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 is presented. Quantitative measurements from a working prototype are then 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.

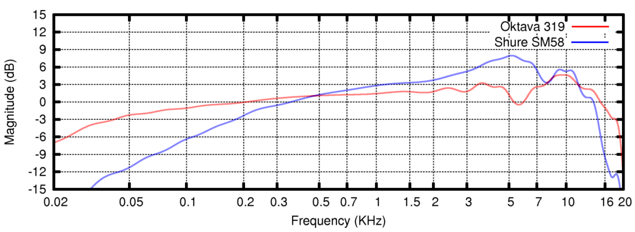

Fig. 1: *Oktava MK-319 condenser microphone[2] and Shure SM58 dynamic microphone[3] (20 Hz to 20 kHz)*

A variety of devices exist for transducing sound. Of commercially viable designs, condenser and dynamic microphones are the most common.[4] Fig. **??** 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. **??**. 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 perforations leading to an internal cavity. Between the membrane 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 P_0.

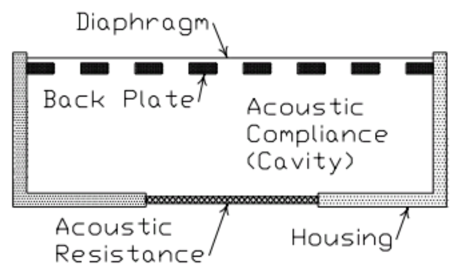

Fig. 2: *Diaphragm system vertical cross-section[6]*

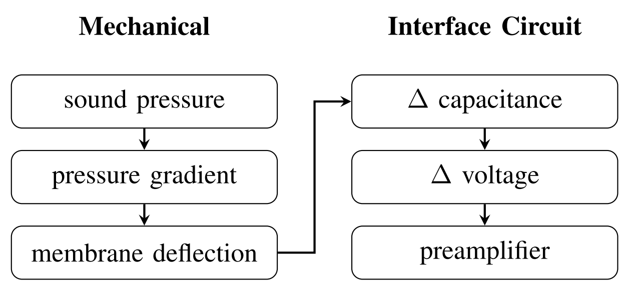

Fig. 3: *Transducer signal chain, first the mechanical process, then the interface circuit*

Condenser microphones convert sound pressure into a change in capacitance by the process shown in Fig. **??**. 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.

A. Membrane Deflection

When sound impinges upon the diaphragm, the membrane oscillates with the sound pressure according to its mechanical properties. We model the deflection with a parabola as shown in Fig. **??**. The parabolic model assumes sound pressure is uniformly distributed across the face of the membrane and the membrane movement is purely vertical along the z-axis (cylindrical coordinates). The apex deflection w_0 occurs at the 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 w_0 using the relation shown in Eq. **??**.[7] This value can then be used to calculate the modeled parabolic deflection at any radius r with Eq. **??**.

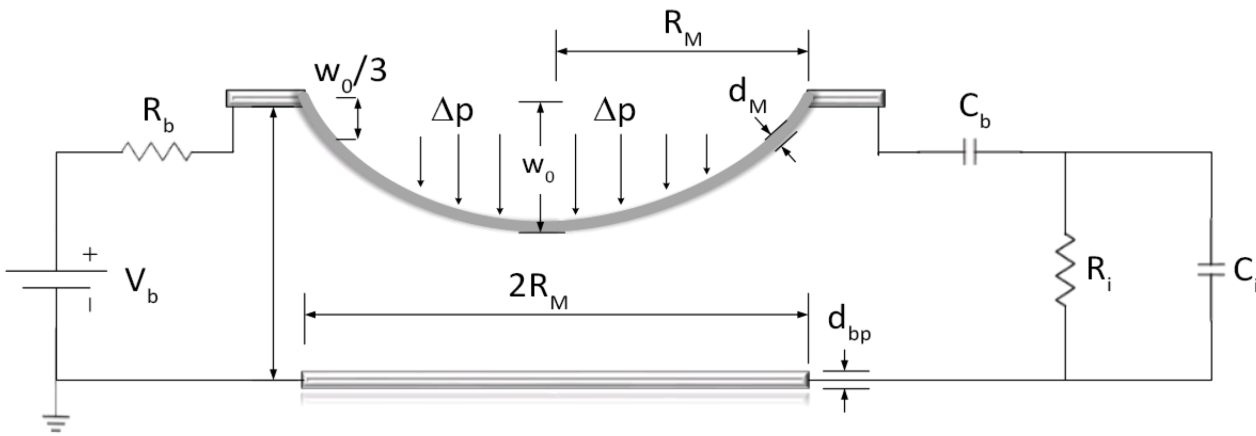

Fig. 4: *Mechanical diaphragm system undergoing deflection while coupled to first part of interface circuit*

