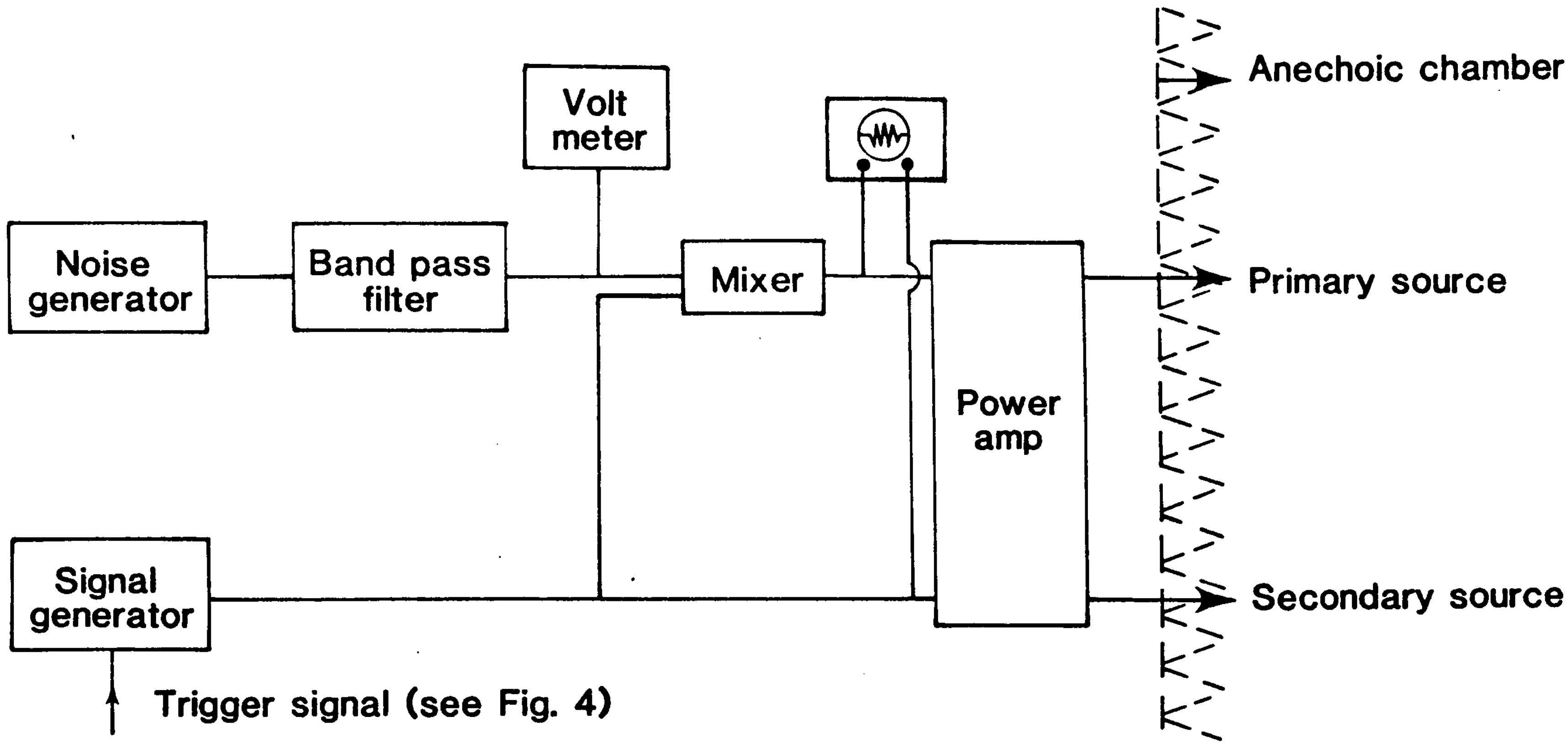

Figure 2.- Input signal generation equipment.

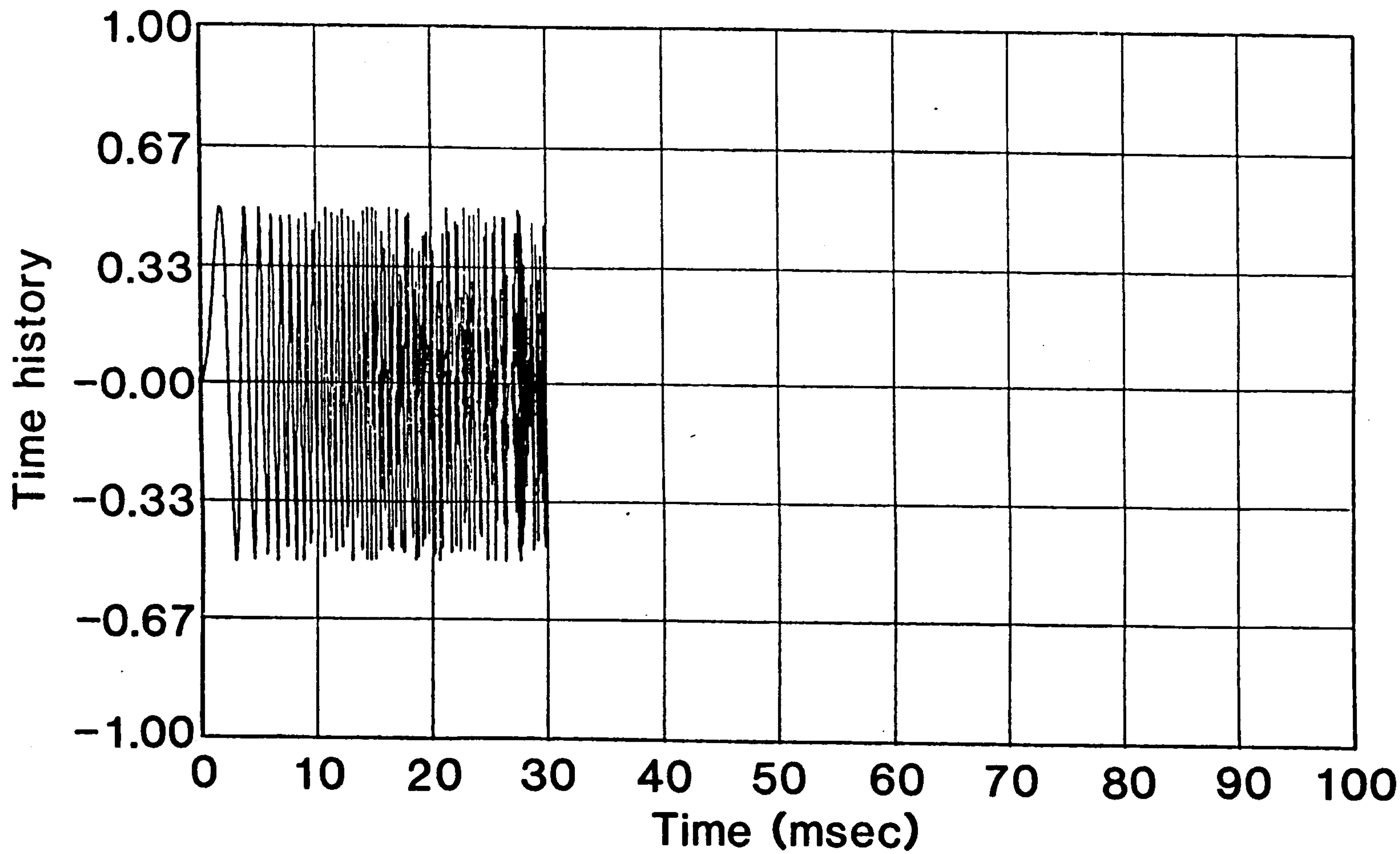

Figure 3.- Test signal time history.

