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A METHOD OF MEASURING COCHLEAR POTENTIALS EVOKED BY TWO-TONE EXCITATION

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This paper presents a new method of measuring cochlear microphonics (CM) evoked by a two-tone acoustic wave. The method is based on phase sensitive detection whereby it is possible to precisely measure not only excitation frequency CM signals but also combination signals. The method can be used in experiments conducted on animals. Exemplary experimental results are given.

Key words: phase sensitive detection, cochlear potentials.

1. Introduction

Cochlear microphonics (CM), sometimes referred to as cochlear potentials, are the cochlea's electric response to excitation by an acoustic wave generated in the external auditory canal. A pure tone is one of the several kinds of acoustic waves used for exciting the electric activity of the cochlea. In the case of such excitation, CM signal values depend on the exciting wave's frequency and amplitude. The latter indirectly determines the exciting acoustic wave's intensity level [dB]. Cochlear microphonics can also be evoked by a two- or more tone acoustic wave. Then the cochlea's response includes not only stimulation frequency signals but also combination frequency signals. For example, when stimulation by a two-tone wave with frequencies f_1 and f_2 is used, signals with frequencies $mf_1 \pm nf_2$ may appear.

In experimental studies CM signals are used to assess the effect of different external factors (e.g. ambient noise, ototoxic drugs, vibration, laser radiation) on the cochlea's electrophysiological activity [1–4, 7]. In such experiments various laboratory animals (usually guinea pigs) are used. Anaesthetized animals are subjected to the surgical procedure of opening the ventral tympanic bulla whereby an approach to the cochlea is obtained. One of the ways of receiving CM signals is by a platinum electrode touching the cochlea's surface at a specified point. The received signals are very weak (at a single microvolt level) and to complicate things, the electrode receives all the signals being the product of the cochlea's nonlinearity.

The authors developed a phase sensitive detection method for the reception of CM signals. Initially this method was used to receive signals excited by a one-tone wave [5]. As advances in digital technology were made it became possible to stimulate cochlear activity by two, or even a larger number of tones, which gave rise to new investigative possibilities [6]. In this paper the developed method is described and preliminary measurement results are reported.

2. Description of method

Phase sensitive detection is possible only when there are two signals: a measured signal and a reference signal. Both signals must be generated synchronously. A schematic diagram of electric signal measurement by the phase sensitive detection method is shown in Fig. 1. The same generator is the source of the two synchronous signals. Immediately at the phase sensitive detector's output there are two signals: a constant signal and a signal whose frequency is twice higher than the excitation frequency. After the low-pass filter there is only the constant signal proportional to the amplitude of the measured signal and the cosine of the difference between the measured signal and the reference one. The regulated phase shifter in the reference channel makes it possible to set the difference between the two signals to zero angular degrees. Then the signal at the detector's output is maximum and equal to the measured one.

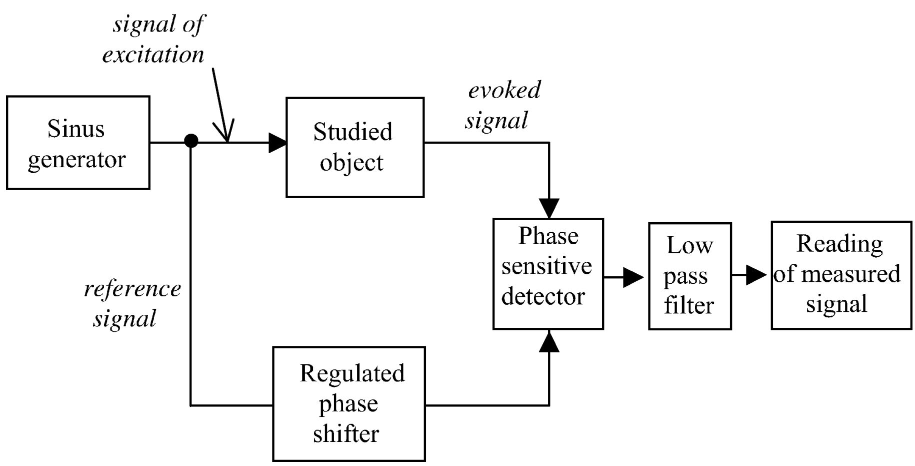

Fig. 1. Simplified block diagram of experimental setup with phase sensitive detection.

In order to apply the above method to CM signal measurement in the case of excitation by a two-tone wave one must use a generator of three synchronous harmonic waveforms with arbitrarily set frequencies. Two of the signals (f_1 and f_2) are exciting signals and the third one (f_3) – synchronous with them – is a reference signal. Frequency f_3 of this signal can be any combination of frequencies f_1 and f_2. Figure 2 shows the implemented and tested design of the experimental setup for measuring CM signals by the phase sensitive detection method using two-tone stimulation.

