# Condenser Microphone

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***Abstract*—For the application of accurate voice reproduction, a cost-effective condenser microphone design is considered. Analysis of theoretical characteristics such as sensitivity, dynamic range, and signal-to-noise ratio is presented. In conclusion, quantitative measurements from a working prototype are corroborated with the theoretical analysis.**

***Keywords*—Capacitive, Condenser, Microphone.**

## I. Introduction

THE accurate transduction of sound into an electrical signal is naturally useful for conveying the human voice. People generally speak at 40 to 60 dB SPL and can hear sound from 20 Hz up to 20 kHz with especial sensitivity to the 1 to 4 kHz region.[1] For the application of accurate sound reproduction, the designer should strive for unity-gain response in these ranges, particularly in the 1 to 4 kHz range.

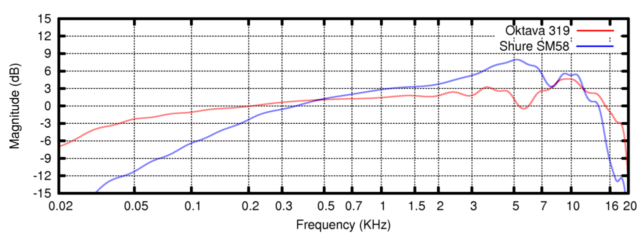



Fig. 1: *Oktava MK-319 condenser microphone[2] and Shure SM58 dynamic microphone[3] (20 Hz to 20 kHz)*

A variety of devices exist for transducing sound. Of commercially viable designs, condenser and dynamic microphones are the most common.[4] Fig. 1 plots the responses of a condenser microphone and a dynamic microphone. The condenser mic (in red) experiences less attenuation at the extremes and provides greater uniformity in between. It is not unusual for condenser mics to have an upper 20 kHz frequency limit compared to the typical 16 kHz limit experienced by dynamic mics.[5] Additionally, the condenser microphone has notably less gain in the 1 to 4 kHz region people are most sensitive to, providing a more balanced response. Generalizing these results, condenser microphones are preferable for applications desiring accurate reproduction.

## II. Sensor Structure and Measurement Principle

The diaphragm portion of the condenser microphone has a cylindrical form-factor. Its vertical cross-section is depicted in Fig. 2. The diaphragm itself is a thin, tensioned membrane which is responsive to sound pressure in the target frequency range. The back-plate is a rigid structure with distributed holes leading to an internal cavity. Between the membrane

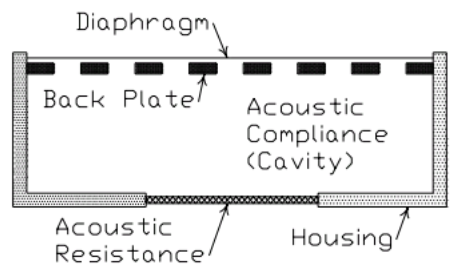



Fig. 2: *Diaphragm system vertical cross-section[6]*

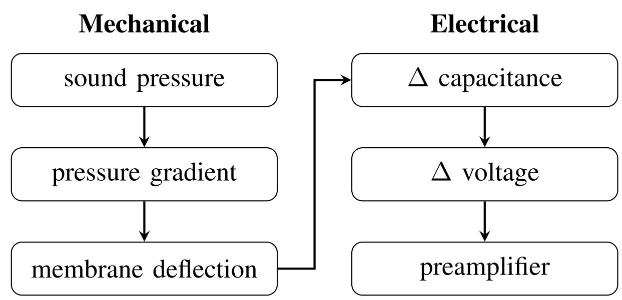


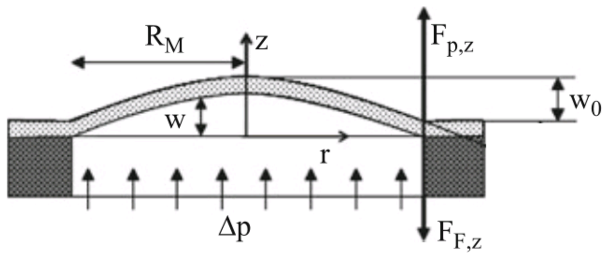

Fig. 3: *Transducer signal chain, first the mechanical process, then the coupled electrical response*

and the back-plate is the air-gap which forms the condenser dielectric. An acoustic resistance at the rear of the internal cavity serves as a normalizing vent, allowing the cavity to equalize to atmospheric pressure.

Condenser microphones convert sound pressure into a voltage signal by the process shown in Fig. 3. In the process, sound pressure gives rise to a pressure gradient which causes deflection across the condenser diaphragm. Membrane deflection in turn causes the capacitance of the condenser to vary. Variations in capacitance produce corresponding changes in voltage on the biasing circuit the condenser is tied to. The resultant AC small-signal can then be extracted from the circuit and fed through a preamplifier to obtain a low output impedance voltage signal representing the source sound.

### A. *Membrane Deflection*

When sound pressure impinges upon the membrane, it oscillates with the pressure according to its mechanical properties. Fig. 4 shows modeled parabolic deflection in cylindrical coordinates. The model assumes sound pressure is uniformly distributed across the face of the membrane. This produces purely vertical membrane oscillation along the $z$-axis in cylindrical coordinates, with the apex deflection $w_0$ occurring at the




$$\Delta p = \frac{4w_0 d_m}{R_M^2}\frac{E_M}{1-v_M^2}\left(\frac{4}{3}\frac{d_M^2}{R_M^2}+\sigma_0+\frac{64}{105}\frac{w_0^2}{R_M^2}\right) \quad (1)$$

$$w(r) = w_0\left(1-\frac{r^2}{R_M^2}\right) \quad (2)$$

| Symbol | Description |
|---|---|
| $r$ | radius in cylindrical coordinates |
| $R_M$ | membrane radius |
| $d_M$ | membrane thickness |
| $w$ | deflection along $z$-axis at a particular radius |
| $w_0$ | apex of deflection, equal to $w(r=0)$ |
| $P_0$ | atmospheric pressure |
| $\Delta p$ | change in pressure relative to $P_0$ caused by sound |
| $F_{p,z}$ | force due to uniform pressure across membrane |
| $F_{f,z}$ | force due to membrane tension and frame |
| $\sigma_0$ | residual stress, modeled with $\sigma_0 = 0$ |
| $E_M$ | Young's Modulus of elasticity for the membrane |
| $v_M$ | Poisson's ratio for the membrane |

Fig. 4: *Modeled parabolic membrane deflection owing to uniform sound pressure*[7]

center of the membrane owing to the maximized moment arm at that point.

Setting residual stress $\sigma_0 = 0$, we can solve for the apex deflection using the relation shown in Eq. 1[7]. The apex deflection $w_0$ can then be used to calculate the modeled parabolic deflection at any radius $r$ with Eq. 2.

### B. Capacitance

Let the back-plate be held at $z = h_0$ above the membrane to create the dielectric air-gap. Assume there is sound pressure and the membrane has a positive apex deflection $w_0 > 0$ and is deflected up towards the back-plate. If we treat the face of the membrane as a collection of cylindrical area differentials with $dA = r\,dr\,d\theta$ we can find the total capacitance under deflection by integrating the differential capacitances $dC$ as shown in Eq. 3 and 4.

$$\int_A dC = \int_A \frac{\epsilon_0\,dA}{h_0 - w(r)} \quad (3)$$

$$C = \frac{\pi\epsilon_0 R_M^2}{w_0}\ln\left(\frac{h_0}{h_0-w_0}\right) \quad (4)$$

### C. Voltage

## III. Conclusion

The conclusion goes here.

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