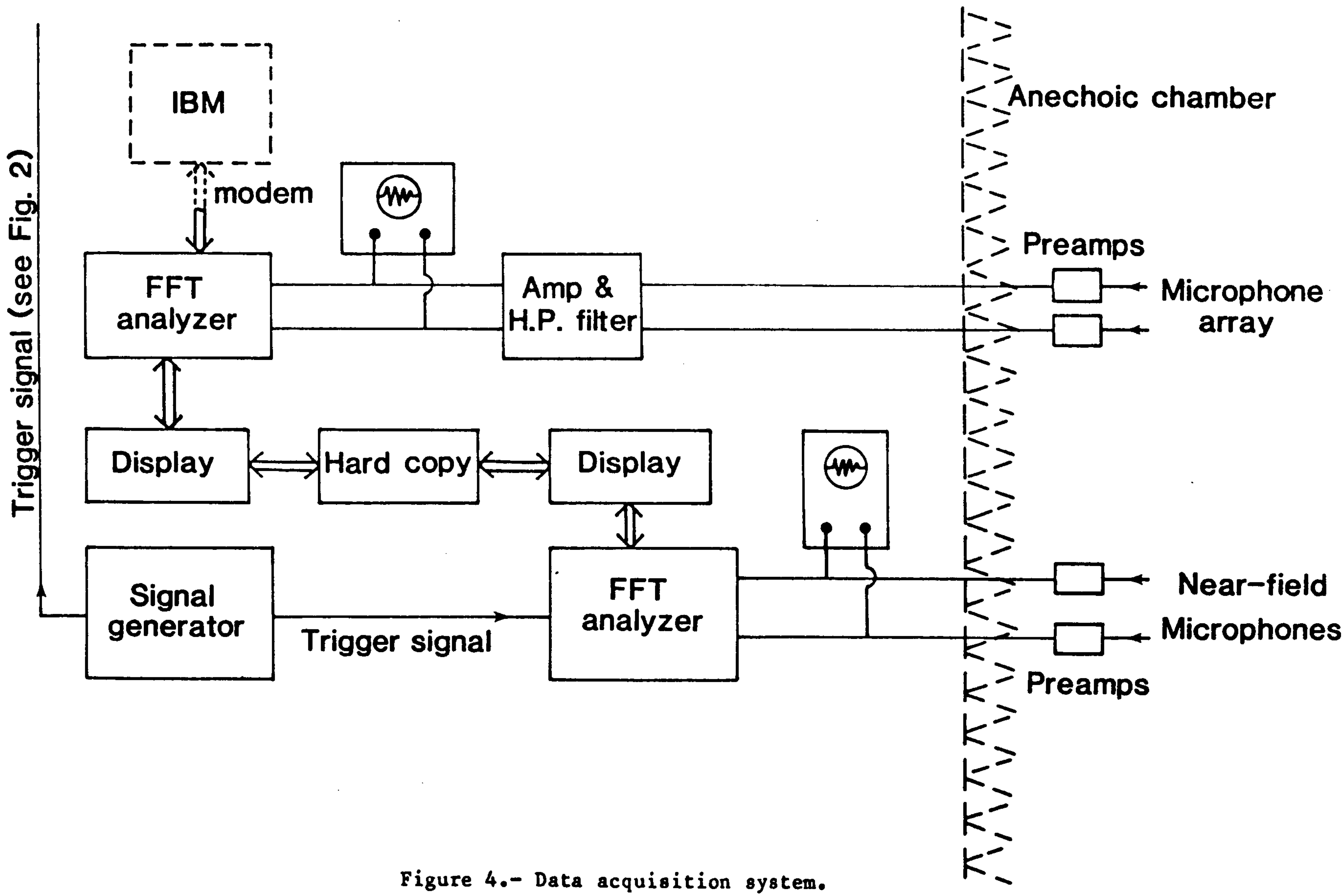

Figure 4.- Data acquisition system.

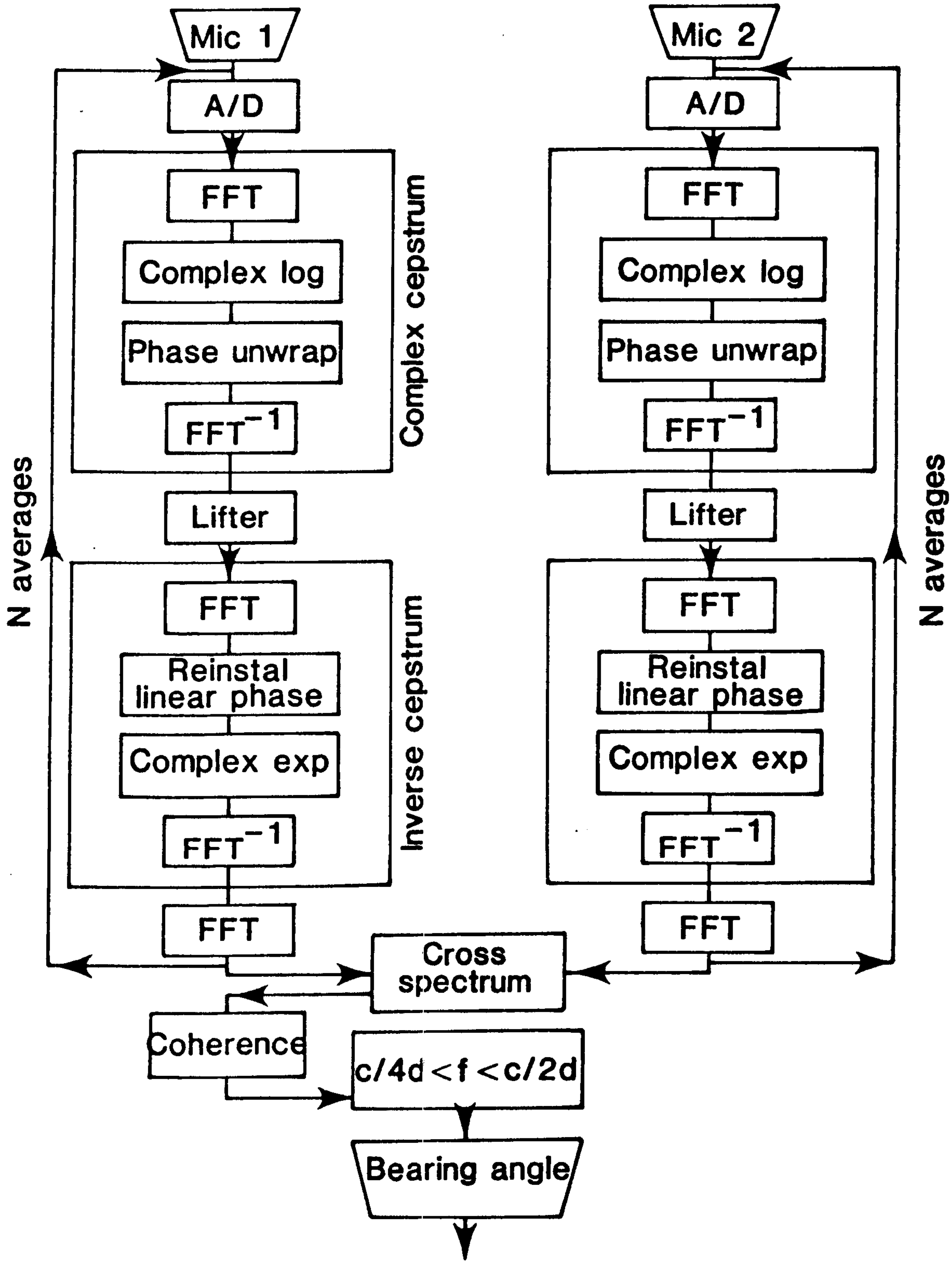

Figure 5.- Flow diagram for bearing calculation procedure.

