CHAPTER VII

APPLICATIONS OF ELECTRETS: MICROPHONE
This chapter describes the use of the foil electrets in microphones, for converting the sound energy into electrical energy.

VII.1 Introduction

Conventional air gap condenser microphones have many desirable features, such as a flat frequency response, a good impulse response, and low distortion. However, two shortcomings have limited their use in practical applications.

(a) The small capacitance of these microphones, approximately $10 \, \mu\text{F/cm}^2$, in a relatively high impedance, necessitating elaborate input amplifiers to ensure a flat low frequency response.

(b) A dc bias usually of the order of 200 volts is required to operate the microphone. Several methods have been proposed to eliminate these shortcomings.

The rather low capacitance of the conventional condenser microphones is, primarily, due to the wide separation between the electrodes and the use of air as dielectric.

The condenser microphone with a very high capacitance (of the order of $50 \, \mu\text{F/cm}^2$) is possible by using a thin metallized dielectric film placed next to a solid back plate with minimum air gap. Such a study was made by Matsuzawa (117). He prepared various condenser microphones each of which consisted of a metallic backplate and a thin
plastic film stretched over the backplate in direct contact with it at a number of points. The surface of the backplate was rouphened or provided with grooves, hollows or holes, while the external surface of the plastic film was made conducting by metallizing it.

This type of thin film condenser microphone increased the capacitance. A d.c. bias is still required to operate the solid dielectric microphone.

The elimination of the d.c. bias had been achieved by several methods. For instance, microphones using thick wax electrets (118) have been described. When these electrets are placed between the electrodes, the resulting capacitance of the system is relatively low; thus a high input impedance amplifier is required. Also the lifetime of the wax electrets is relatively short. Another well known possibility to eliminate the d.c. bias is the use of the microphone to modulate a carrier frequency (119). In this case, additional electronic circuitry is necessary (to reduce self-noise of the circuit).

A new kind of condenser microphone with solid dielectric between the electrodes was found (120) by Sessler and West in Bell laboratories. The electrostatic polarization which makes the foil an electret, can aid or oppose the applied d.c. voltage. The expected advantages of systems with foil electrets suggested the polarization of thin foils. The increasing interest in these new forms
of useful devices encouraged the development of new techniques of formation of thin foil electret.

Several valuable features have been investigated by Sessler and West. These have excellent sound fidelity of the former type of condenser microphones, but do not need a d.c. supply and have much lower electrical impedance. This permits good low frequency response without the need of special matching circuits.

The new type of microphone is inexpensive, exceptionally rugged and immune to wide temperature fluctuations. These microphones were found to remain sensitive which is found to be essentially constant for very long periods. This is due to an inherent compensation, which is only possible with thin film electrets. As the charge on the electret decays, the electrostatic attraction between electret and backplate is reduced. This diminishes the restoring force on the electret, allowing it to vibrate at greater amplitude. The electrical output signal remains, therefore, very constant.

The electrets in thin foils as fluorocarbon, polycarbonate and polyester are expected to retain their polarization for several years.

The small dimensions of the microphone cartridge ~ 5 mm in any direction, and the use of integrated circuitary facilitate miniaturization of the equipment. The low internal and mechanical noise level enables the microphone to be
incorporated in the chassis of tape recorders. The same microphone operating in the reverse sense functions as a loud speaker. Very small unidirectional microphone can replace the directional condenser microphone, and thus it can prove very useful in the external sound recording systems.

