Microphone Measurements, Standards, and Specifications

Introduction

In this chapter we discuss the performance parameters of microphones that form the basis of specification documents and other microphone literature. While some microphone standards are applied globally, others are not, and this often makes it difficult to compare similar models from different manufacturers. Some of the differences are regional and reflect early design practice and usage. Specifically, European manufacturers developed specifications based on modern recording and broadcast practice using condenser microphones, whereas traditional American practice was based largely on standards developed in the early days of ribbon and dynamic microphones designed originally for the US broadcasting industry. Those readers who have a special interest in making microphone measurements are referred to the standards documents listed in the bibliography.

Primary Performance Specifications

1. Directional properties: Data may be given in polar form or as a set of on- and off-axis normalized frequency response measurements.
2. Frequency response measurements: Normally presented along the principal (0°) axis as well as along 90° and other reference axes. For dynamic microphones the load impedance used should be specified as the frequency response often changes with loading.
3. Output sensitivity: Often stated at 1 kHz and measured in the free field. Close-talking and boundary-layer microphones need additional qualification. Some manufacturers specify a load on the microphone's output.
4. Output source impedance.
5. Equivalent self-noise level.
6. Maximum operating sound pressure level (SPL) for a stated percentage of total harmonic distortion (THD). For condenser microphones it is critical to specify a minimum load impedance above which the microphone will deliver the specified maximum SPL and THD. Many condenser microphones have a drastic lowering of maximum SPL as the load impedance drops below some value.

Additionally, a complete listing of mechanical and physical characteristics and any switchable performance features built into the microphone are described in this chapter.

Frequency Response and Polar Data

Frequency response data can be presented in many ways, and the cautious user of such data should always consider how the data is presented. Figure 7.1A shows raw microphone measurement data on a scale that is 10 dB vertical. Figure 7.1B shows the same measurement plotted on a 40 dB vertical scale. Figure 7.1C shows the same measurement plotted on a 40 dB vertical scale with 1/3 octave band averaging applied. Figure 7.1D shows the same measurement plotted on a 40 dB vertical scale with full octave band averaging applied. Figure 7.1E shows the same measurement plotted on an 80 dB vertical scale with full octave band averaging applied. Much of the microphone response data supplied by manufacturers is not only presented with a very coarse vertical resolution, but also averaged by the marketing department having an artist produce a nice-looking approximation of the actual measurement. It is sometimes possible to look at the data as presented and determine if what is presented is actual measured data or an artist's representation of the measured data.

Frequency response data should always state the physical measuring distance so that an assessment of proximity effect in directional microphones can be correctly made. If no reference is made, it can be assumed that measurements are made at 1 meter. Data for professional microphones may be presented with tolerance limits, as shown in Figure 7.2. Here, the data indicate that the microphone's response falls within a range of ± 2 dB above about 200 Hz (slightly greater below that frequency); however, there is no indication of the actual response of a sample microphone.

If the data can be presented with clarity, some manufacturers will show proximity effects at distances other than the reference of one meter, as shown in Figure 7.3. This data is especially useful for vocal microphones that are intended for close-in applications.

Many manufacturers show response at two or more bearing angles so that the variation in response for those off-axis angles can be clearly seen, as shown in Figure 7.4. Here, the response for a cardioid is shown on-axis and at the nominal null response angle of 180°. For supercardioid and hypercardioid microphones, the response at the null angles of 110° and 135° may also be shown.

