Apply electret microphones to voice-input designs

Voice-input computer systems place heavy demands on traditional microphone designs. But electret transducers are sufficiently versatile to meet the challenge.

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Thanks to its high sensitivity, smooth and controllable frequency response and very small size, the electret microphone is emerging as a leading candidate for use in voice-activated computer systems. The device's size, in particular, permits the design of highly effective noise-canceling microphones for those systems. To use these capable components, you must be familiar with the alternatives available, along with such electret-transducer performance characteristics as signal-to-noise ratio, distortion, frequency response, environmental ruggedness/stability and unit-to-unit repeatability.

Sizing up electret competition

Microphones manufactured for communications applications employ one of four basic pressure-sensitive mechanisms: carbon-granule, electrodynamic, piezoelectric and electrostatic transducers **(table).** With the exception of the first, all are reversible—they can provide acoustic-to-electrical or electrical-to-acoustic transformation.

The *carbon-granule* unit is the most common microphone design, mainly because it still enjoys wide usage in the telephone industry. It consists of carbon granules stessed by a dc potential to create a nonlinear resistance. An impinging acoustical wave changes this resistance, creating an ac current component proportional to the induced pressure.

Carbon-granule-microphone advantages include low cost and application simplicity. However, such devices have many negative aspects. For example, the element must be quite large to produce readily usable signal levels—a characteristic that precludes carbon-granule-transducer use in effective noise canceling-microphone designs. Additionally, output levels are not consistent over time or temperature because the carbon granules tend to pack together, reducing activity level. And the carbon element is inherently nonlinear—high acoustical pressure levels produce highly distorted outputs. Signal-to-noise ratio is also poor relative to the other transducer types.

The *electrodynamic* element satisfies several audio-communications applications. However, although a microphone employing this type of transducer requires

KEY RELATIVE MERITS OF REPRESENTATIVE ACOUSTIC-TRANSDUCER ELEMENTS

CHARACTERISTIC	CARBON-GRANULE	ELECTRO-DYNAMIC	ELECTROSTATIC (ELECTRET)
FREQUENCY RESPONSE (VOICE RANGE)	FAIR	EXCELLENT	EXCELLENT
INTELLIGIBILITY (TRANSMITTED VOICE)	FAIR	EXCELLENT	EXCELLENT
SHOCK RESISTANCE	EXCELLENT	GOOD	EXCELLENT
NOISE CANCELLATION	FAIR	GOOD	EXCELLENT
ELEMENT SIZE	LARGE	LARGE	SMALL
EMI IMMUNITY	EXCELLENT	EXCELLENT	EXCELLENT
COST	LOWEST	MEDIUM	MEDIUM
WEIGHT	MEDIUM	HEAVY	LIGHT
PRIMARY ADVANTAGE	LOW COST	RELIABILITY	OVERALL PERFORMANCE

NOTE: PIEZOELETRIC TRANSDUCERS, ALTHOUGH DISCUSSED IN THE TEXT, ARE RARELY USED IN ACOUSTICAL MICROPHONES.

Gauge microphone requirements early to maximize performance

no external bias voltage, it has a much lower output than a carbon-granule unit. Most electrodynamic-device applications therefore require additional amplification stages to produce a usable output level.

The dynamic element features reasonably good signal-to-noise performance. But because of its inherent mass, it suffers from vibrationally induced noise. Its size also makes the element incompatible with effective noise-canceling microphone designs. Additionally, because of its large inductance, a dynamic microphone typically does not have a smooth frequency response. Numerous response-curve peaks and valleys limit its application in digital voice-recognition systems.

Piezoelectic elements are rarely used in acoustical microphones. However, they are compatible with ultrasonic-frequency applications as well as acoustic-emission detection and vibration analysis. Rochelle salts, quartz, ceramic and barium titanate are the most typical piezoelectric-element materials.

Piezoelectic elements have very flat frequency responses but low output levels. Although recent developments in piezoelectic polymers have produced microphone elements with good reproduction quality, their low piezoelectic activity demands that they be quite large to generate output levels comparable to those of carbon and electrostatic devices. As with most piezoelectic transducers, the polymers' high output impedance requires an impedance transformation—typically an FET amplifier.

