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LB-1053

UNI-PRESSURE MICROPHONE

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Approved

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This bulletin describes the theory, construction, and characteristics of a new design for a unidirectional gradient microphone. Good directivity over a wide frequency response and low wind response are features of this new design.

Introduction

A unidirectional microphone is characterized by a substantial sensitivity of response in the general direction of the axis of the microphone. In a practical microphone, the unidirectional directivity pattern should be maintained over the useful frequency response range of the microphone. Unidirectional microphones have been made by combining a bidirectional velocity microphone element with a nondirectional microphone element or by combining a single microphone element with an acoustical delay system. Unidirectional microphones employing these principles exhibit a very high order of fidelity with regard to response as a function of frequency and have a uniform directivity pattern with respect to frequency. The only objection to these microphones is a somewhat higher response to wind as compared to a pressure microphone. The electrical output caused by wind may be several times the output of the highest useful signal output. This high output causes overloading of the electrical elements in the system with resulting distortion.

A unidirectional microphone may also be constructed by employing two pressure microphone units connected in opposition. This design will exhibit a very low voltage response to wind. However, maintaining fidelity in the directivity pattern and the response frequency characteristic becomes a very difficult problem. It is the purpose of this bulletin to describe a unidirectional gradient microphone employing two pressure microphone elements and an electrical delay system. This microphone has been termed a uni-pressure microphone.

Theory

The uni-pressure microphone consists of two dynamic pressure microphone units connected in an inverse electrical manner combined with an electrical delay network. The system is schematically shown in Fig. 1.

The voltage output,, e_1, in volts, of the pressure microphone unit 1 is given by

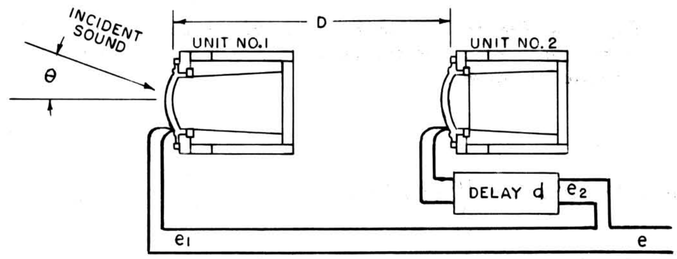


Fig. 1 – The elements of the uni-pressure microphone.

$$e_1 = e_{01} \sin \omega t \tag{1}$$

where e_{01} = amplitude of the voltage developed by pressure microphone unit 1, in volts,

$\omega = 2\pi f$

f = frequency, in cycles per second, and

t = time, in seconds.

In order to provide unidirectional operation, it is necessary to introduce a delay system in the output of the rear microphone unit. Assuming that there is no attenuation in the delay system and the reference of phase in space is unit 1, the voltage output, e_2, of pressure microphone unit 2 at the output of the delay system is given by

$$e_2 = e_{02} \sin \left(\omega t + d + \frac{2\pi D}{\lambda} \cos \theta\right) \tag{2}$$

where e_{02} = amplitude of the voltage developed by pressure microphone unit 2, in volts,

d = delay of the electrical system, in radians,

D = distance between the units, in centimeters,

λ = wavelength, in centimeters, and

θ = angle between the direction of the incident sound and the line connecting the pressure microphones units 1 and 2.

To obtain unidirectional gradient operation the two units are connected in opposition. The resulting voltage, e, is given by the difference of Eqs. (1) and (2), as follows,

$$e = e_1 - e_2 = e_{01} \sin \omega t - e_{02} \sin \left(\omega t + d + \frac{2\pi D}{\lambda} \cos \theta\right) \tag{3}$$

