X. COMMUNICATIONS BIOPHYSICS*

Academic and Research Staff

Prof. L. D. Braida	Prof. W. M. Siebert	Dr. H. J. Liff
Prof. S. K. Burns	Prof. T. F. Weiss†**	Dr. E. P. Lindholm
Prof. H. S. Colburn†	Dr. I. M. Asher	D. W. Altmann†
Prof. L. S. Frishkopf	Dr. J. S. Barlow††	R. M. Brown†
Prof. J. L. Goldstein†	Dr. F. A. Bilsen‡‡	A. H. Crist†
Prof. J. J. Guinan, Jr.†	N. I. Durlach	W. F. Kelley
Prof. R. G. Mark‡	Dr. R. D. Hall	L. H. Seifel
Prof. W. T. Peake†	Dr. N. Y. S. Kiang†	S. N. Tandon

Graduate Students

T. Baer	Z. Hasan	R. P. Lippmann
J. E. Berliner	B. L. Hicks	E. C. Moxon
T. R. Bourk	A. J. M. Houtsma	V. Nedzelnitsky
C. H. Conrad	T. W. James	W. M. Rabinowitz
P. Demko, Jr.	D. H. Johnson	D. B. Rosenfield
G. S. Ferla	C. H. Karaian	J. H. Schultz
S. A. Friedel	G. K. Lewis	D. L. Sulman
D. O. Frost	R. Y-S. Li	R. G. Turner, Jr.

Undergraduate Students

P. Bannister	M. Lee	S. Shamres
J. Bushnell	S. Lee	J. Sheridan
E. Dimeteriou	S. Miller	H. Soong
L. Grochow	D. Myrick	S. Tharp
E. Kohn	M. Rees	J. Walters
	R. Roth	

A. EFFECTS OF ELECTRIC STIMULATION OF THE CROSSED OLIVOCOCHLEAR BUNDLE ON COCHLEAR MICROPHONIC POTENTIAL

Electric stimulation of the efferent on "feedback" fibers forming the crossed-olivocochlear bundle (COCB) can increase the amplitude of cochlear microphonic potential (CM).[1] In the hope of providing some insight into the workings of the cochlea we

*This work was supported by the National Institutes of Health (Grant 5 PO1 GM14940-05).

†Also at the Eaton-Peabody Laboratory, Massachusetts Eye and Ear Infirmary, Cambridge, Massachusetts.

‡Instructor in Medicine, Harvard Medical School, Boston, Massachusetts.

**Instructor in Preventive Medicine, Harvard Medical School, Boston, Massachusetts.

††Research Affiliate in Communication Sciences from the Neurophysiological Laboratory of the Neurology Service of the Massachusetts General Hospital, Boston, Massachusetts.

‡‡Visiting Scientist from Delft University of Technology, The Netherlands.

have investigated this phenomenon further.

Barbiturate-anesthetized cats with severed middle-ear muscles were monaurally stimulated with 1 ms duration bursts of 0.75, 1.0, 2.0, 4.0, and 8.0 kHz tones. Evoked responses were recorded with a wire electrode placed on the surface of the cochlea near the round window and averaged on a computer. CM and neural components of the response were distinguished by their latencies, and CM was measured peak-to-peak. Electric shocks to the COCB were delivered near the facial genu and the shock parameters were set for maximum effect on the neural response.

Changes in the magnitude of CM following COCB stimulation varied with the frequency and intensity of the acoustic stimuli and ranged from an increase of ~6 dB to a decrease of ~4 dB. In most cases CM increased a few dB. In the low-intensity range at 0.75 and 1.0 kHz, CM augmentation increased as sound intensity increased. In the one case in which we have fairly reliable data extending to moderately high sound intensities (at 0.75 kHz), the augmentation was almost zero at the lowest sound intensity tested, increased to 6 dB as the sound intensity was increased 35 dB, and then decreased to less than 1 dB at sound intensities 10-30 dB higher. At 2.0, 4.0, and 8.0 kHz, changes in CM were smaller than 4 dB in either direction and we did not discern any systematic relation to acoustic intensity or frequency.