Taking advantage of normal microphone symmetry, polar plots may be restricted to hemispherical representation, as shown in Figure 7.5. For microphones that are end-addressed, it is clear that response will be symmetrical about the axis throughout the frequency band.
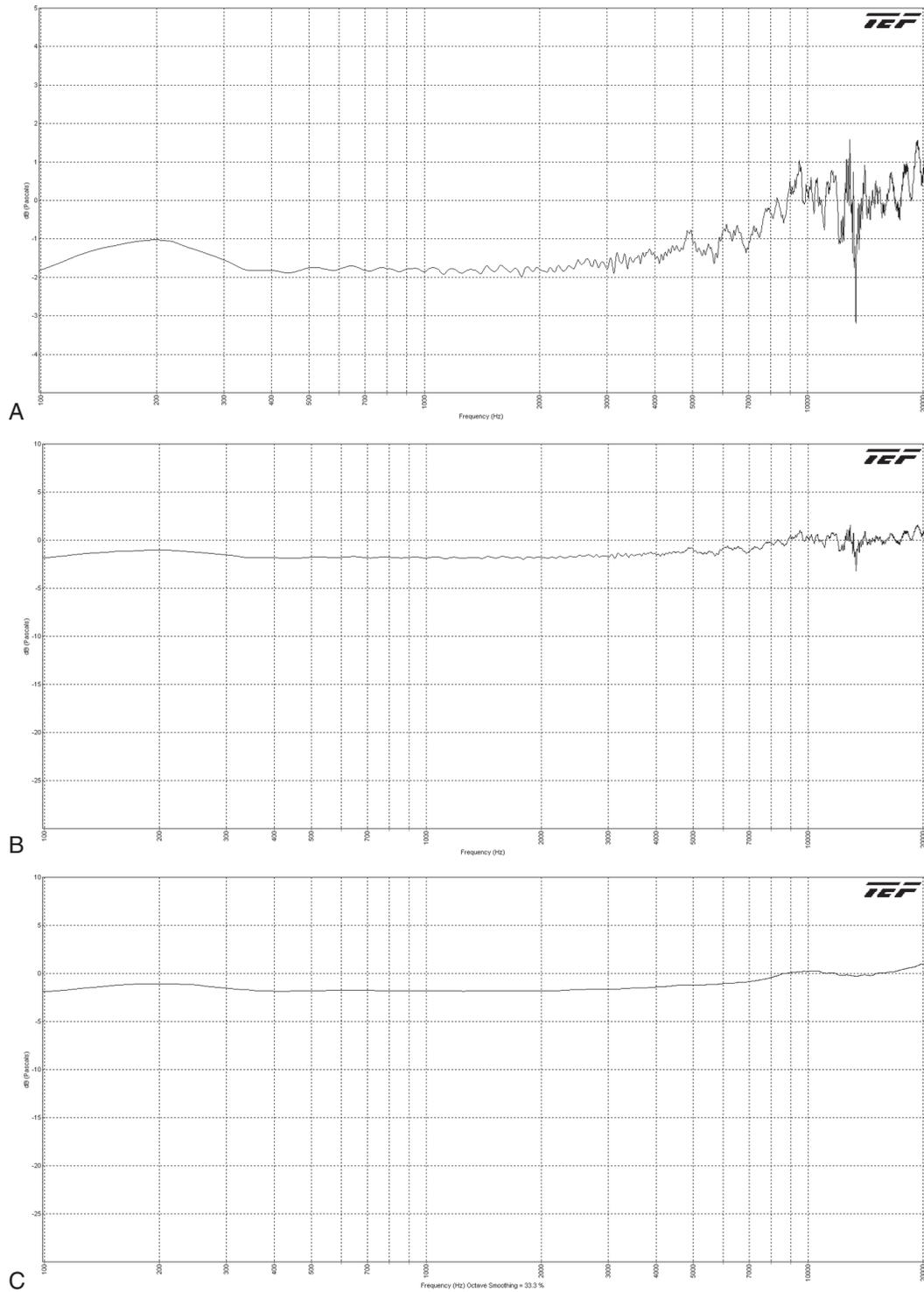
Figure 7.1
Raw data as measured with 10 dB vertical scale (A). Raw data as measured with a 40 dB vertical scale (B). One-third octave band averaged data with a 40 dB vertical scale (C).
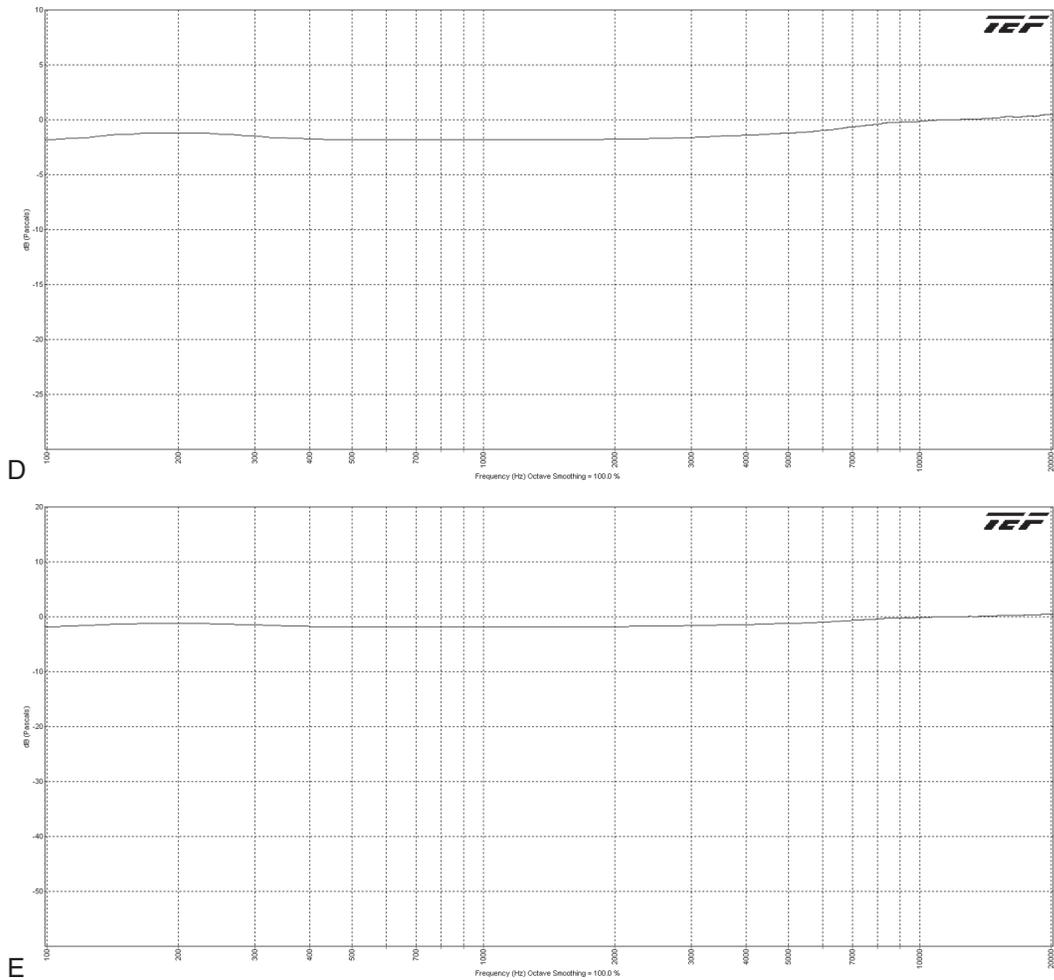
Continued