Assuming that the voltages e_{01} and e_{02} are equal, Eq. (3) becomes,

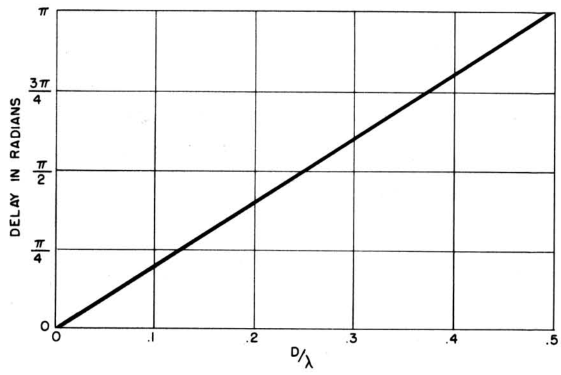


Fig. 2 – The delay characteristic of the delay system of the uni-pressure microphone of Fig. 1 for a cardioid directional pattern.

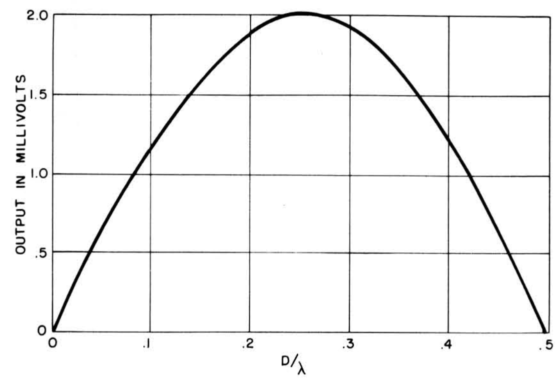


Fig. 3 – Theoretical response frequency characteristic of the uni-pressure microphone of Fig. 1 employing a delay system with the characteristics of Fig. 2.

$$e = 2e_{01} \sin\left(\frac{d}{2} + \frac{\pi D}{\lambda}\cos\theta\right) \sin\left(\omega t + \frac{d}{2} + \frac{\pi D}{\lambda}\cos\theta - \frac{\pi}{2}\right) \quad (4)$$

Neglecting the absolute phase of the output with respect to the impinging sound wave, Eq. (4) may be written

$$e = 2e_{01} \sin\omega t \sin\left(\frac{d}{2} + \frac{D\pi}{\lambda}\cos\theta\right) \quad (5)$$

The directivity pattern will be a cardioid of revolution about the line connecting the two units as an axis if,

$$\frac{d}{2} = \frac{D\pi}{\lambda} \quad (6)$$

The characteristic of the delay system for a cardioid directional pattern in the low frequency range is shown in Fig. 2.
Using Eq. (6), Eq. (5) becomes,

$$e = 2e_{01} \sin\omega t \sin\left(\frac{D\pi}{\lambda} + \frac{D\pi}{\lambda}\cos\theta\right) \quad (7)$$

The response frequency characteristic for $\theta = 0$ as a function of D/λ obtained from Eq. (7) is shown in Fig. 3. The response frequency characteristic shows that the response of the two unit system is zero at $D/\lambda = 0.5$.

The directivity pattern of the microphone system of Fig. 1 is shown in Fig. 4. It will be seen that the response frequency range must be confined to $D/\lambda = 0.5$ in order to maintain unidirectional operation. Therefore, from the consideration of both the response frequency characteristic as well as the directional characteristic, the operation of the microphone as a two unit system must be confined to the frequency range below $D/\lambda = 0.5$.

Referring to Fig. 3, it will also be seen that the response falls off with decreasing frequency. For example, at a point four octaves below $D/\lambda = 0.5$ the response is down about *14 db* below that of a single unit. It is possible to compensate for some of this loss in the design of the microphone units. Practical considerations indicate that if the lower end of the frequency range is placed at 100 cycles per sec then the upper end of operation as a two unit system will be about 2000 cycles per sec.

In the region above 2000 cycles per sec directivity may be obtained by means of diffraction. For this purpose the front unit is placed in a prolate ellipsoid. The response is not materially affected by the diffracting system in the low frequency range where gradient operation is employed. The directivity pattern of a prolate ellipsoid is shown in Fig. 5. It can be seen that a directivity pattern corresponding somewhat to that of a cardioid may be obtained by means of diffraction in the frequency region where $D/\lambda = 0.5$ and above. Some directivity is obtained at $D/\lambda = 0.25$. Thus the diffraction effects may be used to compensate for the loss of directivity in the two unit gradient system in the frequency range corresponding to $D/\lambda = 0.25$ to $D/\lambda = 0.5$.