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

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

$$C_0 = \frac{\epsilon_0 \pi R_M^2}{h_0} \quad (3)$$

$$\begin{aligned}\int_A dC &= \int_A \frac{\epsilon_0\, dA}{h_0 - w(r)} \\ &= \int_0^{R_M}\int_0^{2\pi} \frac{\epsilon_0 r}{h_0 - w(r)}\, d\theta\, dr \\ C &= \frac{\epsilon_0 \pi R_M^2}{w_0} \ln\left(\frac{h_0}{h_0 - w_0}\right)\end{aligned} \quad (4)$$

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 $w(r=0)$
Δp	change in pressure relative to P_0 caused by sound
σ_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
h_0	dielectric air-gap

Fig. 5: *Equations for modeling (i) parabolic membrane deflection due to sound pressure, (ii) resulting capacitance*

B. Capacitance

Let the back-plate be held at $z = h_0$ away from the membrane to create the dielectric air-gap. When there is no deflection, the condenser has capacitance described by Eq. **??**.

Assume there is sound pressure and the membrane has a positive apex deflection $w_0 > 0$ so it is deflected towards the back-plate. If we treat the face of the membrane as a collection of differential parallel-plate capacitors with area $dA = r\, dr\, d\theta$, we can integrate to find the total capacitance as shown in Eq. **??**.

III. Interface Circuit

The interface circuit is the portion of the design responsible for converting variations in capacitance across the condenser into a low impedance voltage signal. It does so in two steps, as shown in Fig. **??**. First the AC small-signal is extracted to obtain a high output impedance voltage signal using the coupling circuit in Fig. **??**. This signal is then transformed into a low output impedance voltage signal using a preamplifier. The final signal can be sent much longer distances without noticeable degradation.[8]

Fig. **??** represents the small-signal equivalent model of Fig. **??**. The interface circuit is inherently non-linear, so analyzing its small-signal equivalent model is an effective method of linearizing the relationship between capacitance and output voltage. In the small-signal equivalent model:

1) The DC-blocking coupling capacitor C_b is shorted;
2) The polarizing DC-only voltage source V_b is shorted;
3) The condenser's varying capacitance ΔC itself is modeled as a small-signal current source i_c

Note that when the polarizing voltage V_b is shorted in the small-signal model, current-limiting resistor R_B is now in parallel with the other devices in the interface circuit, particularly because coupling capacitor C_B is modeled as a short in the small-signal model. Thus, since all elements are in parallel, no additional analysis Miller approximations, for example will be necessary. The result is a simplified Norton circuit with small-signal source seen in eq.**??** and impedance

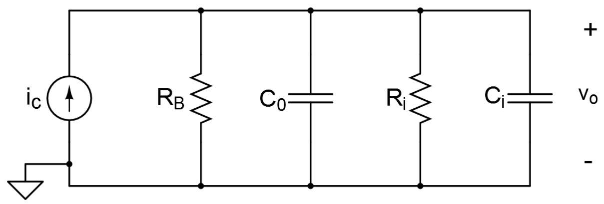

Fig. 6: *Small-signal equivalent model of interface circuit*

seen in Eq.**??**

$$i_c = (j\omega \Delta C)V_b \tag{5}$$

$$Z_eq(s) = Z_R||Z_C = \left(\frac{R}{1+sCR}\right) \tag{6}$$

where

$$Z_R = R_b||R_i \tag{7}$$

$$Z_C = C_0 + C_i \tag{8}$$

By Ohm's Law and principles of source transformation, we derive the voltage output v_o, represented by Eq.**??**.

$$y = \tag{9}$$

$$Z_C = C_0 + C_i \tag{10}$$

IV. Conclusion

The conclusion goes here.

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