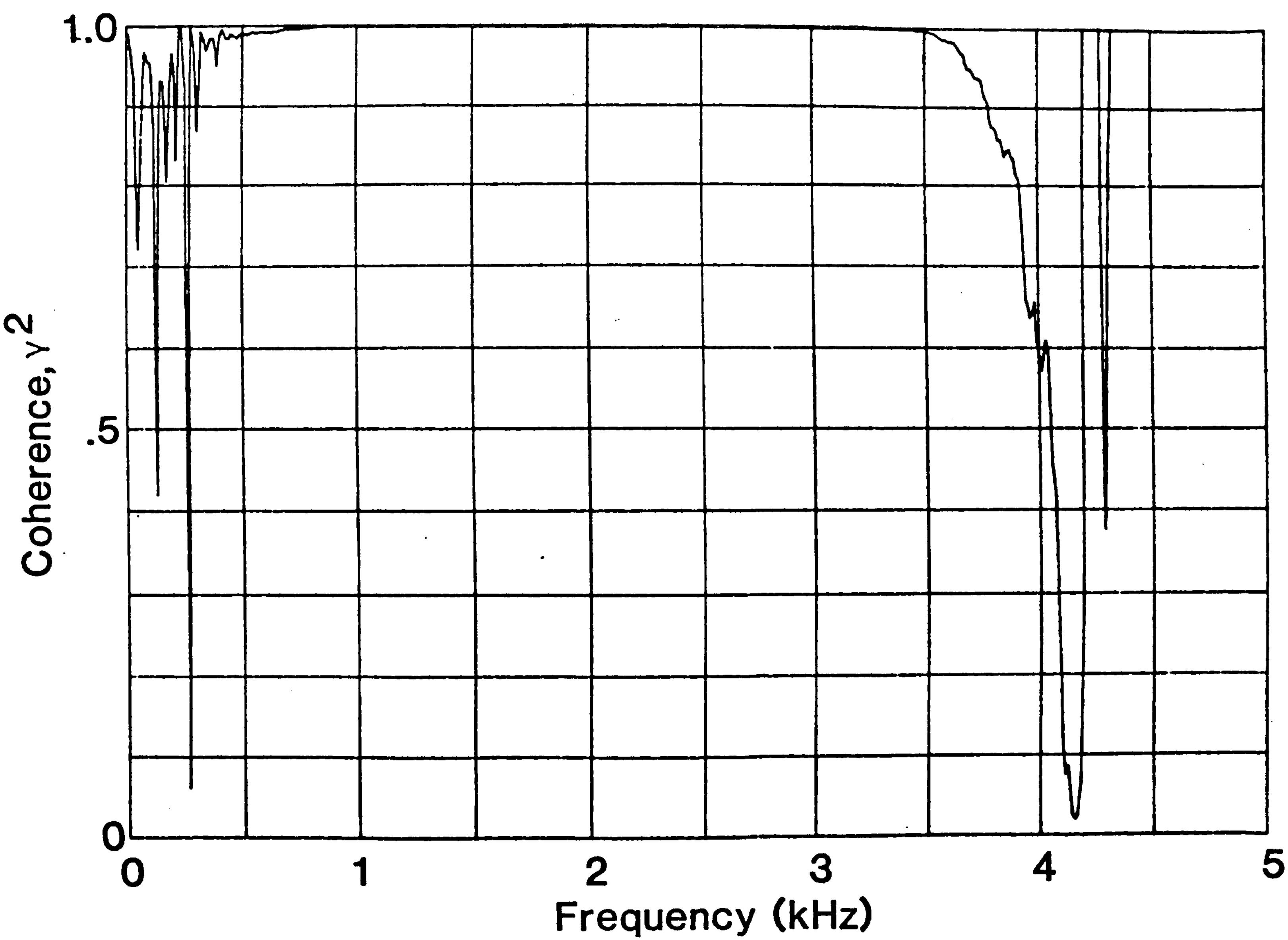

Figure 6.- Coherence between near-field microphones, configuration 1, no added random noise.

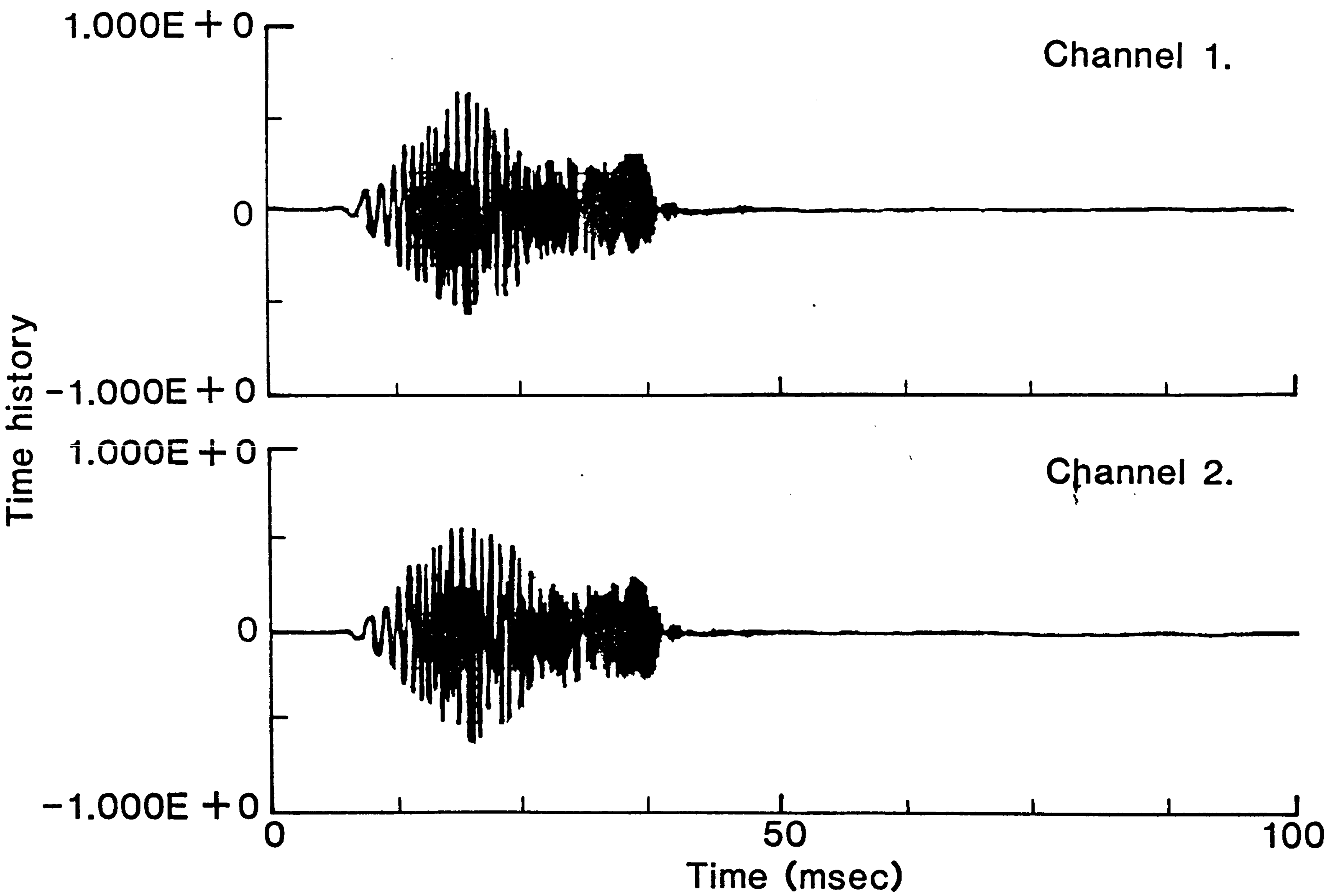

Figure 7.- Time histories of signals acquired at array microphones, configuration 1, no added random noise.

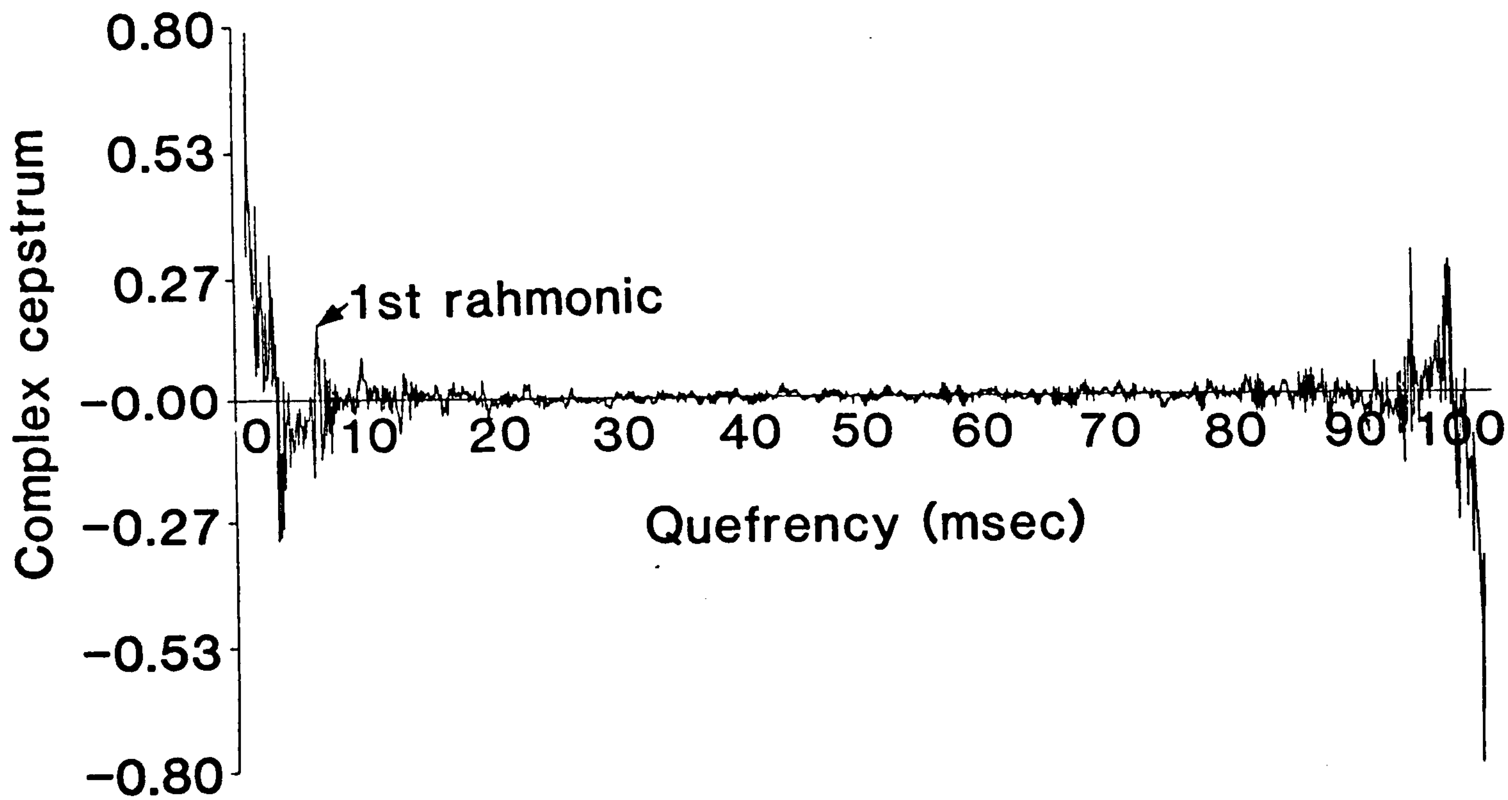

Figure 8.- Complex cepstrum, configuration 1, no added random noise.