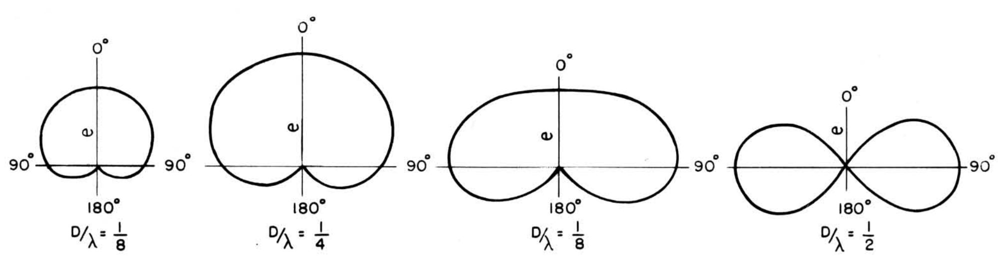


Fig. 4 – Theoretical directional characteristics of the uni-pressure microphone of Fig. 1 employing a delay system of Fig. 2.

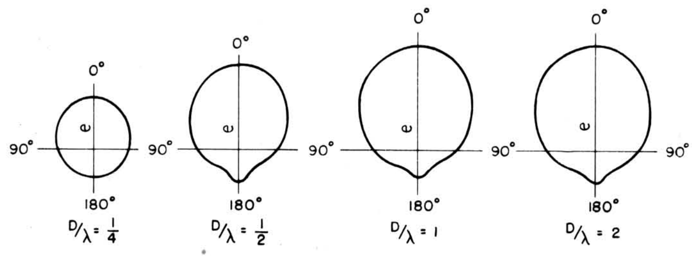


Fig. 5 – Directional characteristics of a pressure microphone mounted in a prolate ellipsoid. D = overall diameter.

Description

The uni-pressure microphone consists of two moving-coil pressure-type microphones, one being spaced behind the other, and a phase shifting network to provide a unidirectional characteristic.

A sectional view and the acoustical network of the microphone motor unit is shown in Fig. 6. The magnetic structure consists of a cylindrically-shaped body of soft iron. The magnet is placed inside the cylindrical shell. The pole tip and the top plate are of soft steel. The aluminum diaphragm consists of a domed-shaped center surrounded by a suspension of two corrugations. The aluminum wire voice coil is cemented to the outer edge of the dome just inside of the suspension system. The outer edge of the suspension system is cemented to a centering ring. The acoustical resistance consists of a layer of felt placed between two perforated rings. This resistance assembly is connected to the air gap behind the voice coil.

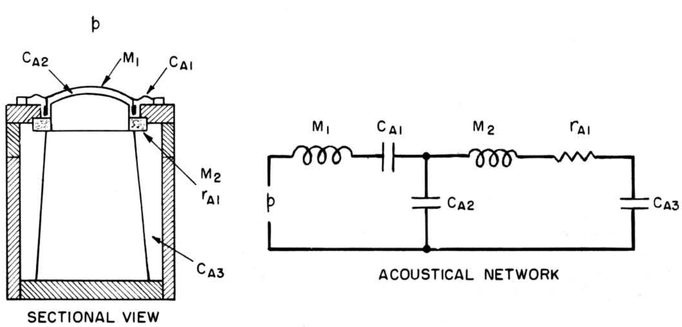


Fig. 6 – Sectional view and acoustical network of a pressure microphone. In the acoustical network: p = sound pressure. M = inertance of the diaphragm and voice coil. C_{A1} = acoustical capacitance of the suspension system. C_{A2} = acoustical capacitance of the space between the diaphragm and pole. M_2 and r_{A1} = inertance and acoustical resistance of the felt. C_{A3} = acoustical capacitance of the case volume.