A design that solves problems

Electret condenser microphones represent a new development in *electrostatic*-type devices. They feature high durability, small size and reasonable cost ($5 to $20, depending on quantity). And because they employ small active elements, they exhibit excellent noise-canceling properties relative to the other types. They also perform well in environments where vibration, low-frequency noise and EMI are prevalent.

In a representative microphone design **(Fig 1),** the active-element construction consists of a layered stack that includes a copper-laminated, gold-plated, etched pc board. An electret, spacer ring and diaphragm are bonded to the board's top side; the bottom side carries an FET chip along with gate and source resistors. One or more through holes provide acoustical coupling from the board's front to back side.

Typically, a small sealed enclosure houses this pc board. In a noise-canceling design, fine stainless-steel mesh (treated to prevent moisture penetration) covers the sound-entry ports at the enclosure's top and bottom, permitting sound waves to impinge on both sides of the diaphragm. (In omnidirectional microphones, a solid plate covers the bottom port, allowing sound waves to enter only from the top.) FET source and drain leads come out on solder pads to provide circuit connections.

The electret itself is a film of Teflon-like material with a charge of a few hundred volts bonded to its surface. The film maintains this charge indefinitely if protected from liquid or mechanical contact: Once the electret element is sealed in the microphone capsule, its charge potential has a predicted half-life of several decades.

An inside look at electrets

To best illustrate an electret microphone's operation, refer to its simplified equivalent circuit **(Fig 2a).** As in

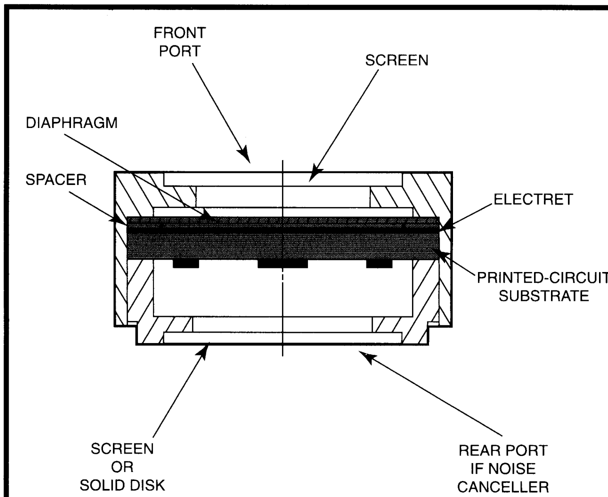

Fig 1—The layered stack construction *of an electret microphone's active element consists of a pc board, the electret, a spacer ring, a diaphragm, an FET and associated gate and source resistors. The bottom sound-entry port is covered with either stainless-steel mesh or solid disks for use in noise-canceling or omnidirectional designs, respectively.*

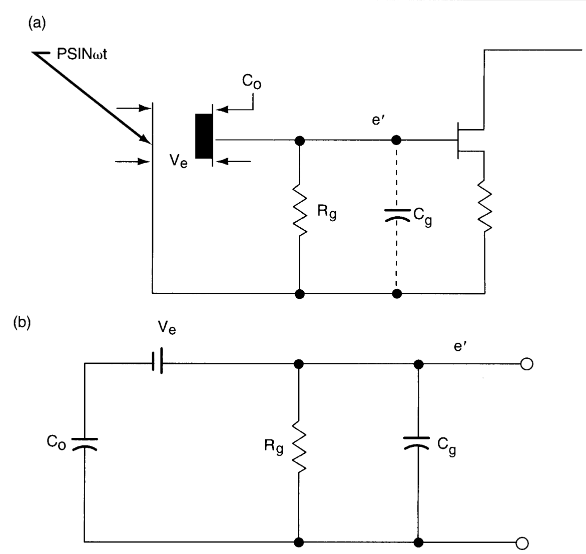

Fig 2—Analyze electret-microphone operation *by examining equivalent circuit* ***(a).*** *When the fractional capacitance change is much less than one, the electret diaphragm element looks like a voltage source whose low-frequency roll-off, determined by the* $R_g(C_o+C_g)$ *time constant* ***(b),*** *can range from 10 to 1000 Hz.*

any microphone, an acoustic pressure wave (Psinωt) impinging on the diaphragm induces a mechanical vibration, which modulates capacitance C_0 according to $C=C_0(1+K\sin\omega t)$, where K equals the fractional change in capacitance. If K is much less than 1, the electret diaphragm element looks like a voltage source VeKsinwt with a source impedance of $1/j\omega C_0$.

