A bimorph microphone using composite piezoelectric polymer

Seiiti Shirai,* Takeshi Yamada,** and Juro Ohga***

*Yokosuka Electrical Communication Laboratory, NTT,
1-2356, Take, Yokosuka, 238-03 Japan
**Ibaraki Electrical Communication Laboratory, NTT,
Tokai-mura, Ibaraki, 319-11 Japan
***Musashino Electrical Communication Laboratory, NTT,
Midori-cho, Musashino, 180 Japan

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A microphone with simple construction, using a bimorph diaphragm made from a composite piezoelectric polymer sheet, is described. A composite of lead-titanate-zirconate powder and polyvinylidene fluoride and/or fluorinated rubber is useful, because its characteristics can be widely controlled by varying its composition, and it is easy to mold into a sheet. A symmetric bimorph structure using two composite polymer sheets is convenient for the structure. Microphone response is calculated, and it is concluded that a microphone, some 10-20 mm in diameter, shows of $-70$ to $-90$ dB response (re volt/microbar) as a telephone microphone. Several experiments confirm these results.

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1. INTRODUCTION

A piezoelectric device is characterized by a simple construction. A previous study on a piezoelectric telephone receiver or microphone structures concluded that the response even for the simplest structure, constructed only of a circular bimorph diaphragm and a slit damper, was as high as that for an electromagnetic transducer for the telephone.1) A conventional "bimorph," i.e., a laminated diaphragm, has been made using both a piezoelectric ceramic plate and a metal sheet. It still has several disadvantages due to the brittleness of the ceramic. For example, because a ceramic plate cannot be clamped rigidly, it is necessary to use a fragile wire, with one end soldered on the metalized surface of the ceramic opposite the metal sheet, to furnish an electric lead from the surface layer.

To overcome these disadvantages in the piezoelectric ceramic, several specific piezoelectric polymers have been studied so far.2) They are more soft, flexible and easily rollable as a wide film than the ceramic. Of practical interest among them is a polyvinylidene fluoride (PVDF) sheet, elongated by uniaxial stretch. A thin film of it (for example, 8-30 μm in thickness) has been utilized as a diaphragm for a microphone, a headphone and a tweeter in a loudspeaker system.3) Another interesting material is a composite piezoelectric polymer. This is a composite system of lead-titanate-zirconate ceramic (PZT) powder and PVDF and/or fluorinated rubber (FR).4) It is suitable for making rather thick film (more than 50 μm in thickness). A recently developed piezoelectric pressure sensitive tablet, for Kanji signal transmission, used a laminated board made of a composite piezoelectric polymer sheet (250 μm in thickness) and a printed circuit board.5)

Another merit of the composite polymer is that
its Young’s modulus can be controlled through variation in the ratio between PVDF and FR. This is convenient to design a diaphragm for an acoustical device. This paper describes a simple structure microphone utilizing a bimorph diaphragm made of piezoelectric composite polymer sheets.

2. COMPOSITE PIEZOELECTRIC POLYMER

The composite piezoelectric material consists of PZT ceramic powder (3~70 μm in size) and a continuous polymer binder, which is PVDF, FR or their mixture. Because the composite polymer is a plastic substance, it is easy to mold into a film of more than 50 μm in thickness.

Physical properties for several piezoelectric materials are shown in Table 1. The composite polymer shows a higher piezoelectric constant than elongated PVDF. Moreover, the ratio between its maximum and minimum Young’s modulus can be enlarged up to ten times. Relations between several physical quantities and compositions for PZT-PVDF-FR system are shown in Fig. 1. Its Young’s modulus shown in Fig. 1(a) relates to the ratio between FR and PVDF. However, its piezoelectric constant and dielectric constant relate mainly to the quantity of PZT powder. Therefore, Young’s modulus can be varied without a marked change in either piezoelectric constant or dielectric constant, by varying the ratio between PVDF and FR without PZT quantity change.

Another merit of the composite polymer is that its piezoelectric constant is excellently stable. Its piezoelectric d-constant shows no decrease in either a high environmental temperature, up to 120 degree centigrade, or in preservation at room temperature for a few years. It is also stable against soaking in water.