The acoustical network of one of the pressure microphone elements is shown in Fig. 6. The volume velocity $\dot{X}$, of the diaphragm, in cubic centimeters per second is given by

$$\dot{X} = \frac{p\,(Z_{A2} + Z_{A3})}{Z_{A1}Z_{A2} + Z_{A1}Z_{A3} + Z_{A2}Z_{A3}} \tag{8}$$

where p = sound pressure, in dynes per square centimeter,

$$Z_{A1} = j\omega M_1 + \frac{1}{j\omega C_{A1}}$$

$$Z_{A2} = \frac{1}{j\omega C_{A2}}$$

$$Z_{A3} = r_{A1} + j\omega M_2 + \frac{1}{j\omega C_{A3}}$$

M_1 = inertance of the diaphragm and voice coil, in grams per $(\text{centimeter})^4$,

C_{A1} = acoustical capacitance of the suspension, in $(\text{centimeter})^5$ per dyne,

C_{A2} = acoustical capacitance of the volume between the diaphragm and pole, in $(\text{centimeter})^5$ per dyne,

r_{A1} = acoustical resistance of the felt, in acoustical ohms,

M_2 = inertance of the felt, in grams per $(\text{centimeter})^4$, and

C_{A3} = acoustical capacitance of the case volume, in $(\text{centimeters})^5$ per dyne.

The velocity $\dot{x}$, of the diaphragm and voice coil, in centimeters per second is given by

$$\dot{x} = \frac{\dot{X}}{A} \tag{9}$$

where A = area of the diaphragm in square centimeters.

The voltage e_1, in volts, generated in the voice coil is given by

$$e_1 = B\,\dot{x} \cdot 10^{-8}\, l \tag{10}$$

where B = flux density in the air gap, in gausses, and
l = length of the conductor, in centimeters.

The acoustical elements of the vibrating system were selected so that the response was accentuated at

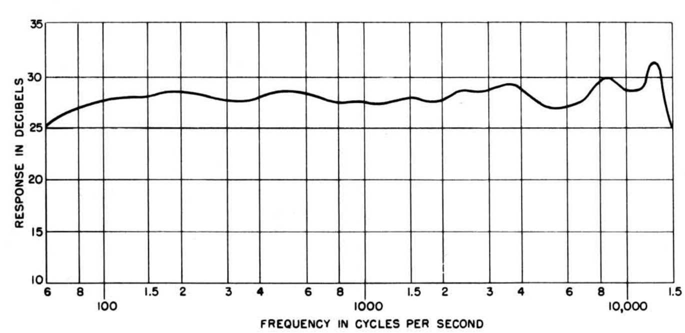


Fig. 7 – Response frequency characteristic of a pressure microphone element of the uni-pressure microphone.

low frequencies. In this way the loss in response in the low frequency range incurred by differential operation is reduced. The response frequency characteristic of a pressure microphone element of the uni-pressure microphone is shown in Fig. 7.

The electrical network used in the uni-pressure microphone is shown in Fig. 8. Transformers are used to step up the electrical impedance of the microphone units from 8 ohms to 2000 ohms. This step up in impedance makes it possible to use smaller parts in the phase shifting network. The network is of the lattice type.

A sectional view of the assembled microphone is shown in Fig. 9. A photograph of the parts is shown in Fig. 10. The main case of the microphone consists of two sections housing the units and electrical network. The two sections are connected by a perforated cylindrical member to allow sound access to the diaphragm of the rear microphone unit. The front diaphragm is protected by a small perforated hemispherical cap. The rear ends of the cylindrical sections are closed to insure pressure operation of the individual microphone units.