A theory for electret microphone is developed by Sessler (63). The resonance frequency was determined by the restoring force and the mass of the foil. The restoring force is mainly determined by the elasticity of the air gap which in turn depends upon the effective thickness 's' of the air cushion behind the foil by an additional cavity connected to the air gap by small holes. The resonance frequency

$$\omega_r = \left( \frac{p_0}{sM} \right)^{1/2}$$ (7.1)

($p_0$ is the atmospheric pressure and $M$, the mass per sq.cm. of the foil) is usually at the upper end of the audio range or higher. The sensitivity of the electret microphone below resonance was calculated to be

$$Q_m = \frac{4\pi\sigma d_2 s}{(\varepsilon_3 \varepsilon_0 + \varepsilon_1 d_{30}) p_0}$$

where $\sigma$ is the charge density, $d_2$ is the thickness of the foil electret and $d_{30}$ is that of the air gap. $\varepsilon_1$ is the dielectric permittivity of the insulating layer between the upper metallic film and the charged layer below the
surface of the dielectric, and $\varepsilon_3$ is that of the air gap $d_{30}$.

Thus, the analysis shows that neither resonance frequency nor the sensitivity of the electret microphone depends on the diameter of the system.

VII.2 Experimental techniques

(a) Preparation of electret

The results of the present methods of electret formation and their properties were used for the construction of microphone. Radio electrets of melinex were employed as the thin membranes in the microphones.

Sessler and West used various materials in the form of thin films as fluorocarbon, polycarbonate and melinex etc., in their microphones, which were prepolarized by thermal and electrical treatment (33).

In the present study the melinex electrets, used as transducers, were polarized by penetrating radiations as described in art. III.2. The film was metallized by vacuum deposition on one of its surfaces with aluminium. Optically thin films were obtained. The metallized film was stretched on the perspex ring (See Fig. 7.1) which was kept over the backplate, so as to face the unmetallized surface of the film. The backplate was provided with small holes constituting a cover for a small air cavity. The air cavity served as a reservoir of air, helping the film
A - CYLINDRICAL CAVITY:

- electret
- perforated backplate
- perspex ring
- Al. cavity
- shield

B - SEMISPHERICAL CAVITY:

- electret
- insulating cover
- perforated backplate
- Al. air cavity
- shield of wire mesh
- brass ring

C - PARABOLIC CAVITY:

- Foil electret
- perspex ring
- metal cover
- parabolic cavity of Aluminium

SECTIONAL VIEW OF ELECTRET MICROPHONES

FIG-7.1
FOIL ELECTRET MICROPHONE
to freely vibrate over the backplate. On the other hand the air cavity helps in introducing a thin molecular layer of air between the backplate and the metallized melinex foil.

The film was irradiated by gamma rays falling normally on its surfaces, while a high electric field was applied to the electrodes. After two hours the field was removed and the melinex foil was polarized.

(b) Measurement of the frequency response

The frequency response of the electret microphone was studied with the help of a standard reference condenser microphone† type U 67 (Neumann model). The microphone was calibrated in a free space. The field free response of the reference microphone was used to determine the free field sound pressure at a certain point, namely 6 inches from the speaker. The experimental microphone was inserted at the same point and its response determined, over the same frequency range which had been employed for the standard microphone. The response in decibels was calculated using the expression

\[
\text{Response in decibels} = 20 \log \frac{E/P}{E_o/P_o} = 20 \log E/P + 20 \log P_o/E_o
\]

(7.3)

† This condenser microphone was provided by 'The Film Institute of India', Poona.
where
\[ P = \text{free field or undisturbed sound pressure in dynes per square centimeter, as measured in a progressive plane sound wave, the microphone being placed at a normal incidence with respect to the wave front.} \]

\[ E_0 = \text{reference potential in volts.} \]

\[ P_0 = \text{reference pressure in dynes per square centimeter.} \]

When \( E_0 = 1 \text{ volt and } P_0 = 1 \text{ dyne per square centimeter} \),
the response in decibels = \( 20 \log \frac{E}{P} \).

VII.4 Statement of results

(a) Frequency response

A few experiments were carried with electret microphones in which their frequency responses were measured. These were fabricated using different shapes for the cavity below the backplate. The schematic diagrams of these microphones are shown in Fig. 7.1 for three different shapes of the cavities.