3. DIAPHRAGM STRUCTURE

Several sorts of diaphragm structures can be considered for a piezoelectric acoustical device. Figure 2(a) shows a simplified model of a conventional laminated structure, i.e., “bimorph,” diaphragm. Figure 2(b) shows a “shell” structure. Recently developed acoustical devices made of an elongated thin PVDF film utilized the latter structure. However, the bimorph structure is more convenient for

<table>
<thead>
<tr>
<th>Table 1 Physical properties of some piezoelectric materials.</th>
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<tr>
<td><strong>Piezoelectric ( d )-constant ((10^{-12} \text{C/N}))</strong></td>
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<tr>
<td>Composite piezoelectric polymer</td>
</tr>
<tr>
<td>Stretched PVDF</td>
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<tr>
<td>PZT ceramic</td>
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</table>

Fig. 1 Graphs of physical quantities for composite piezoelectric polymer. Compositions are shown in per cent of total weight.
(a) Young’s modulus \((10^9 \text{N/m}^2)\), (b) piezoelectric \(d_{31}\)-constant \((10^{-12} \text{C/N})\), (c) relative dielectric constant.
Fig. 2  Simplified models of a piezoelectric diaphragm.  
(a) Bimorph structure, (b) shell structure.

Fig. 3  Some actual structures for a bimorph diaphragm.  
a or b shows radius.  
Surface metal layer thickness is small enough to be negligible compared with sheet thickness.  
(a) Category A, conventional laminated piezoelectric/non-piezoelectric diaphragm.  
(b) Category B, laminated piezoelectric/non-piezoelectric diaphragm. Piezoelectric sheet is clamped by conductor rings.  
(c) Category C, diaphragm made of two piezoelectric sheets. Two sheets are polarized in opposite directions.

A diaphragm made of the composite polymer, because:
(a) Simple flat shape of a bimorph is convenient both to design a simple device and to handle in the manufacturing stage.
(b) The composite polymer is more brittle than the elongated PVDF film. Therefore, reinforcement by lining is desirable.
(c) The optimal thickness of the composite polymer sheet, between 50 µm and 0.3 mm, is extremely larger than that of the adhesive layer, which is several µm in thickness. Therefore, any effect due to inhomogeneity in the adhesive layer can be avoided.

Figure 3 shows some actual bimorph structures. The edge of the diaphragm, with radius a in every figure, should be clamped steadily for avoiding any mechanical insecurity. However, the edge of the "bimorph" part with radius b where the piezoelectric bending moment is generated by input electro-
motive force for receiver function, should not be clamped. Actually radius $b$ should be less than radius $a$. Category A, shown in Fig. 3(a), is a conventional structure, widely used as a laminated ceramic/metal diaphragm. Category B in Fig. 3(b) can be constructed when the piezoelectric sheet can be clamped. The surface metal layer out of radius $a$ should be removed for efficient bimorph function, except for a part for electrical connection. Category C shown in Fig. 3(c) shows a symmetrical bimorph made of two piezoelectric sheets. Two sheets are polarized in opposite directions and the output voltage is generated between metal layers on the upper and lower surfaces, which are also patterned after the shape shown in Fig. 3(b).

In these structures, Categories A and C are considered for the following response calculation. The reason is that the Category B diaphragm seems to be inferior to others, for the following reasons:

(a) Response for Category B is lower than that for Category C, because the diaphragm of the latter is of a symmetrical structure made of two piezoelectric sheets.

(b) Diaphragm for Category B seems to be more difficult to make into a firm diaphragm than that for Category A, because the diaphragm base for Category A need not show piezoelectricity. Therefore, it is possible to select firm material for the base without concern about any piezoelectric quality.

These factors have been confirmed by several experiments.

