MICROPHONES--
Quo Vadis?

James H. Kogen*

A Comparison of the Dynamic and Electret Condenser Transducers for Sound Reinforcement Microphone Applications

One need not be very sophisticated in the art of microphone design to discover that there is no panacea for all problems. Of necessity, any practical design is to some degree a compromise. The best microphones are those in which the most important characteristics have been optimized. What constitutes the "most important characteristics" will differ depending upon the application. A microphone that is optimum for one application may not be so for another. To make a fair and honest comparison of microphones, we must consider the application and base our analysis on those characteristics that are significant for the situation being studied.

The selection of a microphone for a given application is ultimately made by the user. The engineer designing a microphone can only anticipate which features will be most important in determining that selection. His choice of features must be based on a thorough analysis of the many design variables and possible compromises. This requires a careful evaluation of all the pertinent characteristics of available transducer types and acoustical designs, consideration of special features, and a thorough study of the many techniques of mechanical construction. Ultimately, his design will be based upon what he conceives to be the best combination of all of these characteristics to satisfy the requirements of the intended application.

A comparison between the electret condenser transducer and the dynamic transducer must take into account many factors. In this article we will discuss these factors, particularly as they apply to microphones for use in sound reinforcement. Emphasis will be placed on identifying the important factors by which a comparison of transducer types can be made. The conclusions as to which microphone is most advantageous for a given situation will be left to the reader.

The electret condenser transducer is an entirely feasible device for use in microphones. This transducer must, however, be judged by the same standards applied to dynamic, ribbon, ceramic, and other types of transducers commonly used in microphones. As stated previously, no transducer offers a panacea. The successful use of the electret condenser transducer will depend upon its particular features and limitations and the way in which these relate to the application of the microphone.

A comparison of the electret condenser transducer and the dynamic transducer, in general purpose sound-reinforcement microphones, covers a very broad range of applications. We will not at this time consider applications such as professional recording and broadcast, mobile communications, and laboratory test microphones. Clearly, the conclusion reached with regard to sound-reinforcement application might not apply for these other applications since the emphasis may be on different characteristics.

Complexity of Microphone Evaluation

When one considers the details, the evaluation of a microphone is a complex matter, and this is particularly true for directional microphones. There is no simple overall criterion of performance that describes the quality of a microphone; there are many criteria for making a judgment and each must be considered separately. Consider the following characteristics by which a microphone can be judged.

1. *Sound Quality.* Several factors affect the sound quality of a microphone. These factors include the frequency response, the polar response (the relative sensitivity of the microphone in all directions), and the distortion at all sound-pressure levels, from the minimum to the maximum to which the microphone will be subjected. Although these parameters can all be measured with great accuracy, our ability to relate these parameters in detail to the subjective sound quality is still quite limited. As a result, in addition to making the laboratory measurements, we must also make an evaluation based on listening—which of course is entirely subjective.

2. *Extraneous Noises.* Since microphones are designed to respond to minute changes in sound pressure measured in microbars (a microbar is one-millionth of barometric pressure or 14.7 x 10^{-6} psi), they are often sensitive to other kinds of mechanical energy input as well. Structure-borne noise can be very disturbing in many applications. When a microphone is held in the hand, for example, a variety of characteristics become important, such as cable noise, frictional noise caused by rubbing the hand or clothing against the microphone, and "thump" noise when the microphone is placed on a floor stand. Such noise can be a very significant factor in judging the quality of a microphone.

Another type of extraneous noise is the "pop" that often occurs when a user expresses the letter "p" or "t." In close-talking applications, excessive "pop" sensitivity can make a microphone practically unusable.

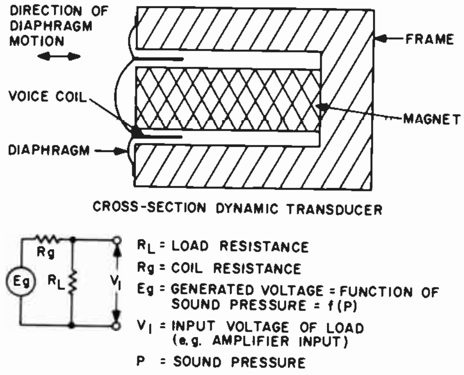
A third type of extraneous noise is that produced by wind. In outdoor applications, the relative sensitivity of a microphone to wind noise may well determine whether or not the microphone can be used.