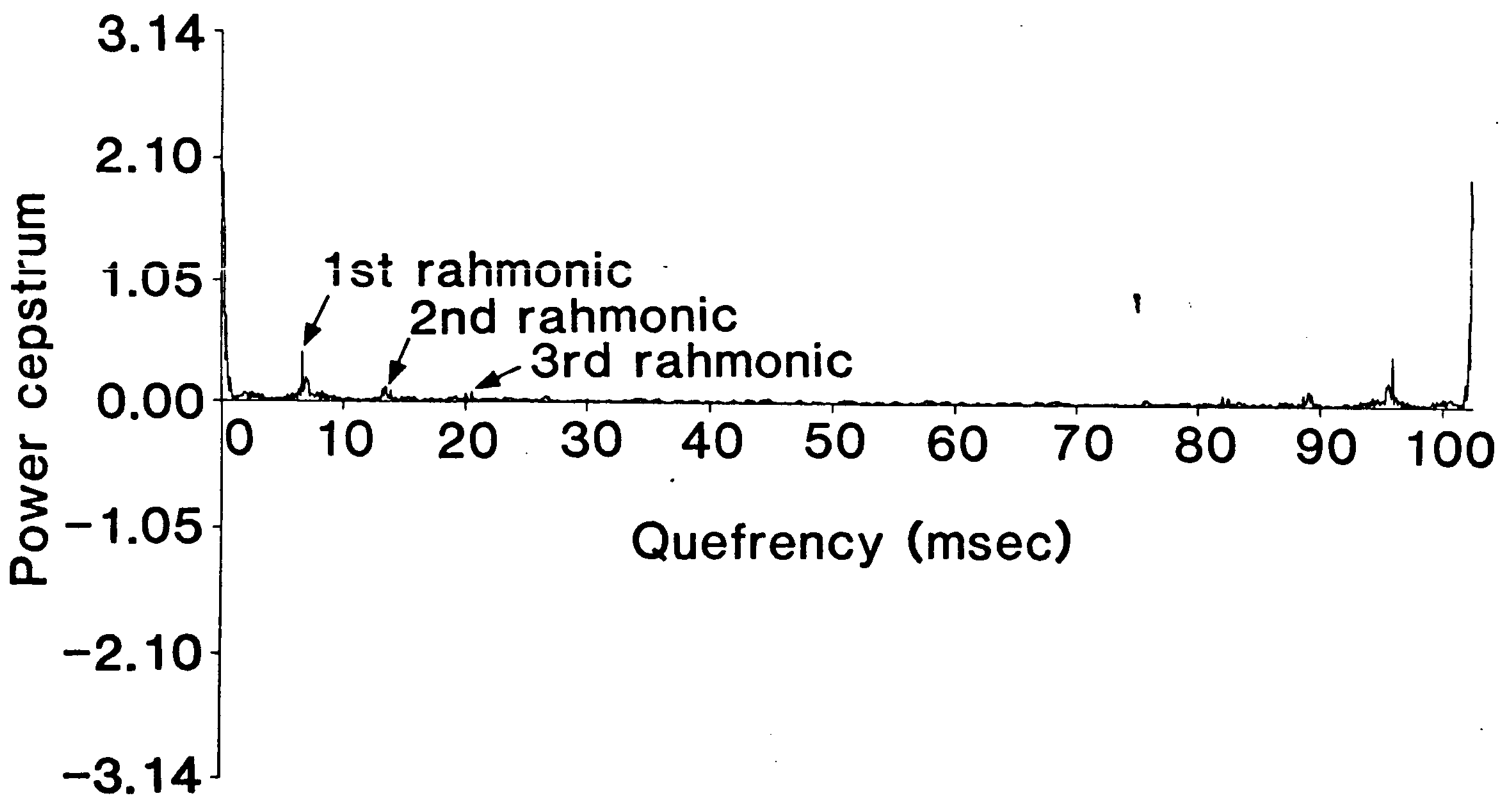

Figure 9.- Power cepstrum, configuration 1, no added random noise.

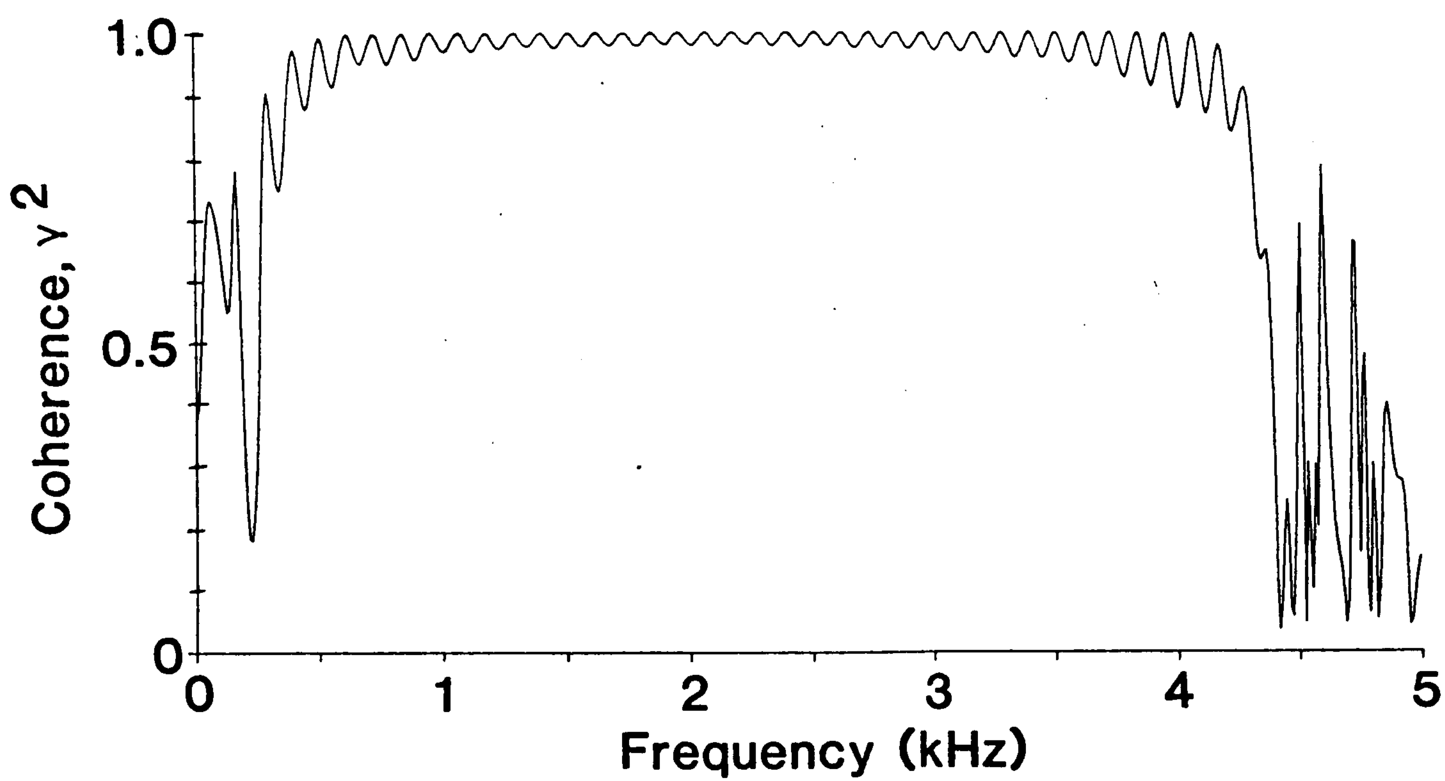

Figure 10.- Coherence between recovered array signals, configuration 1.