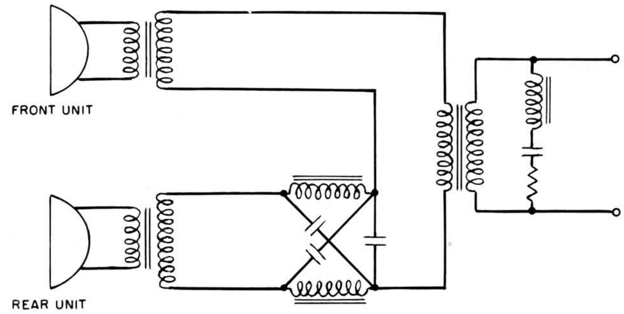


Fig. 8 – Electrical network of the uni-pressure microphone consisting of the pressure microphone units, the delay network and the transformer system.

The diffracting element used for maintaining directivity in the high frequency region consists of an aluminum shell in the form of a section of a prolate ellipsoid of revolution. The outside diameter of the ellipsoid is three inches.

A large cylindrical screen with hemispherical ends forms the outer screen for the microphone. This screen in addition to providing mechanical protection for the microphone also serves as a wind screen. A photograph of the complete microphone is shown in Fig. 11.

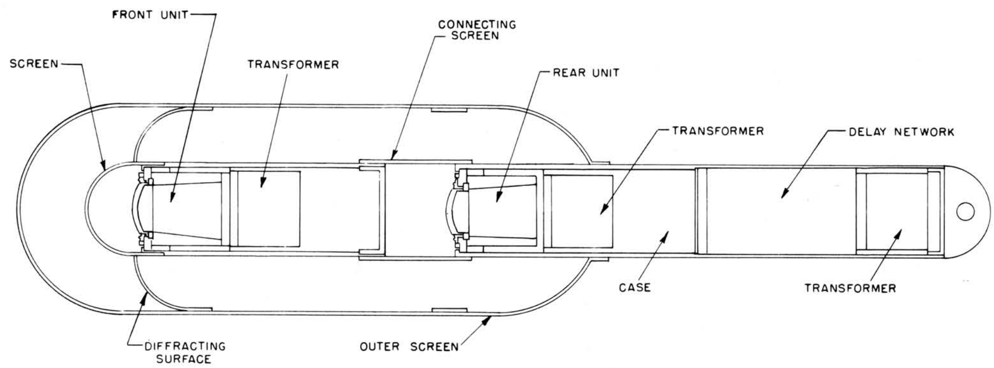


Fig. 9 – A sectional view of the uni-pressure microphone.

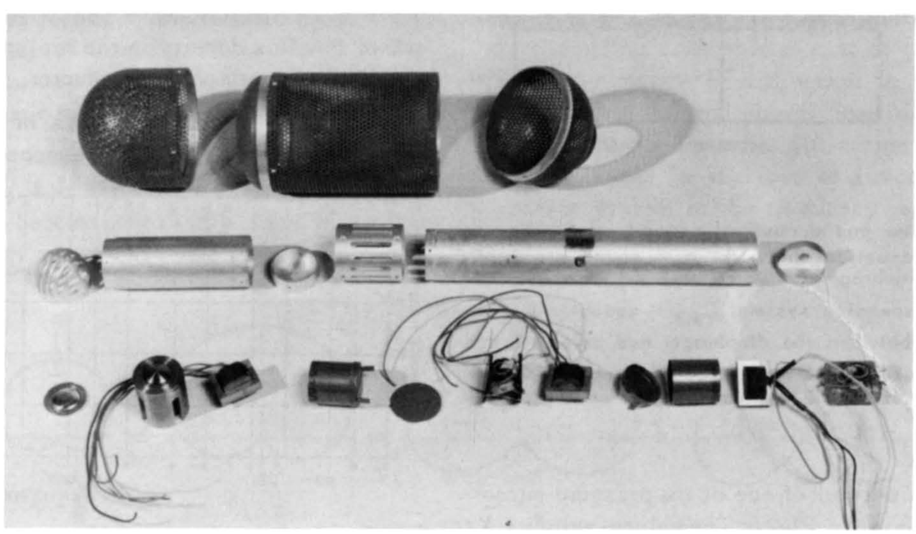


Fig. 10 – Exploded view of complete uni-pressure microphone, case and wind screen.