3. *Reliability.* A microphone with a multitude of superb features, but with poor reliability, is essentially worthless. Sound-reinforcement applications require reliability often under conditions of severe abuse. We have seen microphones swung by their cables and dropped on floors on many occasions. To qualify as a reliable sound-reinforcement product, a microphone should be capable of being dropped on a hardwood stage without deterioration of performance.

Other factors related to reliability are humidity and temperature. Sound-reinforcement microphones are employed outdoors in sub-zero weather and in the heat of a tropical sun. They are used in arid desert regions as well as in highly humid atmospheres.

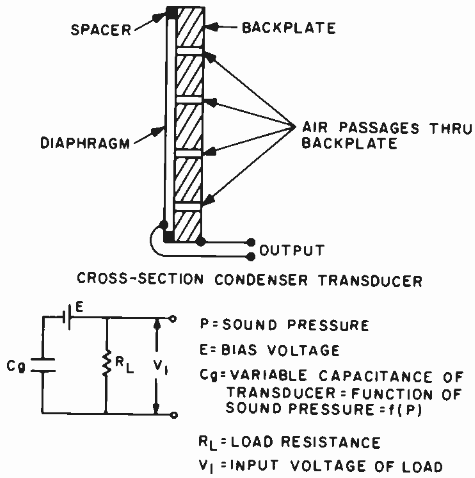
4. *Output Level and Signal-to-Noise Ratio.* Output level is a significant factor because the signal-to-noise ratio of the system depends upon the output of the microphone in relation to the noise of the system (usually as determined by the input

*Vice President, Development and Design Engineering, Shure Bros., Inc.



$$V_l = E_g \frac{R_L}{R_g + R_L} = f(P)$$

Fig. 1—Equivalent electrical circuit of a dynamic transducer.



$$V_l = f(E, C_g) = \text{CONSTANT} \times P$$

Fig. 2—Equivalent electrical circuit of a condenser transducer.

stages of the mixer or preamplifier). A higher output level from the microphone can be advantageous in improving the signal-to-noise ratio. However, an excessively high output level may overload the input stages of the mixer or preamplifier. This means that the output level must be designed to consider peripheral equipment as well as the internal design of the microphone itself.

These are just a few of the factors that must be considered in evaluating a microphone. Each factor must be considered in detail, and specifications, where possible, must be assigned to assure proper performance. The selection of a transducer must then be made in terms of how that transducer performs for each and every one of these specifications. As we stated initially, no transducer offers a panacea. Each transducer has its own particular features and we must select the device that best suits our application requirements.

In the remainder of the article, we will first describe the operating principles of the dynamic and the electret condenser transducers, and then we will compare the two on the basis of a number of important specifications. These specifications include power supply requirements, frequency response, polar response, handling noise, "pop" and wind noise, reliability, output level, distortion, and transient response.

Operating Principles and Major Characteristics

The following is a very brief review of the principles of operation and major characteristics of the dynamic and electret condenser transducers.

The dynamic transducer operates as an electrical generator. A coil of wire (the voice coil) is attached to a metal or plastic diaphragm that moves in response to an input of sound energy. The coil is placed in a magnetic field and a voltage is produced when there is relative motion between the coil and the magnetic field. The dynamic transducer is a self-generating device that requires no external source of power. The equivalent circuit and the equation that relates output to input, shown in Fig. 1, is highly simplified and presented to indicate the steady-state relationship between sound input and electrical output.

The three significant characteristics of the dynamic transducer pertinent to much of the discussion later in this article are:

1. It is self-generating and requires no external power supply.
2. It has a low internal impedance in the range of 25-1000 ohms at all frequencies in the audio spectrum.
3. As compared to the condenser transducer, it has relatively high diaphragm-coil mass.

Both the standard and electret-type condenser transducers convert acoustical energy into a variation in electrical capacitance. This variation occurs when the diaphragm is moved by a sound pressure, thus changing the distance between the diaphragm and the backplate. This capacitance change is reflected as an electrical output in a circuit, such as that shown in Fig. 2. The microphone acts as a varying series element in this circuit. (As in Fig. 1 for the dynamic transducer, this circuit is simplified in order to show the relationship between the acoustical input and the electrical output.) The equation relating output voltage to acoustical input is also shown in Fig. 2. In an electret condenser transducer, the bias voltage results from a permanently stored electrical charge in the transducer; conventional condenser transducers require an external voltage supply.