In summary, we have found that the augmentation of CM varies with acoustic intensity and frequency, can be as much as +6 dB, and may even be negative. A more detailed report of our results may be found in Frost's thesis.[2]

D. O. Frost, J. J. Guinan

References

1. J. Fex, "Augmentation of the Cochlear Microphonics by Stimulation of Efferent Fibres to the Cochlea," Acta Oto-laryngol., 50, 540-541 (1959).

2. D. Frost, "Effects of Electric Stimulation of the Crossed Olivocochlear Bundle on Tone-Evoked Cochlear Microphonics," S.M. Thesis, Department of Electrical Engineering, M.I.T., 1971.

B. SYSTEM FOR DISPLAYING CALIBRATED VELOCITY WAVEFORMS OF STRUCTURES IN THE EAR USING THE MÖSSBAUER EFFECT

1. Introduction

Recently, three laboratories[1-4] have reported measuring the velocity of structures in the ear utilizing the Mössbauer effect. We report here a method that is basically the same as that of Gilad, et al.,[1] with the additional development of a computer system that displays on-line a calibrated velocity waveform. It is intended that this system be used in studying mechanical signals in the middle and inner ear.

The essential components of the system are indicated in Fig. X-1b. A small piece of cobalt 57 is placed on the structure whose velocity is to be measured. The gamma radiation emitted by this source is detected after passing through an iron 57 absorber. Because of the resonant absorption of the Mössbauer effect and the Doppler shift in the energy of the emitted photons, the counting rate R is a minimum at the "resonant" velocity V_i (Fig. X-1a). The shape of this curve is described by the formula in Fig. X-1a.

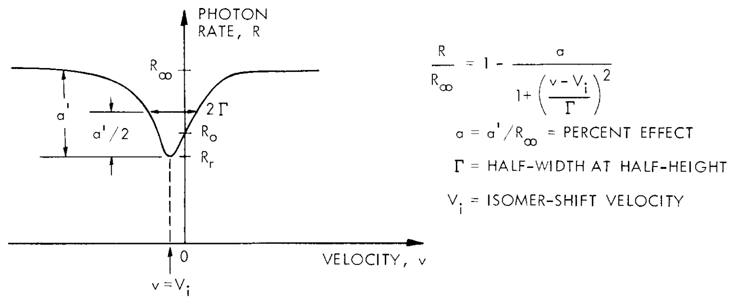
In our previous use of this method[5] photon counts were accumulated in a set of registers that are gated to the process R(t) for time intervals that are synchronized with the stimulus repetitions. The resulting set of numbers is divided by the number of stimulus repetitions and displayed on-line to give an estimate of a function that is proportional to R(t). If the velocity amplitude is small enough, the waveform will be proportional to v(t). Difficulties are encountered, however, in determining the calibration factor v/R when a small piece of source material is placed in the ear.[6] Since the source material is obtained by plating ^{57}Co on palladium, the source radiation varies with direction. Because of the small size of the source and the anatomical arrangement of the structures on which it is placed, it is not possible to control precisely the orientation of the source relative to the detector. Hence we must take into account variations of the parameters a, Γ, V_i, R_∞ that might occur for different geometrical arrangements of the source, absorber, detector, and intervening materials. The calibration must therefore be performed for each case with the source and detecting equipment in place.

2. Method

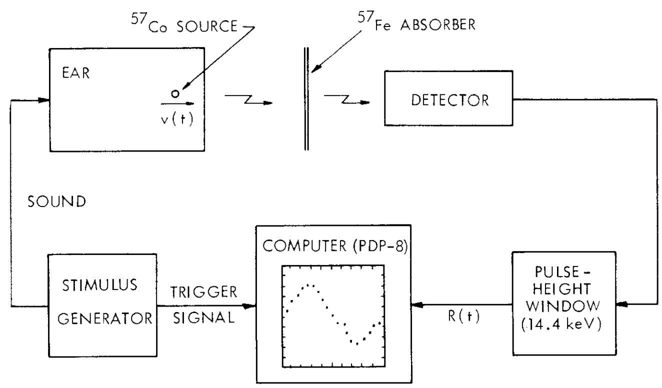
The basic assumptions of our method are that R and v are related by the formula in Fig. X-1a and that the isomer shift V_i is not affected by the arrangement of the source and detector. The parameters a, R_∞, and Γ have been found to depend on the angle of the source plane with respect to the detector and on intervening material such as flesh or bone.