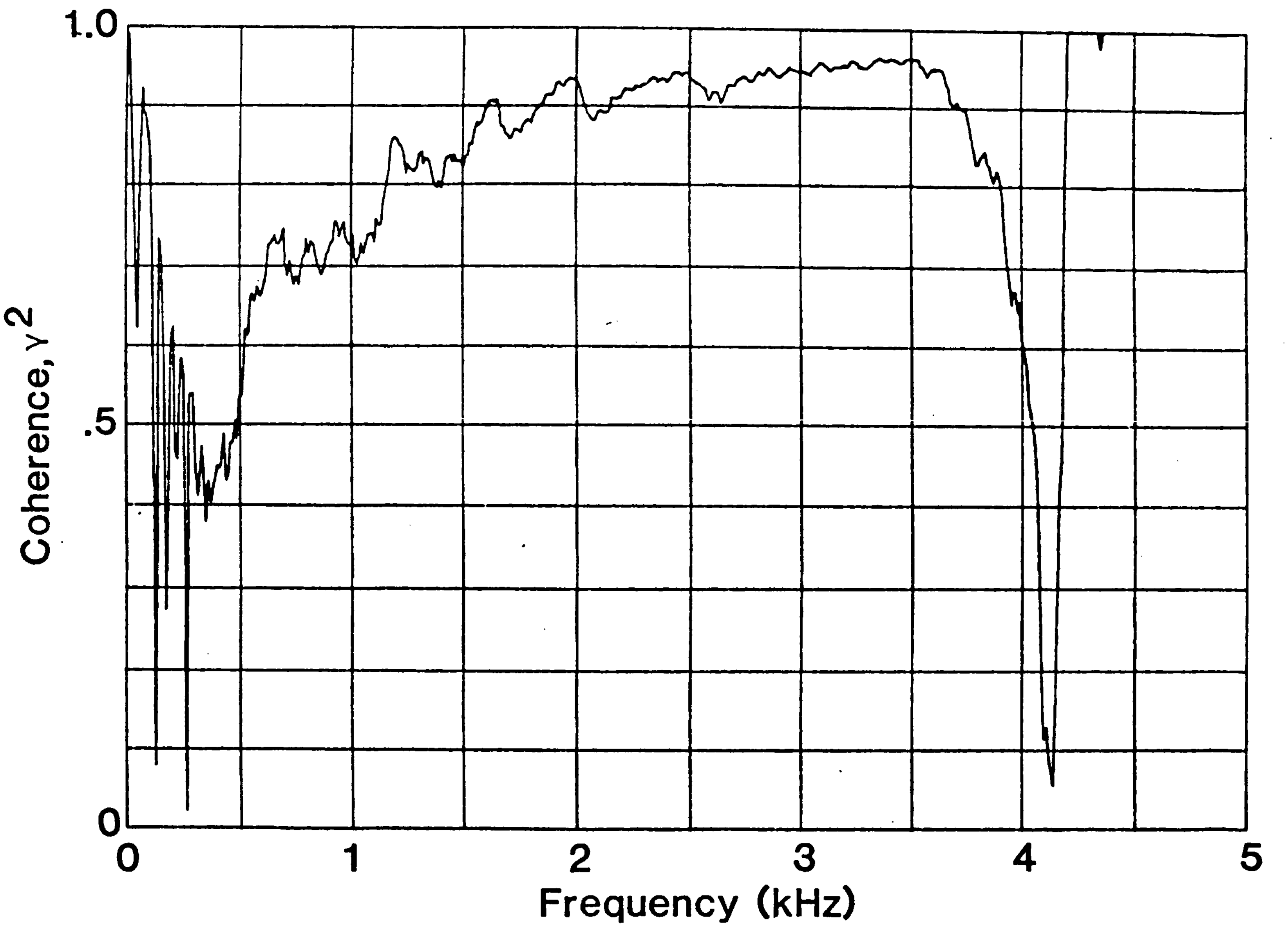

Figure 11.- Coherence between near-field microphones, configuration 1, with added random noise.

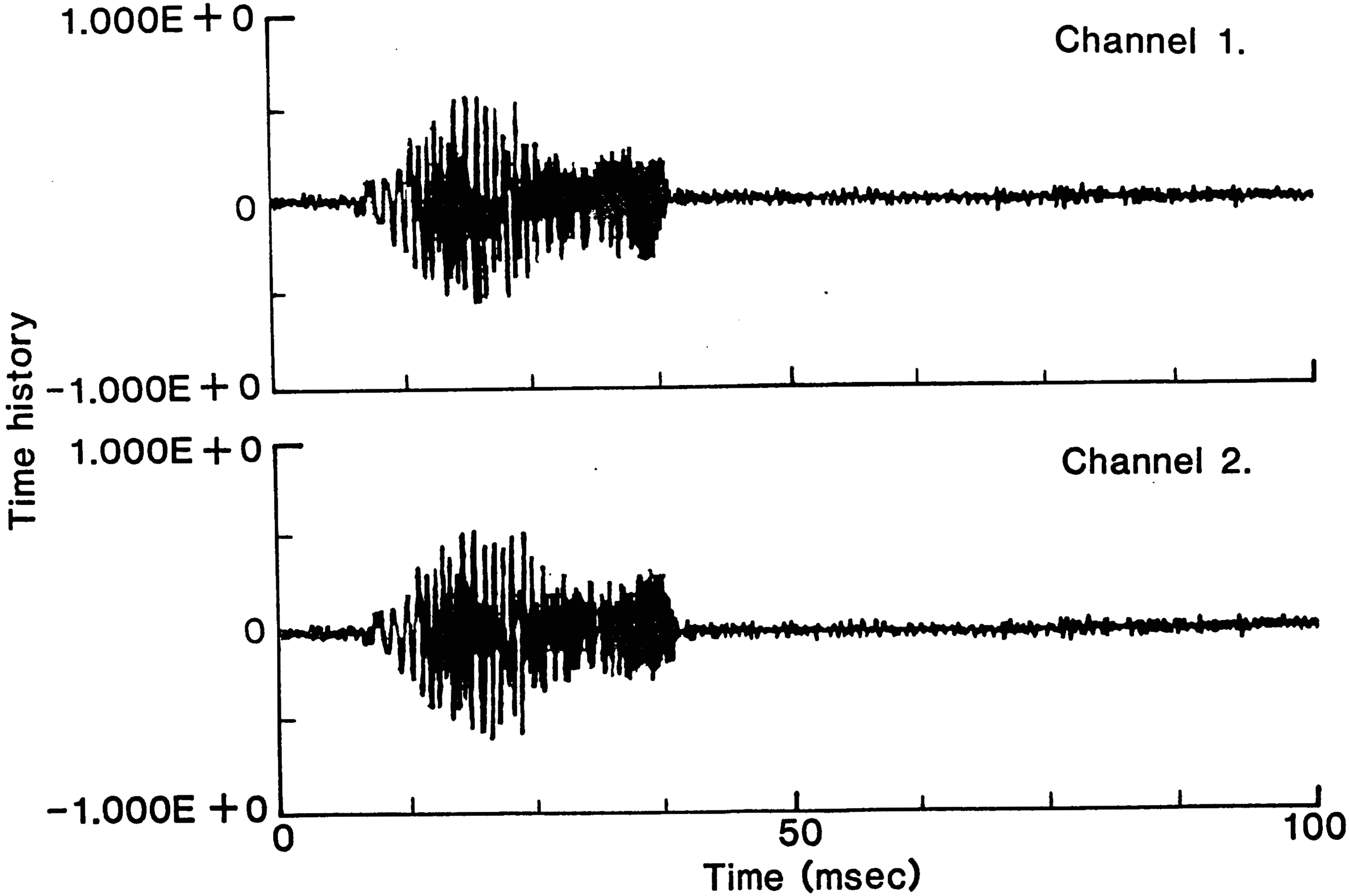

Figure 12.- Time histories of signals acquired at array microphones, configuration 1, with added random noise.