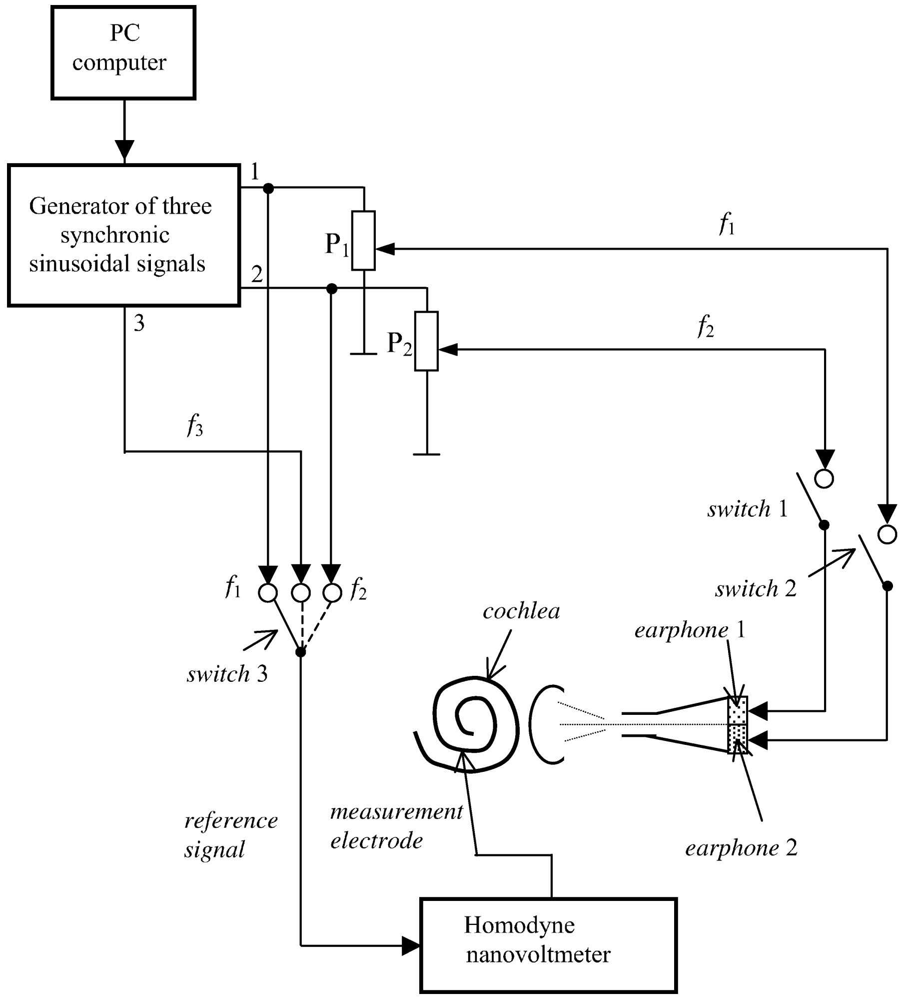

Fig. 2. Block diagram of experimental setup for measuring CM signals evoked by two-tone acoustic wave.

A computer-controlled digital generator of three sinusoidal waveforms, with adjustable frequencies and amplitudes, was developed for the measuring setup. Each of the three generated frequencies is characterized by high stability (accidental changes in frequency amount to merely a few mHz). The signal from output 1 of this generator controls, via voltage divider P_1 and switch 1, earphone 1. Similarly, the signal from output 2 controls earphone 2. The two earphones are placed in the auditory canal of the tested animal. Depending on the position of switches 1 and 2 the cochlea can be excited by a one-tone wave with frequency f_1 or f_2 or by the two tones simultaneously. The cochlea's electric response to each of the three excitations is received by a platinum electrode touching the cochlea's surface. Using switch 3 one sets the reference signal frequency and in this way determines what signal will be measured.

3. Preliminary results

The measuring setup concept was tested experimentally *in vivo* on an anaesthetized guinea pig in which an approach to the inner ear cochlea was surgically obtained. The cochlea was simultaneously stimulated by two tones with frequencies f_1 and f_2 and ratio f_2/f_1 was changed from 1.10–1.50 so as to obtain the same combination frequency $f_3 = 2f_1 - f_2$. This combination frequency is used in screening hearing test equipment. For each set combination signal frequency f_3 and for each pair of stimulating signals with frequencies f_1 and f_2 such amplitudes of the signals were selected so as to obtain the maximum amplitude of the signal with the combination frequency. Exemplary results for two different combination frequencies $(f_3)_1 = 1$ kHz and $(f_3)_2 = 2$ kHz are presented in Tables 1 and 2.

Table 1.

f_2/f_1	f_1 [Hz]	f_2 [Hz]	f_3 [Hz]	Measured signals [μV]			Level $(CM)_3$ [dB]
				CM_1	CM_2	CM_3	
1.10	1111	1222	1000	120	102	40	65.5
1.20	1290	1580	1000	135	104	54	67.5
1.30	1428	1856	1000	139	92	60	68.3
1.40	1667	2332	1000	132	64	74	70.3
1.50	2000	3000	1000	96	44	70	69.7

Table 2.

f_2/f_1	f_1 [Hz]	f_2 [Hz]	f_3 [Hz]	Measured signals [μV]			Level $(CM)_3$ [dB]
				CM_1	CM_2	CM_3	
1.10	2222	2444	2000	59	38	11	65.8
1.20	2500	3000	2000	42	29	15	67.8
1.30	2857	3714	2000	30	12	18.5	69.5
1.40	3333	4666	2000	23.8	6	13	66.8
1.50	4000	6000	2000	9	9	4.5	60

Excitation levels in dB which should be used for one-tone excitation at a frequency of respectively 1000 Hz and 2000 Hz in order to obtain the same value CM_3 as for two-tone excitation are shown in the last column. The levels of the measured signals with combination frequencies $f_3 = 2f_1 - f_2$ turned out to be close to the levels of the signals with excitation frequencies. This means that the reception of the signals from the cochlea's surface occurred close to the place where the signals originated. The measurements also show that there is a certain frequency ratio f_2/f_1 at which the value of the signal with frequency f_3 is the highest.

4. Conclusion

The experiments have shown that the reception of CM signals by the phase sensitive method is possible not only for one-tone excitation but also for two-tone excitation. The method can be easily extended to cover the simultaneous excitation of the cochlea by many tones. The proposed method widens the possibilities for investigating the electric function of the cochlea and the effect of different external factors on this function.

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