The scheme involves two steps: (i) Calibration Procedures, and (ii) Velocity Display. In the calibration procedure the parameters a, Γ, and R_∞ are determined; the velocity display uses these parameters and the formula to convert count-rate into velocity.

We can determine a and Γ from the rates R_o, R_r, and R_∞ (see Fig. X-1a). The calibration procedure entails measuring these three rates and storing them in the computer for use in the velocity display. R_r is determined as indicated in Fig. X-2. The horizontal location of the upward-pointing arrow is adjusted by the operator to be approximately under the minimum of the waveform. The computer then determines a parabola that fits (with the least-square error) the points in an interval



(a)



(b)

Fig. X-1. (a) Graphical and algebraic description of the relation of counting rate, R, and velocity, v.
(b) Diagram of equipment involved in the velocity-measuring system.

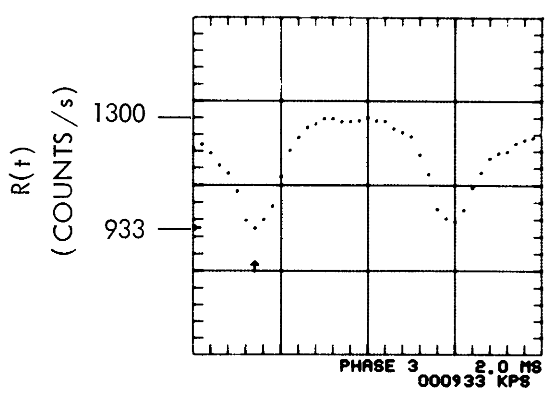


Fig. X-2.

Averaged counting rate vs time with a sinusoidal velocity at 500 Hz. The velocity amplitude is approximately $5V_i$, so that the counting rate goes through the resonant velocity (twice in each cycle). Each dot represents an average obtained in a 0.50 μs interval. Counts were accumulated over 250,000 repetitions of the stimulus. The minimum value of the parabola fitted by the computer is displayed in the lower right (933 counts per second). The pointer on the left-hand side indicates the level of this rate. The total time required to obtain this display is 2 × 250,000/500 = 1000 s = 17 min. (The factor of 2 results because the computer triggers only on every other period of the stimulus.)

centered on the arrow. The number of points to be fitted is chosen by the operator. The minimum value of the parabola is indicated by the marker on the left-hand side of the display and the corresponding rate, which is the estimate of R_r, is displayed below the raster.

The zero velocity rate, R_o, is estimated by determining an average rate with no motion of the source. The large velocity asymptote, R_∞, can be estimated either from the average rate obtained with

$$v = V \sin \omega t \quad \text{and} \quad V \gg \Gamma,$$

or by using the pointer method of Fig. X-2 to designate a point where $R \approx R_\infty$.

After these three parameters have been estimated, estimates of $R(t)$ can be converted to velocity by performing the calculation

$$\frac{v_j}{V_i} = 1 + \sqrt{\frac{R_\infty - R_o}{R_o - R_r} \cdot \frac{R_j - R_r}{R_\infty - R_j}},$$

where R_j is the average rate in the j^{th} interval, and v_j is the corresponding velocity. This calculation is the solution of the formula in Fig. X-1a for the velocity, with a and Γ replaced by

$$a = \frac{R_\infty - R_r}{R_\infty}$$

and

$$\left(\frac{\Gamma}{V_i}\right)^2 = \frac{R_\infty - R_o}{R_o - R_r}.$$

Since a given rate corresponds to 2 values of velocity, there is an inherent ambiguity in the solution for v. In general, v can be determined only if it is assumed that $v > V_i$. For the materials that we have used (^{57}Co in palladium and ^{57}Fe in stainless steel), $V_i = 0.25$ mm/s. It is also clear that difficulties will occur when $v - V_i$ is small, since then there will be some rate estimates, R_j, that are less than the estimate of the resonant rate, R_r. In order to identify these points, they are placed on the bottom line in the computer display.