Characteristics of the electret condenser transducer pertinent to later discussion are:

1. It is a self-generating device requiring no external power supply.
2. It has a very high impedance since it is a capacitor of a few hundred picofarads minimum and requires a preamplifier located physically close to the transducer.
3. It has minimum mass for a diaphragm-type transducer in that nothing is suspended from the diaphragm.

Comparison of Transducers

1. *Power Supply Requirements.* While both the electret condenser and the dynamic transducer are self-generating devices, there is a considerable difference in application in that the former is a high-impedance device and the latter has a relatively low impedance. It is standard practice to employ low-impedance dynamic microphones with cables of hundreds of feet in length without significant problems with hum pickup and deterioration in frequency response. This is accomplished without preamplification at the microphone location.

On the other hand, the high impedance of the condenser microphone necessitates the use of a preamplifier in close proximity to the transducer element. In practical application, the best solution is to build the preamplifier into the microphone and provide either a battery or an external power supply to energize this amplifier.

An external power supply provides a suitable solution but does mean that this extra element must be included in the system or, alternatively, d.c. voltage must be made available at the input terminals of the microphone amplifier. The latter arrangement provides the neatest solution, but at the present time, sound-reinforcement equipment is not normally provided with such a voltage source. As a consequence, if the extra element (the external power supply) is to be avoided, an internal power source must be provided, which means a battery in the microphone.

When a microphone incorporates a battery, one must immediately be concerned with battery life. It is possible to design a preamplifier with current drain so low that the battery

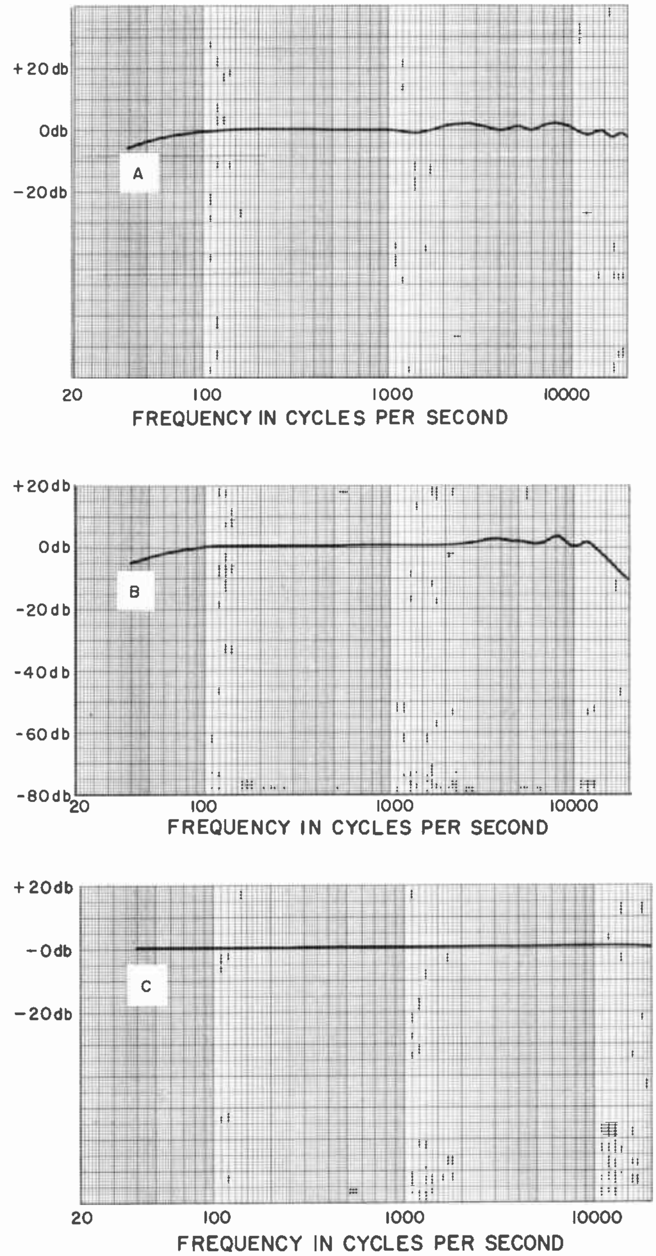


Fig. 3A—Free field axial response of a professional quality omnidirectional dynamic microphone. **B,** Free field axial response of a professional quality omnidirectional condenser microphone. **C,** Free field axial response of a ½-in. laboratory condenser microphone.