At the FET gate (Fig 2b), the signal e′ is given by

$$e'=\frac{V_eKC_O}{C_O+C_g}\sin\omega t$$

with a low-frequency roll-off determined by the time constant $R_g(C_O+C_g)$. You can set this frequency between 10 and 1000 Hz by choosing the appropriate value of R_g.

High-frequency response—a function of diaphragm tension and acoustic loading—can be flat to 10 kHz. However, you can make it roll off sooner: In most communications-type microphones, 3-dB high-frequency roll-off is typically set at 3 to 4 kHz.

An electret microphone delivers its output through an FET; output options typically include a choice of source-follower or common-source-amplifier configurations. When the microphone operates in the follower mode **(Fig 3a),** you can treat it as a constant-voltage source with a source impedance of approximately 2500Ω. In the amplifier mode **(Fig 3b),** the electret looks like a constant-current source with high internal impedance.

With a 1-pascal (1-N/m^2) sound-pressure input, a typical electret microphone exhibits voltage and current sensivities of –40 and –120 dB, respectively. Near-field voice sound-pressure input is typically 3 pascals. Therefore, e_O and i_O are approximately 30 mV and 3 μA, respectively. Obviously, amplification is required before you attempt any signal handling.

Two such amplifier circuits appear in **Fig 3c;** these particular networks were designed for an aviation application in which an electret unit replaces a carbon-granule microphone. The amplifiers must drive the voltage and load circuits already in place in the radio communications system. Although designed for a specific application, they are compatible with different gain, bandpass and impedance requirements. Both circuits employ a Darlington-pair gain stage, which you can view as a triode having μ of 500 and r_p of 1000Ω.

Characterizing electret performance

Key electret-microphone parameters include sensitivity, frequency response and dc bias requirements. Manufacturers usually specify the first at 1 kHz in terms of voltage output (in dBV) for an input sound pressure of either 1 microbar (1 dyne/cm^2) or 1 pascal. For these input levels, electret microphones generally exhibit sensitivities on the order of –60 and –40 dBV, respectively, and sensitivity tolerance typically specs at ±4 dB.

Frequency-response specifications usually come from a median curve, along with notes concerning allowable deviation. Some manufacturers, however, use upper- and lower-limit curves and guarantee that the response falls within the window they form. For analog voice-system applications, response is customarily spec'd very tightly in the 0.3- to 5-kHz band and relaxed outside those limits.

Bias requirements, as a function of the FET, are similar for all electret microphones. DC current level depends on the value of source resistance, but figures