4. RESPONSE FORMULATION

Because a piezoelectric electroacoustical transducer is a reversible one, it is possible to calculate both its response for microphone function and that for receiver function. The microphone response is defined as follows

$$K_T = e_o/p_i,$$

where $e_o$ is output voltage when the electrical terminals of the transducer are open circuited, and $p_i$ is input sound pressure. The receiver response is defined as follows

$$K_R = p_o/e_i,$$

where $p_o$ is output sound pressure produced in a cavity put to the receiver, whose volume is denoted $V_c$, and $e_i$ is input voltage. Using the reciprocity principle, the relation between $K_T$ and $K_R$ is given by

$$K_T/K_R = j\omega V_c Z/\kappa.$$  \hspace{1cm} (3)

Here, $\kappa$ is volume stiffness of air and $\omega$ is angular frequency. If a slight vibration mode difference in the diaphragm between the microphone function (driven by air pressure) and the receiver function (driven by bending moment due to the piezoelectric effect) is neglected, Eq. (3) is valid for a piezoelectric transducer made with a bimorph diaphragm.

To simplify the response formulation procedure, $K_R$ is calculated and then converted into $K_T$, using Eq. (3). The notations described in Table 2 are employed. Ratios $\alpha$, $\beta$ and $\delta$ are defined as shown in the table, respectively. Additionally,

$$\eta = b/a, \quad \zeta = (1 - \alpha \beta^2)(1 + \alpha \beta).$$  \hspace{1cm} (4)

Volume displacement for the Category A diaphragm, shown in Fig. 3(a), for an $e_i$ input voltage, is given by

$$U_{sa} = (\pi/4)M_1a^4 \cdot \eta^2 (1 - \eta^2) \times \left[ \left( D_1'(1 + \mu_1) + D_2'(1 + \mu_2) + D_3(1 - \mu_3) \right) - \eta^2 \left( D_1'(1 + \mu_1) + D_2'(1 + \mu_2) - D_3(1 + \mu_3) \right) \right]^{-1}.$$  \hspace{1cm} (5)

Here, $M_1$ is the bending moment due to the piezoelectric force, given by

$$M_1 = Y_{1h3d4}e_i(1 + \beta)/2(1 - \mu_1),$$

where $d_{31}$ is piezoelectric $d$-constant for the piezoelectric sheet, and $D$ values represent the flexural rigidities, such that

Table 2 Nomenclature for calculation.

<table>
<thead>
<tr>
<th></th>
<th>Young's modulus $Y_1$</th>
<th>Poisson's ratio $\mu_1$</th>
<th>Thickness $h_1$</th>
<th>Density $\rho_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piezoelectric sheet</td>
<td>$Y_1$</td>
<td>$\mu_1$</td>
<td>$h_1$</td>
<td>$\rho_1$</td>
</tr>
<tr>
<td>Base</td>
<td>$Y_2$</td>
<td>$\mu_2$</td>
<td>$h_2$</td>
<td>$\rho_2$</td>
</tr>
<tr>
<td>(Ratio)</td>
<td>$\alpha = Y_1/Y_2$</td>
<td>$\beta = h_1/h_2$</td>
<td>$\delta = \rho_1/\rho_2$</td>
<td></td>
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</tbody>
</table>
If it is considered that the diaphragm is made both of a piezoelectric polymer sheet and of an ordinary polymer plastic sheet, it can be assumed that

\[ D_1' = \frac{Y_1h_1^3}{3(1-\mu_1^2)} \alpha \beta \left( \beta^2 + \frac{3}{2} \beta \zeta + \frac{3}{4} \xi^2 \right) \]

\[ D_2' = \frac{Y_2h_2^3}{3(1-\mu_2^2)} \left( 1 - \frac{3}{2} \beta \zeta + \frac{3}{4} \xi^2 \right) \]

\[ D_s = \frac{Y_3h_3^3}{12(1-\mu_2^2)} \].

(7)

If it is considered that the diaphragm is made both of a piezoelectric polymer sheet and of an ordinary polymer plastic sheet, it can be assumed that

\[ Y_1 \approx Y_2 \approx Y \quad \text{and} \quad \alpha \approx 1 \]

\[ \mu_1 \approx \mu_2 \approx \mu . \]

(8)

In such a case, both \( h_1 \) and \( h_2 \) should not be too small, in order to avoid any undesirable effect due to the adhesive layer. Thus, it is convenient that

\[ h_1 = h_2 \approx h \quad \text{and} \quad \beta = 1. \]

(9)

Then, it can be seen that

\[ \zeta = 0. \]

(10)