life will be quite long. The life of a battery may vary over a considerable range, depending upon the normal quality variations of batteries and upon the temperatures to which they are subjected. The life of a battery might be as high as 10,000 hours or a little over one year. However, the variation in life is very large and might extend from as little as a few months to many years.

The major point of consideration here is that although battery life can be reasonably long, the batterv is still a replacement item that must be maintained. A dead battery means a dead microphone. A weak battery may mean a marginally operating microphone. A leaky battery could mean a damaged microphone. The dynamic microphone does not have this problem. The electret condenser transducer must offer features to overcome this disadvantage when compared to the dynamic transducer.

2. *Frequency Response.* As we have stated, the frequency response of a microphone presents only a rough indication of the sound quality. It is nevertheless a standard by which microphones are compared and must be considered as a very important basis of comparison. In the following, we will consider low frequency response extension, high frequency response extension, and mid-frequency smoothness.

In terms of low frequency response extension, the condenser transducer potentially has an advantage. Through the use of very high impedance preamplifiers, this transducer can be made to operate at frequencies well below the low end of the audio range (20 Hz). Dynamic transducers can be made to operate at very low frequencies also, but in order to achieve such response, a compromise must be made that tends to make the microphone more sensitive to handling noise. The advantage of response below 50-100 Hz is of questionable value in sound reinforcement, although this potential advantage of the condenser element might be useful in other applications.

In terms of high frequency response extension, we cannot state with certainty at this time that either transducer has an advantage insofar as audio frequencies are concerned. Figures 3A and 3B are response curves of two popular omnidirectional dynamic and condenser microphones. Both of these types exhibit response to 20 kHz within a few decibels. Figure 3C is the response of a laboratory-type condenser microphone with frequency response extending well beyond 20 kHz. For sound-reinforcement applications, both types of transducers have the capability of satisfactory high-frequency response.

Smoothness of response in the mid-region can be accomplished by both transducers, as shown in Figure 3. The condenser element might have an advantage in having fewer small variations in its response curve, but the variations in a good dynamic microphone response would be in the order of 2 dB or less, and it is doubtful whether this would affect the sound quality sufficiently to be detected when the two types of transducers are compared subjectively.

In our judgment the frequency response possibilities of the two types of transducers, for use in sound reinforcement, are similar. We must, however, remind the reader of the point made previously with regard to frequency response and subjective sound quality. Frequency response does not tell the whole story with regard to sound quality. The frequency response of a dynamic and electret condenser microphone may be similar, but the sound quality could differ because of other factors.

3. *Polar Response.* Theoretical analysis indicates that neither the dynamic nor the electret condenser transducer has an advantage with regard to polar response. This characteristic is primarily a function of the acoustical design of the microphone in conjunction with the transducer. Measurements on existing microphones have corroborated this theoretical analysis.

The unidirectional dynamic microphone requires a mass-controlled transducer having a relatively low fundamental resonant frequency. The condenser microphone requires a resistance-controlled transducer having a resonant frequency in the mid-range. The acoustical networks required to achieve unidirectional characteristics can be similar for the two transducers, and there are a variety of networks available for either type. Ultimately, we may discover that a particular network in conjunction with one or the other of the transducers offers some practical advantage. At the present time, however, this is not the case, and the two types of transducers are comparable with regard to polar response of the microphone in which they are employed.