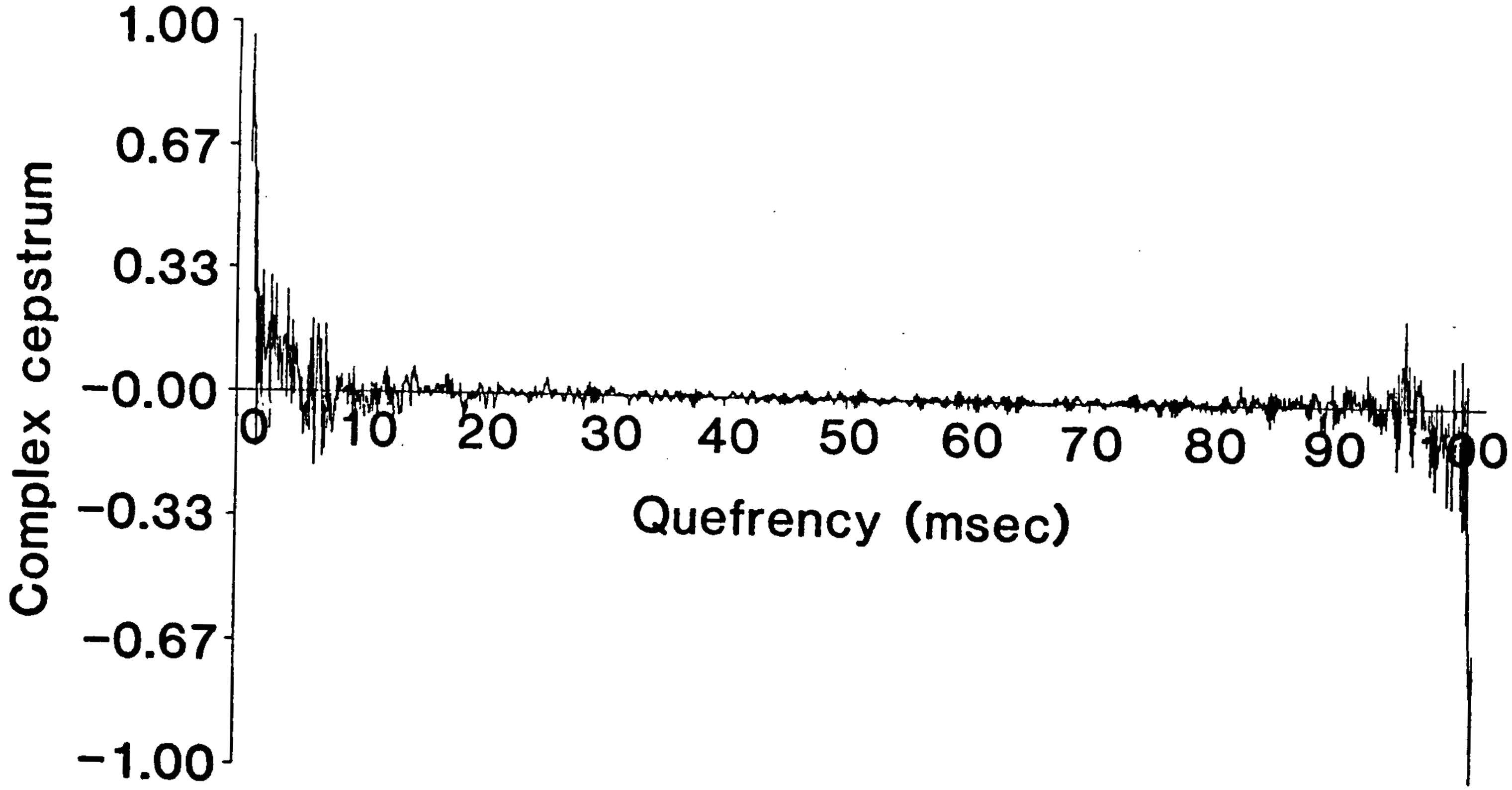

Figure 13.- Complex cepstrum, configuration 1, with added random noise.

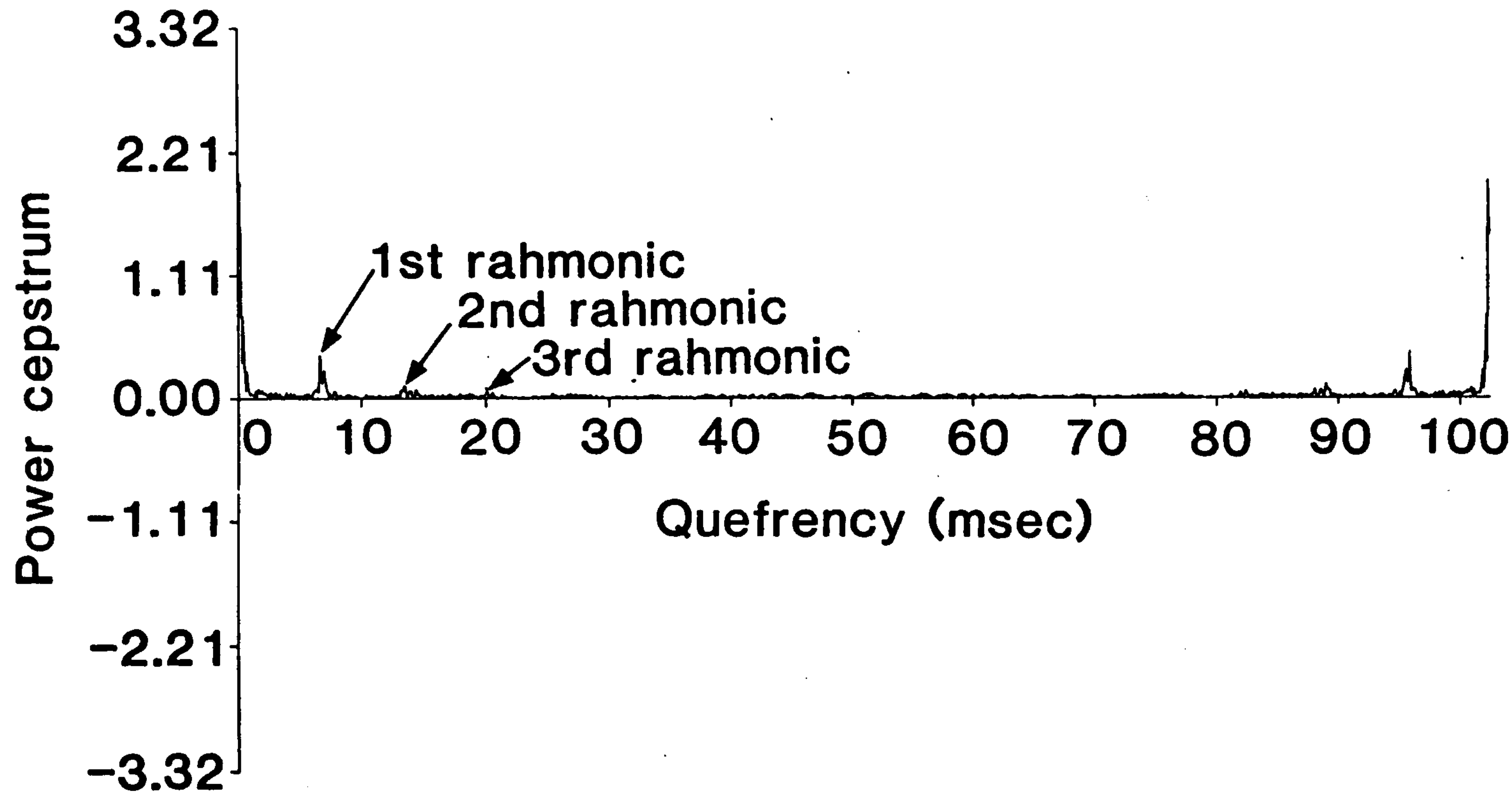

Figure 14.- Power cepstrum, configuration 1, with added random noise.