Fig. 11 – Completely assembled uni-pressure microphone.

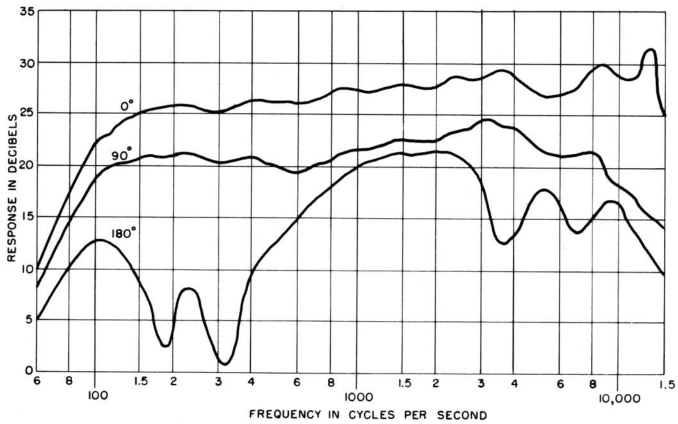
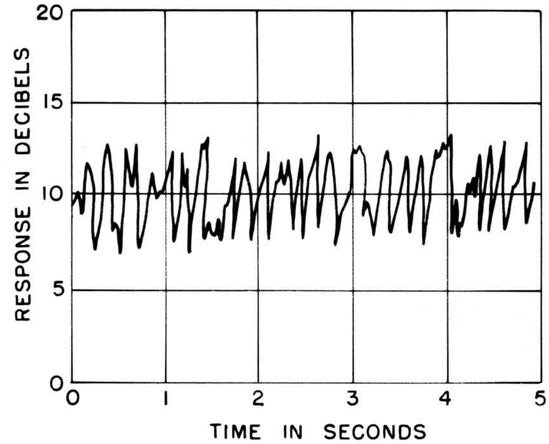
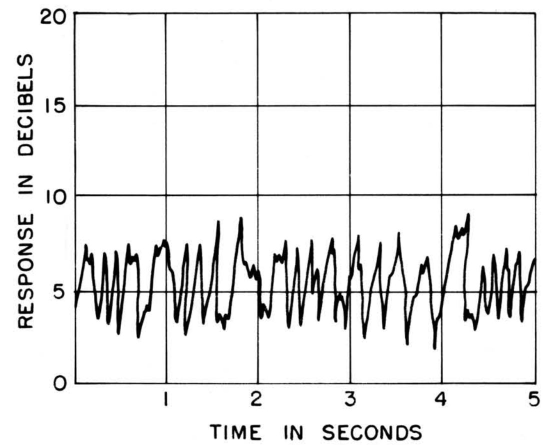


Fig. 12 – Response frequency characteristics of the uni-pressure microphone for sound incident at 0°, 90° and 180°. 0° corresponds to the cylindrical axis of the microphone.



A. Dynamic pressure microphone.



B. Uni-pressure microphone.

Fig. 13 – Wind response of microphones recorded on a high speed level recorder.

Performance

The response frequency characteristics of the uni-pressure microphone, for sound incident at angles of 0 degrees, 90 degrees, and 180 degrees with respect to the cylindrical axis of the microphone, are shown in Fig. 12. The response frequency characteristic for $\theta = 0$ degrees is uniform from 90 to 15,000 cycles. Furthermore, it will be seen that the discrimination at 90 degrees is very close to 6 *db* for the entire frequency range. This is the same as in the case of the cardioid pattern. With the type of response shown in Fig. 12, there will be no frequency discrimination in the front hemisphere of pickup. The discrimination for sound in the rear hemisphere ranges from *8* to *25 db* for the frequency range 80 to 15,000 cycles.

The wind response of the uni-pressure microphone as compared to a pressure microphone with the same sensitivity and response frequency characteristic is shown in Fig. 13. It will be seen that the wind response is somewhat less than a pressure microphone. This is because the two pressure microphone units are connected in opposition.

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