4. *Handling Noise.* This is a characteristic that is often overlooked but one that can be very important. A microphone is

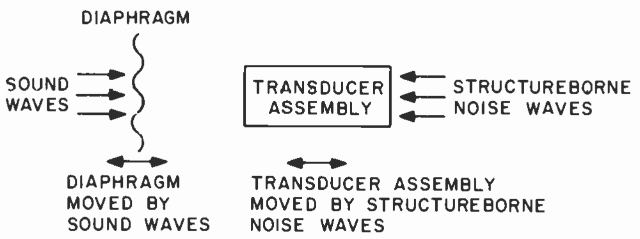


Fig. 4—Voltage generation caused by structure-borne noise. Relative motion between diaphragm and assembly produces electrical output and can result from either diaphragm or assembly motion.

a unique instrument in that it must be highly sensitive to the input of sound energy but should also be insensitive to the input of structure-borne energy. These are decidedly conflicting requirements. As a general rule, the sensitivity to structure-borne sounds will increase with the mass of the diaphragm in the transducer. The electret condenser transducer unquestionably has an advantage over the dynamic transducer in this regard. Figure 4 shows a simplified representation of how the microphone transducer reacts to structure-borne noise. In order to reduce the effects of this type of noise, it is standard practice in dynamic microphone designs to introduce a shock absorber between the outer case of the microphone and the dynamic transducer. Because of its inherent low sensitivity to structure-borne noise, the requirement for shock isolation of the condenser microphone is significantly less than that of a dynamic microphone. This results in two important considerations.

A. For a given structure-borne noise sensitivity, the cost of the shock isolation in a dynamic microphone will be higher than that of a comparable electret condenser microphone.

B. The requirement for shock isolation will add to the size of the dynamic microphone. Stated conversely, the electret condenser microphone could be made smaller because of the simplicity of the shock isolation required. This feature has merit, for example, in a lavalier microphone or a microphone mounted on a headset boom. The advantage is less in situations where microphone size is determined by other factors such as windscreens, pop filters, and cable connectors.

We feel that insensitivity to structure-borne noise can be the major advantage of electret condenser microphones in sound-reinforcement applications.

5. *Pop and Wind Noise.* Measurements on a large variety of dynamic and condenser microphones indicate that both transducers are equally susceptible to pop and wind. A reduction of pop and wind noise must be achieved through the use of external windscreens and pop filters in either case.

6. *Reliability.* As stated previously, reliability is an extremely important factor in comparing products for sound-reinforcement applications. We will consider three factors relating to reliability: mechanical ruggedness, the effect of humidity, and the effect of temperature.

With regard to ruggedness, the dynamic microphone has proved itself over a period of more than 30 years. A properly constructed dynamic microphone is sufficiently rugged to withstand the rigors of severe sound-reinforcement applications. The electret condenser microphone has yet to prove itself. The answer to the question of relative ruggedness will only be gained through experience over an extended period of time.

In humid conditions, the dynamic transducer presents no problem. Care must be taken, of course, to adequately protect metallic parts, but this is standard practice in all quality microphones. The electret transducer, on the other hand, has potentially severe problems in humid atmospheric conditions. High humidity can cause the loss of the electret charge. This was a problem in electret devices made several decades ago, using Carnauba wax, and presents a potential hazard to modern-day electrets employing plastic materials. Clearly, for the microphone to be satisfactorily reliable, the electret charge must be maintained under the extreme conditions often found in sound-reinforcement applications.

In laboratory tests, our company considers life of 1,000 hours at 100% relative humidity to be a minimum requirement for any microphone. We have tested several electret microphones that would not withstand this test at room temperature. Our conclusion is that suitable electrets can be made, but that humidity still presents a potentially serious problem for the electret.

In comparing the two transducer types under conditions of high temperature, we find the onus again is on the condenser to match the known performance capability of the dynamic. Dynamic microphones made by Shure are required to withstand storage temperatures from -20 degrees F to +165 degrees F and must operate within standard performance specification at temperatures from -20 degrees F to +140 degrees F. We have found these to be suitable temperatures to guarantee reliability in performance of the microphone under field conditions. The electret condenser microphone must, of course, also be capable of withstanding these extremes of temperature. The high end of the temperature range will offer the most difficult problem for the electret, particularly when combined with high humidity.

An additional factor that must be considered in evaluating the electret condenser microphone at high temperature is the effect of temperature on the dry cell incorporated in many of these microphones. Most alkaline and carbon zinc batteries will not withstand a temperature of +165 degrees F for an extended period of time. We would include the dry cell in temperature tests to determine whether any leakage of the cell might damage the microphone. Since the dry cell is normally easy to replace, we feel that it is reasonable to change to a new dry cell for subsequent testing after the high temperature exposure is completed.