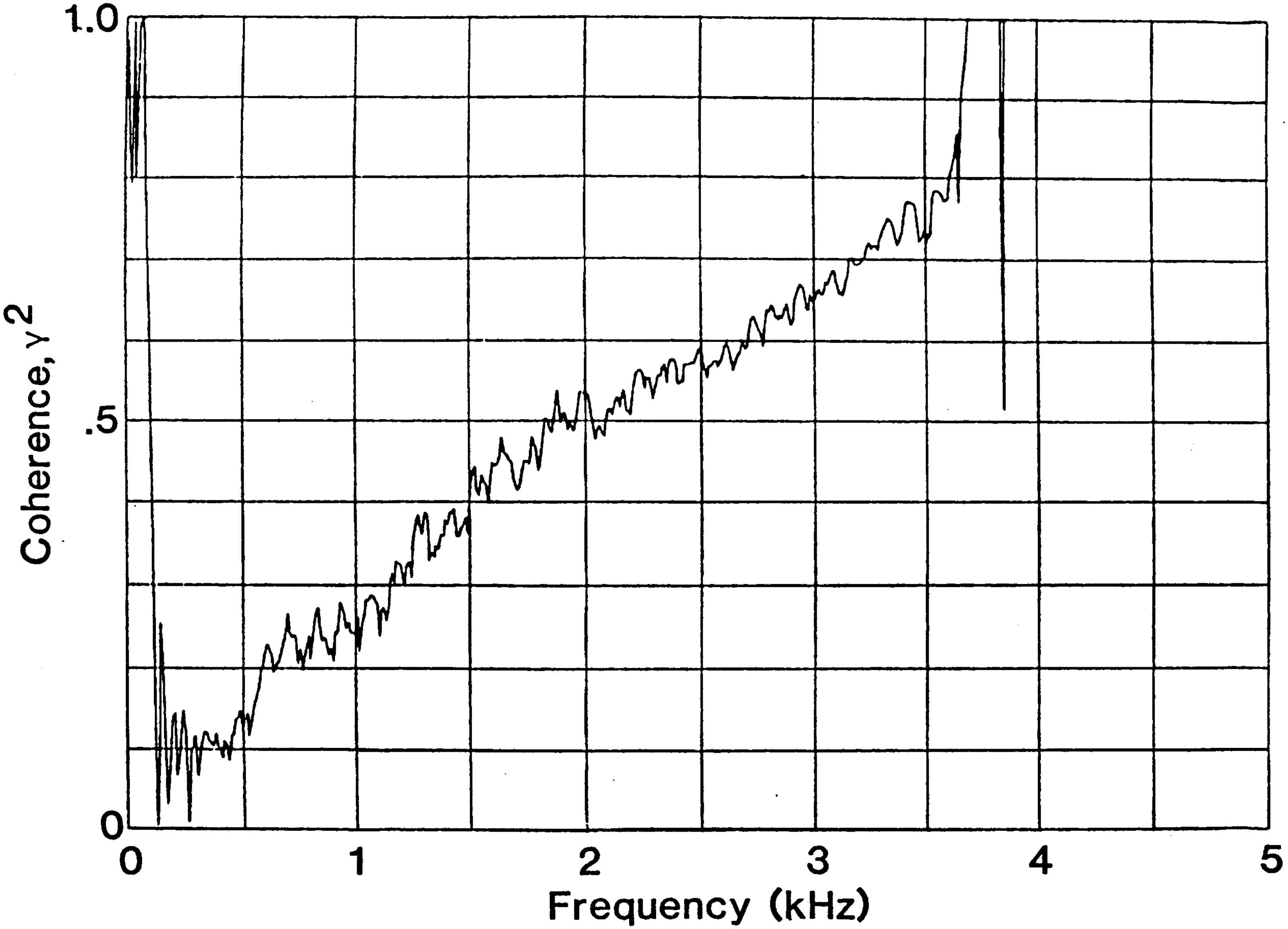

Figure 15.- Coherence between near-field microphones, configuration 2, with added random noise.

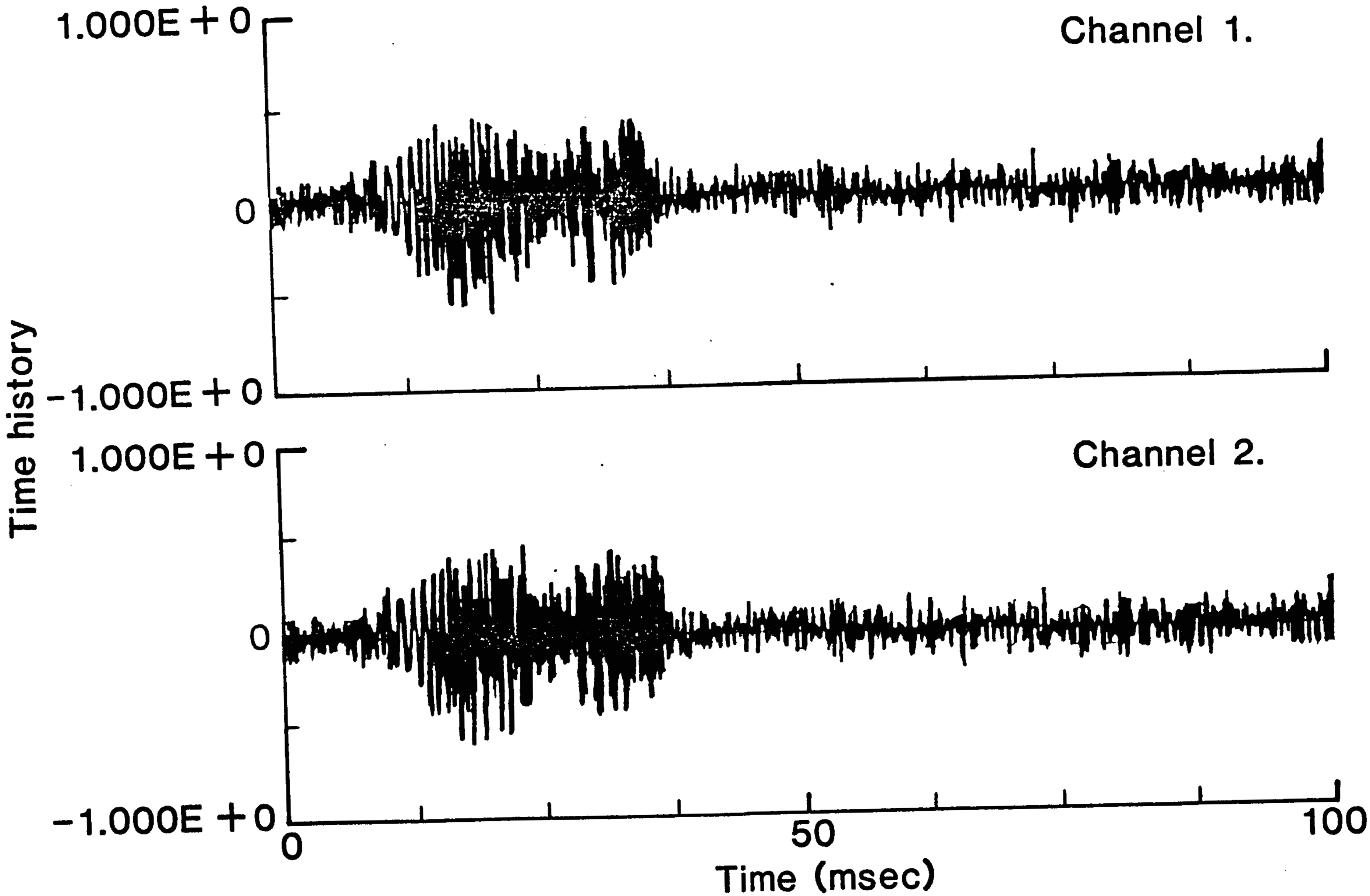

Figure 16.- Time histories of signals acquired at array microphones, configuration 2, with added random noise.

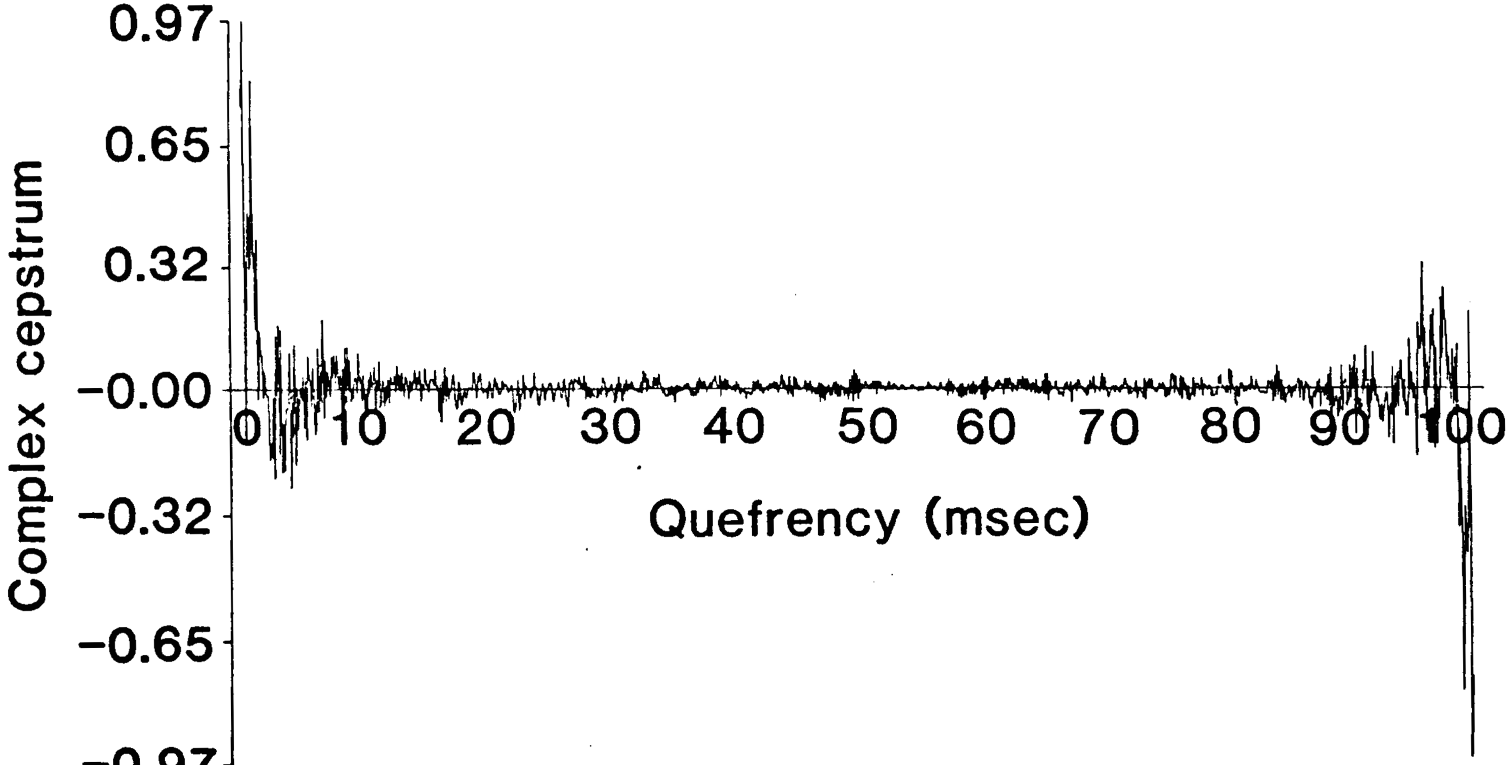

Figure 17.- Complex cepstrum, configuration 2, with added random noise.