Therefore, Eqs. (5), (6) and (7) are reduced as

\[ D_1' \approx \frac{Yh^3}{3(1-\mu^2)} = D' \]

\[ \approx D_2' \]

\[ D_s = \frac{Yh^3}{12(1-\mu^2)} = D'/4 , \]

\[ U_{BA} \approx \frac{\pi}{4} M_s a^4 \frac{A^2(1-\eta^2)}{D'[8(1-\eta^2)(1+\mu) + (1-\mu) + \eta^2(1+\mu)]} . \]

(11)

and

\[ M_s = \frac{Yhd_s e_t}{2(1-\mu)} . \]

(12)

Volume displacement for the Category C diaphragm, shown in Fig. 3(c), is given by a similar procedure. Relations described as Eqs. (8), (9) and (10) are satisfied exactly, because both the upper and lower sheets are the same. Besides,

\[ D_s = \frac{3Yh^3}{4(1-\mu^2)} = 2D' , \]

(14)

because, all the diaphragm thicknesses are equal to \( 2h \). Therefore,

\[ U_{BC} = \frac{\pi}{16} M_s a^4 \frac{\eta^2(1-\eta^2)}{D'} . \]

(15)

Assuming that the diaphragm stiffness is much larger than that for cavity \( V_c \), output sound pressure \( p_o \) is given by

\[ p_o = \kappa U_{BA}/V_e . \]

(16)

Thus, receiver response, \( K_{RA} \) or \( K_{BC} \), is given by a formula

\[ K_r = \frac{\kappa}{V_e} \left( \frac{U_s}{e_t} \right) . \]

(17)

Then, the microphone response, \( K_{TA} \) or \( K_{TC} \), is given by using Eq. (5) as

\[ K_T = j\omega Z \left( \frac{U_s}{e_t} \right) . \]

(18)

Electrical impedance, \( Z \), for a piezoelectric transducer is purely capacitive, except at its resonant frequency, such that

\[ Z = 1/(j\omega C) . \]

(19)

where \( C \) is the capacitance. For Category A, it is given as

\[ C_A = e_p \pi a^2 h_1 , \]

(20)

and for Category C,

\[ C_C = e_p \pi a^2 h_2 , \]

(21)

where, \( e_p \) is relative dielectric constant for the piezoelectric sheet.

5. BIMORPH STRUCTURE COMPARISON

Here, responses, \( K_{RA} \), \( K_{BC} \), \( K_{TA} \) and \( K_{TC} \), are estimated to compare efficiencies for Categories A and C. To generalize this estimation, the simplest bimorph diaphragm model, shown in Fig. 4, is introduced as a reference.

![Fig. 4 Simplest bimorph diaphragm model as a reference. It is simply supported at its edge.](image)
Volume displacement produced by the model, due to $e_i$ input voltage, is given by

$$U_{BM} = \frac{(\pi/4)M \alpha^4}{[D_1(1+\mu)+D_2(1+\mu_2)]}.$$  \hspace{1cm} (22)

The moment $M$, in this formula is given by Eq. (6). If it is assumed that Eqs. (8), (9) and (10) are satisfied, $U_{BM}$ is reduced as

$$U_{BM} \approx \frac{(\pi/8)M \alpha^4}{[D'(1+\mu)]},$$  \hspace{1cm} (23)

where, $M$, is given by Eq. (13).

The receiver response and the microphone response for the reference model are denoted as $K_R$ and $K_T$, respectively. Then, it is possible to normalize $K_R$ and $K_T$ for Category A or Category C. From Eqs. (12), (17) and (23), normalized receiver response is given as

$$k_{RA} = K_{RA}/K_{RM} = \frac{8\eta^2(1-\eta^2)(1+\mu)}{(1-\eta^2)(1+\mu)+\eta^2(1+\mu)}.$$  \hspace{1cm} (24)

and, from Eqs. (15), (17) and (23),

$$k_{RC} = K_{RC}/K_{RM} = \frac{\eta^2(1-\eta^2)(1+\mu)/2}.$$

Assuming the 0.33 Poisson's ratio $\mu$ as a typical value, $k_{RA}$ and $k_{RC}$ are estimated as represented by the broken lines in Fig. 5. Receiver response for Category C is less than that for Category A, because stiffness in the circumferential region ($a \leq b$) for a Category C diaphragm is larger than that for a Category A diaphragm.