7. *Output Level.* Since the electret condenser microphone must be supplied with a built-in preamplifier, there is a possibility of providing a very high output level—much higher than with the unamplified dynamic microphone. Care must be taken in providing a low-noise preamplifier in order to achieve suitable signal-to-noise performance. The design must also consider the problem of amplifier saturation in order to minimize distortion at high sound-pressure levels. The advantage of a high-output level is somewhat mitigated by the fact that an excessively high-output level can result in overloading the input stages of the mixer or amplifier to which the microphone is connected. Typical output of a dynamic microphone is in the order of -57 dB with reference to one volt per microbar. We would question the value of an output level of greater than roughly -52 dB because of the probability of overload in subsequent stages of amplification.

8. *Distortion.* Dynamic microphones usually exhibit very low distortion. We have measured a large variety of both omnidirectional and unidirectional dynamic microphones at levels up to 150 dB sound-pressure level. Total harmonic distortion is typically below 1% up to the highest pressure measured. (As a point of reference, 130 dB sound-pressure level can cause physical damage to the ears.) Similar measurements on condenser microphones indicate total harmonic distortion below 2% for the majority of microphones, and below 1% for the higher quality condenser microphones up to sound pressure levels of 130 dB SPL. Condenser microphones exhibit a relatively sharp overload point in the range of 130 to 150 dB SPL, at which level the distortion rises very rapidly. This type of distortion can be caused by bottoming of

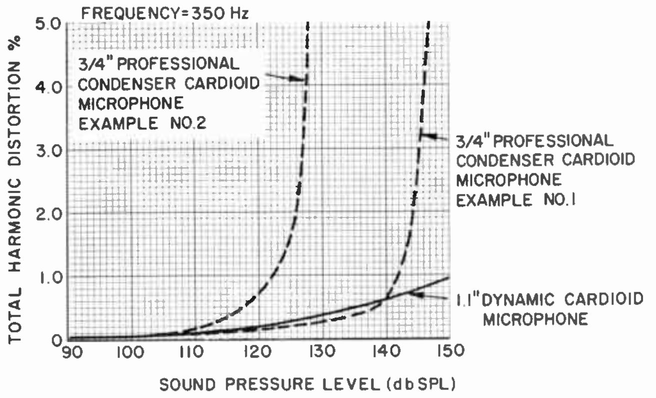


Fig. 5—Overload characteristic examples of condenser and dynamic microphones.

the diaphragm but is normally the result of clipping in the preamplifier. Figure 5 shows total harmonic distortion versus sound-pressure level for typical dynamic and condenser microphones.

The two transducers can be comparable in terms of distortion at normal sound-pressure levels and can be suitable for maximum sound-pressure levels normally found in sound-reinforcement applications. The dynamic transducer is inherently less difficult to control with regard to distortion and has an advantage in being able to handle extremely high peaks of sound pressure, which may sometimes occur in "close talk" applications.

9. *Transient Response.* At this time, there is no standard test for transient response of a microphone. While this type of test is commonly used in evaluating amplifiers, loudspeakers, servomechanisms, and so on, there are several problems in applying the test to microphones. One problem is that of creating a standard transient; and at this date, no such standard has been devised or specified. A second problem is correlating the results of such a test with other types of measurements (such as frequency response) and with subjective reaction.

Since no standard test procedure exists, and since there is little documentation with regard to the significance of transient response tests, we do not feel that it is proper to make a comparison of microphones on this basis at this time. While one might easily design a test that will display differences between two microphones, to be fair one would have to document the significance of the differences noted. One major aspect of this documentation would certainly be the subjective differences. We strongly emphasize that this type of testing must be very carefully controlled with many variables to be considered. One cannot make a judgment based on a simple demonstration.

Conclusion

In summary, then, we would like to make the following points. Any comparison of microphone types must consider the application for which the microphone was intended. Comparison of microphone types is complex and must include all of the many pertinent characteristics. In comparing transducer types, one must consider the way in which the total microphone is designed and built. Either the dynamic or the electret condenser transducer can be employed in a good or bad microphone design.

This article has attempted to describe some of the more important characteristics pertinent to electret condenser and dynamic microphones in sound-reinforcement applications. The selection of a microphone will be made by the user and will be based on those characteristics that are most significant to the application. Æ