3. Test of the System

To test the system, velocity waveforms were determined with a source mounted on the cone of a loudspeaker. The detector was placed either in front of the source or behind it. This represents the most extreme change in the geometrical arrangement of source and detector that might be expected in the ear. Comparison of the parameters for the two cases (see Fig. X-3) indicates that there is a change in the shape of the curve (a and Γ change significantly) in addition to the change in scale (R_∞). The velocity display takes these changes into account, and the waveforms are not significantly different for the two arrangements (except for 180° phase shift). On the other hand, the magnitude of the rate waveform changes for the two arrangements by a factor (approximately 3) which is much larger than the change in R_∞.

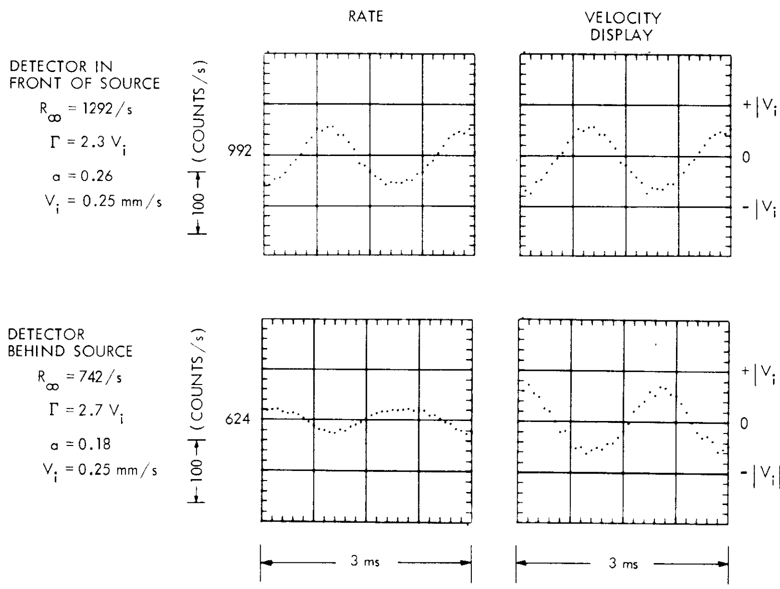
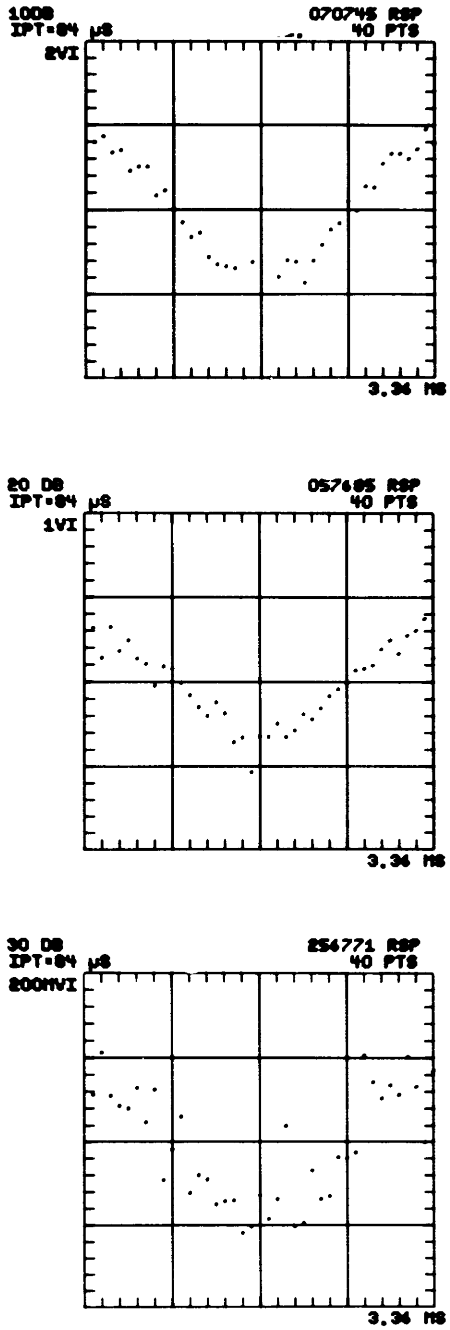