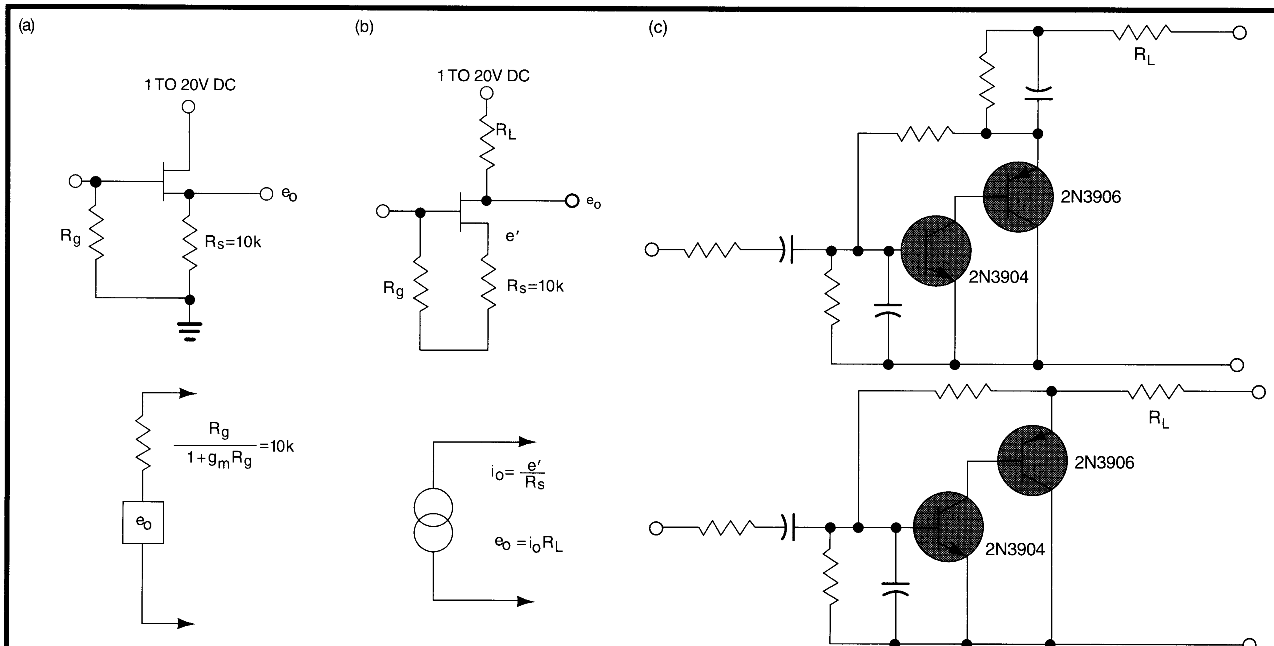

Fig 3—Output configuration *determines how you incorporate an electret into a design. When the device operates in the follower mode* ***(a),*** *it looks like a constant-voltage source; operating in the amplifier mode* ***(b),*** *it behaves like a constant-current source. Although the required amplifier circuits* ***(c)*** *were designed to satisfy specific applications, they are sufficiently flexible to serve many other requirements as well.*

of 20 to 50 μA are typical.

Noise canceling, a key electret application, is by no means a new concept. Electrovoice's EV-87, which employs a dynamic element, has proved moderately effective as a noise-canceling microphone. Highly effective performance, though, calls for an element that is equally sensitive to acoustic signals from both directions. Additionally, this element must be small compared with the acoustical-signal wavelengths in the speech-frequency spectrum (300 to 3000 Hz). Electrets meet these requirements admirably, whereas any attempt to decrease the size of a dynamic microphone inherently decreases sensitivity and increases cost.

To illustrate the use of an electret unit as a noise-canceling microphone, consider the case of a small bidirectional microphone excited by a variety of sound waves **(Fig 4).** You can represent a speaker with his lips close to the microphone's front side as a point source (P_O) emitting a spherical sound wave. If the effective acoustic difference in path length between the front and rear of the microphone (Δl) is less than the acoustic wavelength (f/c), the amplitude of the net pressure wave in the diaphragm is

$$\overline{P_1 - P_2} \approx \frac{\Delta l}{l_o + \Delta l}$$

where P_1 and P_2 equal the pressure on the diaphragm's front and back sides, respectively.

This approximation is valid over the voice range if Δl equals roughly 1 cm and l_0 (source-to-diaphragm distance) falls in the 1- to 2-cm range. However, if the signal consists of unwanted noise from a distant point ($l_0 << 1$),

$$\overline{P_1 - P_2} = \sqrt{2 - 2\cos\omega\left(\frac{\Delta l}{c}\right)} = 2\sin\frac{\omega}{2}\left(\frac{\Delta l}{c}\right).$$

Thus, distant (far-field) signals are attenuated inversely with respect to frequency.

Fig 5a shows the close-talking (near-field) and distant-noise (far-field) performance of a typical electret noise-canceling microphone. It also demonstrates how well electret microphones can satisfy applications requiring rising **(Fig 5b)** and flat **(Fig 5c)** responses.