Microphone response is given by receiver response and capacitance. From Eq. (20)

$$C_A = \frac{e_i \varepsilon_{p} \pi a^2 h}{2\varepsilon_c},$$  \hspace{1cm} (26)

and the capacitance for the model, $C_m$, is

$$C_m = \frac{e_i \varepsilon_{p} \pi a^2 h}{2\varepsilon_c/\eta^2}.$$  \hspace{1cm} (27)

Thus, normalized microphone responses are given as

$$k_{TA} = \frac{K_{TA}}{K_{TM}} = \frac{C_m}{C_A} \frac{K_{RA}}{K_{RM}} = k_{RA}/\eta^2,$$  \hspace{1cm} (28)

and

$$k_{TC} = \frac{K_{TC}}{K_{TM}} = 2k_{RC}/\eta^2.$$  \hspace{1cm} (29)

Estimated $k_{TA}$ and $k_{TC}$ are represented by the solid lines in Fig. 5. The response for Category C, at the region where $0.5 \leq \eta \leq 0.7$, is as large as that for Category A. The reason for this result, which seems different from the receiver response case, is that capacitance $C_m$ is less than $C_A$.

Thus, it is concluded that the sensitivity of a microphone with a Category C bimorph diaphragm is as high as that of a microphone with a conventional structure, Category A, diaphragm. Moreover, the Category C diaphragm is characterized by a simple structure with no fragile lead wire. Therefore, only the Category C structure, for a microphone diaphragm made of composite piezoelectric polymer, will be dealt with the following section.

6. RESPONSE ESTIMATION

A convenient structure for a microphone and the formula for calculating its response were given in the previous section. The physical quantities for the composite piezoelectric polymer, necessary for the response calculation, were already given in Section 2. Therefore, it is now possible to estimate the available value for microphone response.

Microphone response is given by

$$K_{TC} = \frac{1}{C_0} \frac{U_{BC}}{e_i} = \frac{3}{16} \frac{d_{31}}{e_{p} \varepsilon_{p}} \frac{a^2}{h} (1-\eta^2)(1+\mu).$$  \hspace{1cm} (30)
In evaluating this, it is desirable to note the fundamental resonant frequency for the diaphragm, which determines the upper frequency limit, because the response is inversely proportional to it. Fundamental resonant frequency for the Category C diaphragm is given by

$$f_0 = \frac{(3.1961)^2}{2\pi} \frac{h}{a^2} \sqrt{\frac{Y}{3\rho(1-\mu^2)}}.$$  (31)

Thus, $k_{tc}$ is modified as

$$K_{tc} = \frac{\sqrt{3}}{32\pi} \frac{1}{f_0} \frac{d_{31}}{\epsilon_0 \epsilon_r (1-\eta^2)} \sqrt{\frac{Y(1+\mu)}{\rho(1-\mu)}}.$$  (32)

It can be seen that $K_{tc}$ for a given $f_0$ depends only on the radius ratio, $\eta$, and the physical quantities of the material. Namely, it is independent from diaphragm size, $a$ or $h$.

Smaller radius ratio, $\eta$, brings higher response. However, it also brings smaller electrical capacitance, $C_c$. Too small a capacitance causes an inadequate signal to noise ratio. For the estimation described here, it was decided that

$$\eta = 0.6,$$  (33)

refering to estimated $k_{tc}$ shown in Fig. 5.

For conventional telephone use, a microphone need not transduce input sound pressure for more than 3.4 kHz. Therefore, diaphragm resonant frequency, $f_0$, is designed to be 1 to 3 kHz. Under this condition, responses were estimated for three sorts of microphones, made of the following diaphragms:

1. Category C structure, made of composite piezoelectric polymer.
2. Category C structure, made of elongated PVDF film.
3. Category A structure, made of PZT ceramic and a brass sheet, whose response formula has already been given. Ceramic and brass sheet thicknesses are assumed to be equal.