Figure 7.1—cont'd

Octave band averaged data with a 40 dB vertical scale (D). Octave band averaged data with an 80 dB vertical scale (E).
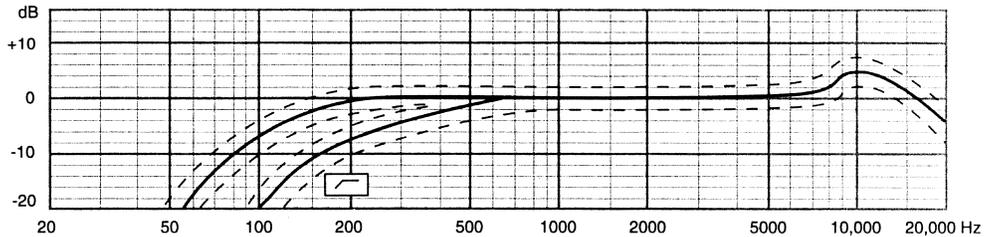

Figure 7.2

Amplitude response versus frequency with upper and lower limits for a condenser vocal microphone; effect of LF cut is also shown. *(Figure courtesy of Neumann/USA.)*
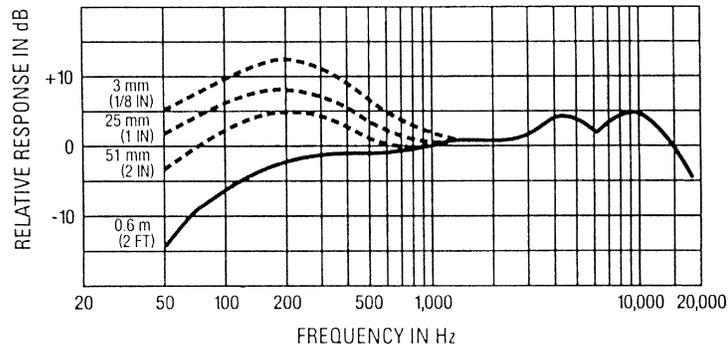
Figure 7.3
Proximity effect for a dynamic vocal microphone shown at several working distances.
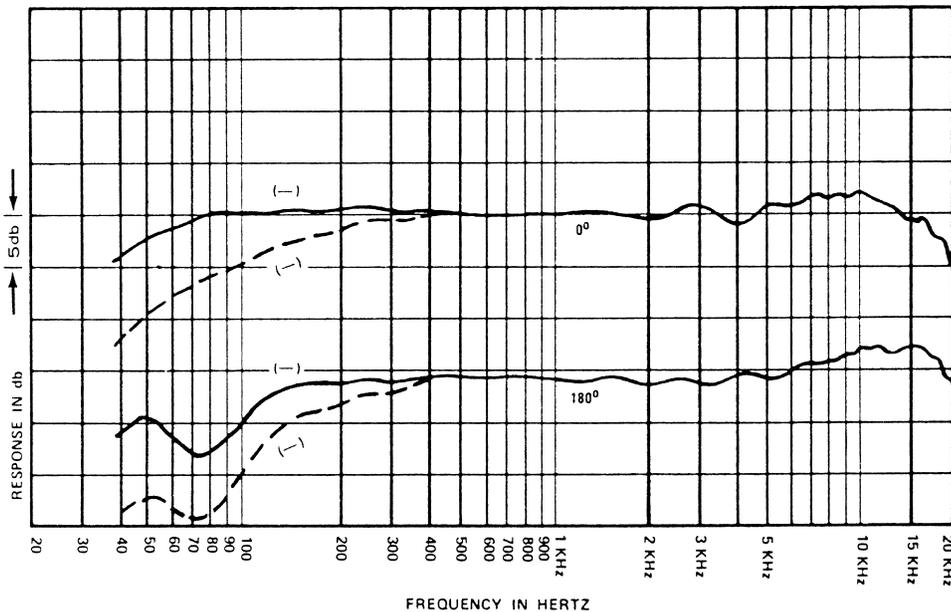*(Figure courtesy of Shure Inc.)*

Figure 7.4
Amplitude response shown at reference angles of 0° and 180° for a Variable-D dynamic
microphone. *(Figure courtesy of Electro-Voice.)*

However, for side-addressed microphones, there will be variations, especially at higher
frequencies where the asymmetry in diaphragm boundary conditions becomes significant.
Normally, this data is not shown, but there are interests within the microphone user community
to standardize the presentation of more complete directional information. As present, such
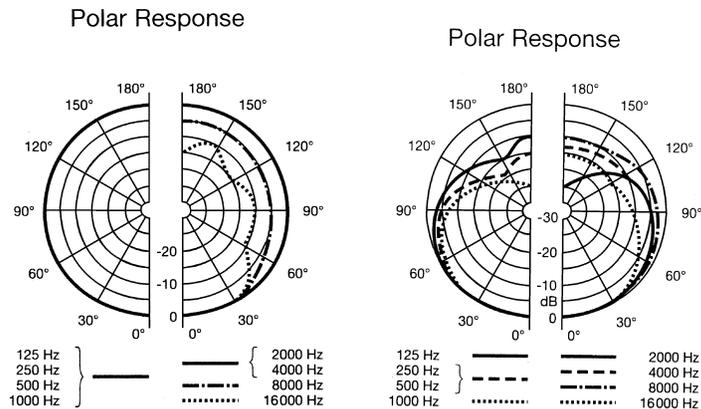additional data is presented at the discretion of each manufacturer.