The volume of the semispherical cavity was equal to 6 c.c. The area of the electret exposed for the sound pressure was 3 cm. in diameter. The density of holes in the backplate was 30 holes per square centimeter. The thickness of the aluminium deposition over one of the surfaces of the electret foil was of the order of 100 Å, while, the thickness of the foil was 0.01 cm. The mass of the foil per square centimeter of its area was equal
to 1.8 gms. The electrets were prepared with \( \gamma \)-radiations at a field strength of 300 kV/cm. The sensitivity of the microphone calculated by Eqn. (7.3) was found to be equal to -87 dB at 1000 Hz at a sound pressure of 1 dyne per sq.cm. The output impedance of the microphone measured by an a.c. bridge was found to be equal to 8 \( \mu \)F. The capacitance of the system was of the order of 103.0 \( \mu \)F.

The frequency response for this microphone is shown in Fig. 7.2(a). The response is considerably flat from 50 Hz upto 4 KHz, with a few fluctuations.

The second design of the microphone containing a cylindrical cavity is shown in Fig. 7.1(b). The volume of the cavity was equal to 4 cubic centimeters. The other parameter (the area of the diaphragm, output impedance, and the capacitance of the system) remained same.

The sensitivity was found to be -92 dB at 1000 Hz at a sound pressure of 1 bar per square cm. A nearly flat portion was obtained in the frequency range of 1500 Hz to 400 Hz (See Fig. 7.2 (b)). This response was not very satisfactory.

Another design of the microphone is shown in Fig. 7.1(c) in which a parabolic cavity was employed. The volume of the air cushion was kept equal to 1.37 cubic centimeters. The corresponding frequency response is shown in Fig. 7.2(c). The sensitivity of the microphone was -62 dB per \( \mu \) bar at 1000 Hz.
Fig. 7.2a Frequency response of cylindrical cavity electret microphone

Fig. 7.2b Frequency response of semispherical cavity electret microphone

Fig. 7.2c Frequency response of parabolic cavity electret microphone
The design may be modified further by employing a shallow parabolic cavity.

(b) **Directional characteristic**

The directional characteristics of any microphone show the response of the microphone for the sound waves incident on the membrane in all possible directions (i.e. from $0$ to $180^\circ$). The microphone being most sensitive for the normal incidence which is taken as the zero angle.

The directional patterns are named as (a) 'non-directional', (b) 'omnidirectional', (c) 'bidirectional', (d) 'super cardioid' and (e) 'Hyper cardioid'. These are shown in the Fig. 7.3.

![Fig. 7.3](image)

The directional characteristic of the electret microphone with a cylindrical air cavity is presented in Fig. 7.4. The result shows that the electret microphone can be used as a directional microphone. The directional pattern for an unidirectional microphone, given by Rettinger (121) for an 'ideal' unidirectional microphone is similar to the one obtained in the present study. This indicates that
the voltage output from the unit is zero for a plane-
wave sound incident at $180^\circ$ and is the same for all fre-
quencies for all planes through the microphone at right
angles to the moving element. In practice, however, can-
cellation (reduction of pickup from the rear) rarely exceeds
20 decibels and varies somewhat with the frequency and the
plane through the unit.

This type of directional characteristic is called
'cardioid'.

The survey of sales literature and of field installa-
tion indicates that the unidirectional microphone has
become an immensely popular transducer. In the motion
picture studios 90% of all dialogue recording is done with
such units.

From the results obtained it is concluded that highly
sensitive and good quality microphones can be obtained by
using thinner fluorocarbon foils, which is one of the best
known materials which can be used in microphones. In any
capacitor, thinner the dielectric the higher the capacitance.
Dielectric films can be made 0.00012 to 0.001 inch thick.
This type of very thin foils will prove useful in improving
the sensitivity, frequency response and life of the electret
microphone.

The radio electrets will prove themselves to be useful
when a repolarization is required, to restore the response.
The process of polarization by radiations is so simple that this would not disturb the other physical conditions of the microphone.