Applying noise-cancelation devices

Computer voice- and word-recognition applications present a special challenge to microphones, one that electret units meet quite effectively. The acoustical-to-electrical transformation must be precise in both cases—especially when security considerations are

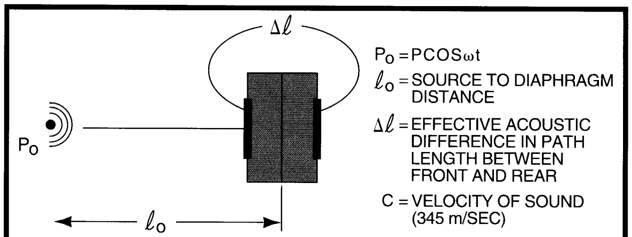

Fig 4—Electrets achieve good noise-canceling characteristics *because they are sensitive to acoustic signals from both directions. Additionally, they exhibit the required short effective acoustic difference Δl in front- to rear-face path length.*

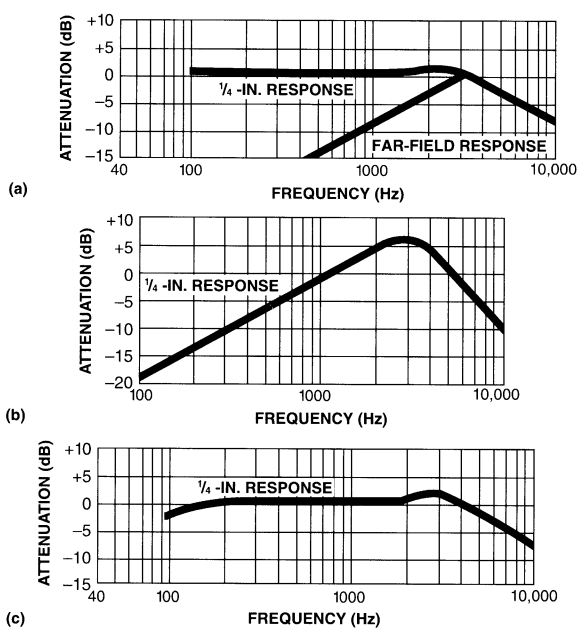

Fig 5—Good noise-canceling performance is evident (a) *when you examine how far-field signals are attenuated in a manner inversely proportional to frequency. However, electret microphones also satisfy applications requiring rising* ***(b)*** *and flat* ***(c)*** *response characteristics.*

Electrets—past and future

Although nearly 80 yrs old, electret bonded-charge technology has until recently virtually languished in the research laboratory.

Earliest investigations in this field centered on the use of waxes as active elements; subsequently, Bell Labs and Canada's Northern Electric pioneered development of an electret microphone based on an active element's mechanical properties. In 1974, though, emerging military needs for ruggedness and miniaturization spurred electret developments.

Military uses—helmet and oxygen-mask microphones, for example—remain a big electret market area. However, many other practical nonmilitary applications exist for the devices, including computer I/O, traffic control and warehouse inspection; the newspaper and printing industries; telecommunications; pocket tape recorders; and portable-radio police and emergency communications.

Electrets' miniature size and military-environment heritage broaden their utility. In essence, the design engineer's imagination is the only factor limiting electret application.

involved. And microphone response should be as flat as possible and not vary with time or changes in temperature or humidity. However, absolute sensitivity may vary slightly with changing environmental factors because only the relative amplitudes of the voice frequencies determine voice input recognition.

To successfully interface with a computer voice terminal, you must maximize signal-to-noise ratios. Any combination of electrical or acoustical noise can mask the wanted information and produce an erroneous input. Electret microphone elements can minimize the effects of both noise forms.

First, despite its small size, an electret produces a greater electrical output for a given acoustical input than any other type of microphone. In essence, it exhibits a built-in high signal-to-noise ratio. Second, properly designed electret microphones exhibit a high near-field-to-far-field crossover frequency. Maximizing this parameter increases low-frequency noise cancelation because the far-field sensitivity decreases at 6 d/B /octave.

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