Physical properties for these piezoelectric materials are shown in Table 1. For the brass sheet, $1.05 \times 10^{11}$ N/m$^2$ is used for $Y$, 0.33 for $\mu$ and $8.39 \times 10^3$ kg/m$^3$ for $\rho$.

Figure 6 represents relations between ratio $a^2/h$ and resonant frequency. Solid lines, and the hatched area enclosed by them, show the region in which the resonant frequency, $f_0$, is between 1 and 3 kHz. Figure 7 represents relations between microphone response and ratio $a^2/h$. The region in which $f_0$ is $1 \sim 3$ kHz is also shown. From these estimations, it can be seen that this bimorph microphone with a composite piezoelectric polymer diaphragm is convenient for use in constructing small diameter microphones, and that this microphone shows a practically allowable response (from some $-90$ dB to $-70$ dB) in all the convenient resonant frequency region.

Figure 8 represents relations between diaphragm diameter and thickness $h$ (half of the total bimorph thickness). Diaphragm for the composite bimorph microphone can be less than 10 mm in diameter,
without using a very thin piezoelectric sheet.

7. EXPERIMENTAL

This section describes some results obtained by checking characteristics for the composite bimorph microphone structure on the bases of several experiments. First, microphone diameter is discussed. The conventional smallest size microphone model for a telephone set was the TR-70 electromagnetic transducer, whose diameter was 23 mm and whose diaphragm diameter, 2a, was 20 mm. Referring to Fig. 8, we can see that the following two diameters will be convenient for the presently discussed microphone.

Size (m): 2a = 17 mm (assuming some 22 mm microphone size).
Size (s): 2a = 9 mm (some 13 mm size).

Figure 9 represents relations of quantities $\sqrt{Y/\rho}$, thickness h and resonant frequency $f_0$, for bimorph diaphragms in these two diameters. It also shows the characteristics of some composite piezoelectric polymer sheets made for experiments. As is seen, the composite polymer could be molded to a sheet whose thickness is between 70 and 250 $\mu$m.

So far, two kinds of acoustical (i.e., mechanical) system construction have been determined for a telephone microphone to make the resonant frequency as low as possible, and to assure compatibility between sufficient frequency range and high efficiency. They are:

- System (a): Two degree-of-freedom system, including two poles on its frequency characteristics. Resonant frequency for its diaphragm should be 2~2.5 kHz.
- System (b): Three degree-of-freedom system, including three poles. The resonant frequency should be 1~1.5 kHz.

It is concluded from Fig. 9 that, for the size (m) microphone, both systems (a) and (b) can be constructed using the experimentally made piezoelectric composite sheets. However, the size (s) microphone can only be made by constructing system (a), i.e., the two degree-of-freedom system.

Table 3 describes some experimental results concerning the microphone response at a low frequency, and the resonant frequency. Samples A, B and C are size (m) models. Samples B and C utilized polymers with larger Young's modulus. Sample B was assumed to be for a two degree-of-freedom system, and sample C was assumed to be for a three degree-of-freedom system, by using thin sheets. Sample D was a size (s) model.
Actual response values were measured by acoustical driving technique using a coupler and a standard receiver. Responses for individual samples were about 13 dB lower than the estimated values. Some of the reasons are enumerated as follows:

(1) Increase in apparent diaphragm stiffness:

The actual resonant frequencies were higher than those calculated. Causes are both increase in the apparent diaphragm stiffness, due to the adhesive layer effect or unavoidable static tension, caused by clamping, and decrease in the effective diaphragm mass, due to the change in the vibrating mode. The former brings about a decrease in the response.

Table 4 describes some measured quantities for diaphragm samples A and D. Their measured effective diaphragm areas were equal to or less than those calculated. Assuming that the effective mass is proportional to this area difference, it is possible to estimate apparent diaphragm stiffness increase from the calculated value, using the resonant frequency increase. As shown in Table 4, the results, which give response decrease, were 3.6 dB or 4.5 dB.

(2) Capacitance increase by the clamped part of the diaphragm:

As is suggested by Figs. 3(b) and (c), the capacitance between two clamp rings is unavoidably joined parallel with the microphone capacitance. For example, the capacitance due to only the bimorph part of sample A was 560 pF, the capacitance due to its clamp rings was 310 pF and the coaxial lead for the measurement was 90 pF. Therefore, apparent response was estimated to be −4.7 dB lower than that when there were no outer capacitances.