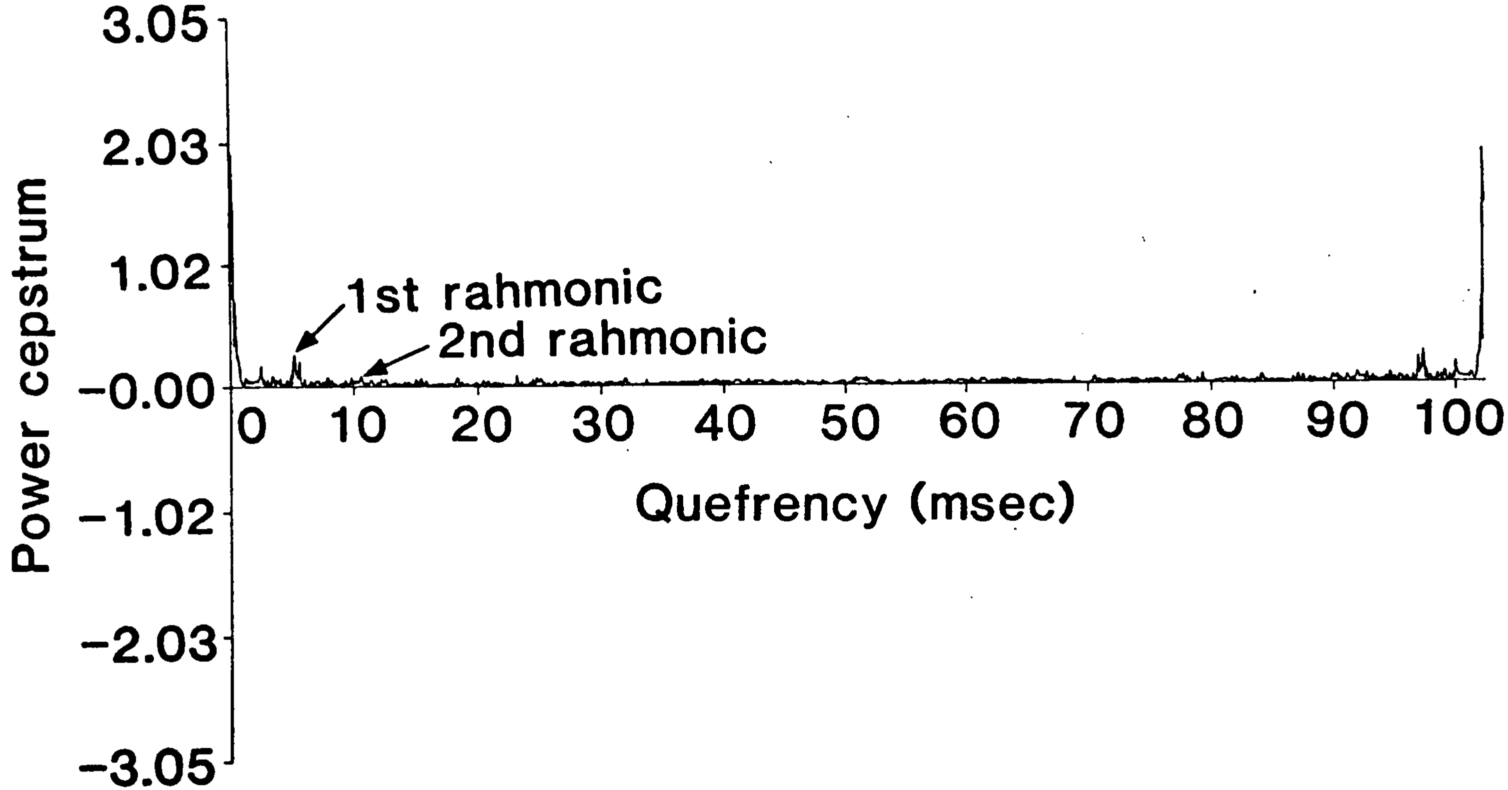

Figure 18.- Power cepstrum, configuration 2, with added random noise.

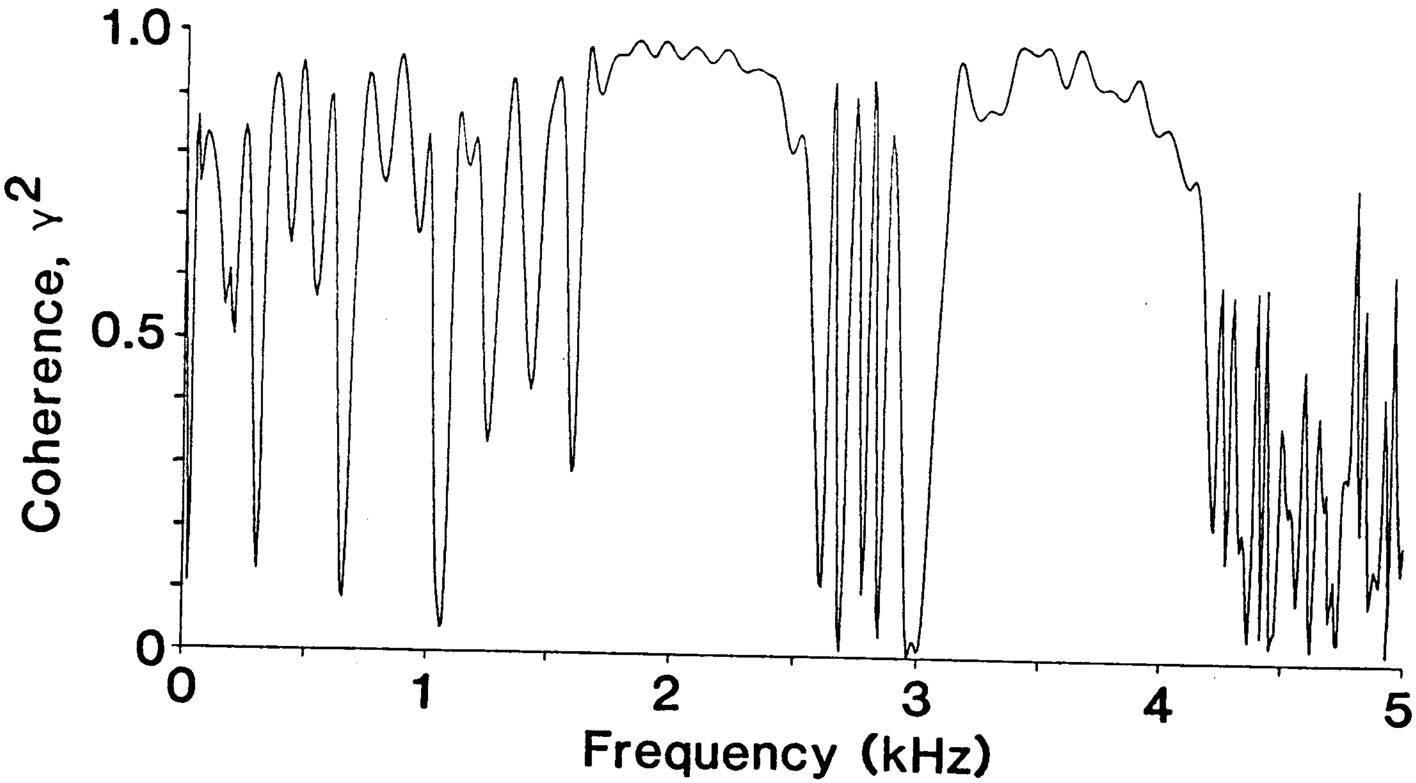

Figure 19.- Coherence between recovered array signals, configuration 2.

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16. Abstract

The effect of the presence of two acoustic sources (one, the primary, whose location is to be detected) of varying coherence on a cepstral bearing finding procedure is experimentally studied. The coherence between the acoustic sources was altered by adding random noise of various SNR (signal-to-noise ratio) to the input signal of the primary source; the same base signal being fed to both sources. The results demonstrate that, when block liftering is used, the primary source bearing is reliably estimated for coherences as low as $\gamma^2 \gtrsim 0.5$. The results also imply that background noise (unreflected) of SNR $\gtrsim$ 10 dB will not markedly affect the accuracy of the bearing estimation algorithmn.

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