Fig. X-3. Computer waveform displays for two locations of the detector. The computed values of the parameters a, R_∞, and Γ, are indicated for both locations. The two displays on the right-hand side represent the output of the velocity display for the two locations of the detector. (The 180° phase shift results from the reversal of location of the detector relative to the velocity). The left-hand displays show that the amplitude of the rate waveform changes by approximately a factor of 3, which is consistent with the changes in R_∞, a, and Γ.

In the velocity display the calibration is given in terms of V_i. The value of V_i (0.25 mm/s) can be determined from measurements supplied by the manufacturer. This figure was checked by comparing velocity displays with displacement measurements made under stroboscopic illumination and with the output of an accelerometer. Although a systematic set of measurements has not been completed, measurements at half-decade intervals from 10 Hz to 10 kHz indicate rough agreement between methods.



10 min

8 min

36 min

Fig. X-4. Velocity displays for 3 sinusoidal velocity levels, 10 dB apart. Total averaging time is indicated. The source strength and location were such that $R_o \approx 1000$ counts/second. Other parameters are as in the upper section of Fig. X-3. Each interval is 84 µs long. VI = V_i, and MVI = $V_i \times 10^{-3}$.

In the measurement system used by Johnstone, Taylor, and Boyle[3] and by Rhode,[4] $V_i = 0$ has been used, and the velocity magnitude has been determined from the mean rate R(t). With this method useful measurements can be made over a maximum range of velocities of ~30 dB. The method presented here can be used theoretically for as small a velocity as desired; for a given sampling interval, however, the time required to obtain a given signal-to-noise ratio in the velocity display is approximately inversely proportional to the square of the signal level. The examples shown in Fig. X-4 illustrate this for three different signal levels. In going from the center display to the lower display the signal decreased approximately by a factor of 3. Although the averaging time was increased by 4.5, the signal-to-noise ratio is smaller in the lower display. The absolute time required depends on the density of the source material, the size of the source that can be placed on the ear structure that is to be measured, the distance from the source to the detector, and the velocity signal. The values shown in Fig. X-4 are probably of the order of magnitude that can be obtained in the ear. Hence there are limitations on the velocities that can be measured which result from the length of time that is available for the measurement.

G. K. Lewis, W. T. Peake

References

1. P. Gilad, S. Shtrikman, P. Hillman, J. Rubinstein, and A. Eviatar, "Application of the Mössbauer Method to Ear Vibrations," J. Acoust. Soc. Am. 41, 1232-1236 (1967).
2. B. M. Johnstone and A. J. F. Boyle, "Basilar Membrane Vibration Examined with the Mössbauer Technique," Science 158, 390-391 (1967).
3. B. M. Johnstone, K. J. Taylor, and A. J. Boyle, "Mechanics of the Guinea Pig Cochlea," J. Acoust. Soc. Am. 47, 504-509 (1970).
4. W. S. Rhode, "Observations of the Vibration of the Basilar Membrane in Squirrel Monkeys Using the Mössbauer Method," J. Acoust. Soc. Am. 49, 1218-1231 (1971).
5. B. A. Twickler and W. T. Peake, "Measurement of Velocities in the Middle Ear Using the Mössbauer Effect," Quarterly Progress Report No. 92, Research Laboratory of Electronics, M.I.T., January 15, 1969, pp. 402-403.
6 D. R. Wolfe, "Velocity Measurements in the Ear Using the Mössbauer Technique," E.E. Thesis, Department of Electrical Engineering, M.I.T., February 1970.