Thus, 8.3 dB out of 14 dB for the response decrease from the calculated value for sample A can be explained. Consideration about other causes for the response decrease will be a topic for future research.

However, these measured response, −81 dB for model (m) and −90 dB for model (s), are sufficient for practical purposes. Therefore, their frequency response is studied in the next stage.

Figure 10 shows the concept of a microphone con-
Fig. 10 Concept of a microphone constructed as a three degree-of-freedom system.

Fig. 11 Equivalent circuit of a microphone shown in Fig. 10, for a size (m) model.

Fig. 12 Measured and estimated frequency response for a size (m) microphone.

Fig. 13 Measured response of both a size (m) model and a size (s) model.

Fig. 14 Practical construction of a size (m) microphone.

Fig. 15 Measured responses of some practical microphone models.

Sound pressure (mouth piece) $m_1, r_1$

$\pi \cdot 1$

$m_1, r_1$

$S_0, m_0$

(damper)

Fig. 10 Concept of a microphone constructed as a three degree-of-freedom system.

Fig. 11 Equivalent circuit of a microphone shown in Fig. 10, for a size (m) model.

Fig. 12 Measured and estimated frequency response for a size (m) microphone.

Interpreting the necessary upper frequency limit following a conventional telephone microphone design, it is possible to design the acoustical construction for a size (m) microphone by a simulation technique using an equivalent circuit shown in Fig. 11 and the physical quantities of the diaphragm given in Table 4. Figure 12 shows measured and simulated frequency response. They agree satisfactorily. Here, a nonwoven fabric sheet was used as the acoustical damper.

Frequency response for the size (s) model was designed in a similar manner. Microphone responses for both models are represented in Fig. 13. They seem somewhat to be over-damped, considering use for a telephone microphone.

Finally, some practical structure microphone model having improved frequency response were made to confirm the present microphone construc-
tion. Figure 14 shows the size (m) model, for example. The frame was made to be reliable for repeated diaphragm exchange during measurements. Therefore, its volume, or diameter, can be reduced in a mass production stage.

Responses for the models are represented in Fig. 15. They were satisfactory for telephone microphones.

8. DISCUSSIONS AND CONCLUSIONS

Characteristics for the composite polymer bimorph microphones are compared with some conventional microphones, whose diameters are 10–20 mm, as shown in Table 5. Responses for the composite polymer microphones are as high as that for a ceramic bimorph microphone or an electromagnetic microphone, and their electrical impedances are moderate.

Simple construction of the composite polymer microphone is also a merit. Some weak structures for conventional microphones, such as fragile lead wires for a ceramic bimorph and an electrodynamic microphone, or a thin air gap for a condenser and an electromagnetic one, can be obviated.

Reliability of the composite polymer diaphragm has not been mentioned in this paper, because durability of a laminated structure made of the composite polymer has already been proven in the development procedure for a piezoelectric pressure sensitive tablet.7)

This paper describes the proposal of and investigation on a microphone using a bimorph diaphragm made of composite piezoelectric polymer sheets. Conclusions reached are:

(1) The composite made of PZT powder and PVDF and/or FR shows useful performance. For example, its Young’s modulus can be controlled without a marked change in both piezoelectric d-constant and dielectric constant by varying the ratio between FR and PVDF, and it can be easily molded into a sheet.

(2) A symmetric bimorph structure using two piezoelectric polymer sheets is shown to be useful from microphone response calculations and comparison of several bimorph diaphragm structures.

(3) Response of the symmetric bimorph microphone made of the composite piezoelectric polymer calculated to be −70−90 dB (re volt/microbar).

This value was confirmed experimentally.

(4) A three degree-of-freedom acoustical system can be applied to a microphone with some 20 mm in diameter. Two degree-of-freedom system is convenient for a microphone with some 10 mm in diameter.

As a whole, utility of this microphone was investigated by trial manufacture of several practical models. One of the future studies is explanation of the difference, in a few decibels, between calculated and measured response values.

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