Polar Response

Polar Response

Figure 7.5
Microphone polar groups, hemispherical only, for omni condenser (A) and cardioid condenser microphones (B). *(Figure courtesy of AKG Acoustics.)*

Dynamic microphones in particular may have differing frequency response depending on the electrical impedance they are driving. Therefore what impedance load was used to get the response curve shown should be specified. If it is not specified, you can assume it is no less than ten times the rated output impedance of the microphone.

Microphone Pressure Sensitivity

The principal method of presenting microphone sensitivity is to state the output rms voltage in millivolts (mV) when the microphone is placed in a 1 kHz free progressive sound field at a pressure of 1 Pascal (Pa) rms (94 dB L_P) or millivolts per Pascal (mV/Pa). A microphone load impedance such as 1000 ohms may be stated as well, but the standard is to specify the "open circuit" (infinite load impedance) output voltage of the microphone. Another way of stating this data is to give the rms voltage output level in dB relative to one volt (dBV):

$$\text{Output level (dBV)} = 20 \ \log \ (\text{rating in mV rms}) - 60 \ \text{dB} \tag{7.1}$$

Microphone Output Power Sensitivity

Microphone power output specifications were developed during the early days of broadcast transmission when the matched impedance concept was common. Here, the microphone is loaded with an impedance equal to its own internal impedance, as shown in Figure 7.6A. When unloaded, as shown at B, the output voltage is doubled.

The rating method is somewhat complicated, and we now give an example: consider a dynamic microphone with rated impedance of 50 ohms and an open-circuit output sensitivity of 2.5 mV/Pa.
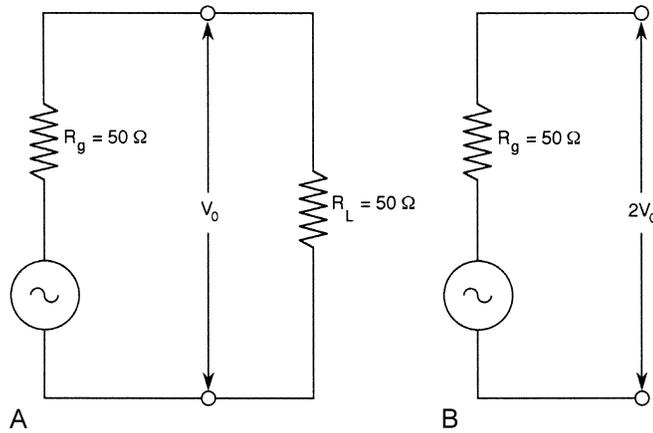
Figure 7.6
Microphone output loaded (A); unloaded (B).

In modern specification sheets this voltage level may also be expressed as –52 dBV. The same microphone, if its loaded output power is given, would carry an output power rating of –45 dBm (dB relative to a power level of 1 milliwatt). This is solved as follows.

When the microphone is given a matching load of 50 ohms, its output voltage will be reduced by one-half, or 1.25 mV. The power in the load will then be:

$$\text{Power} = (1.25)^2/50 = 3.125 \times 10^{-8} \text{ W, or } 3.125 \times 10^{-5} \text{ mW}$$

Solving for power level in dBm:

$$\text{Level} = 10 \text{ log } (3.125 \times 10^{-5}) = -45 \text{ dBm}$$

The nomograph in Figure 7.7 lets us solve this directly, as indicated by the line that has been drawn over the nomograph. Here, we simply take the unloaded output voltage level (re 1 mV) of +8 dB (60 – 52) and locate that value at *A*. The nominal impedance of the microphone (50 ohms) is located at B. A line is then drawn between the two points and the microphone's sensitivity, in dBm per pascal, is read directly at B.

Other rarely used variations of this method are:

1. Output in dBm per dyne per square centimeter (dBm measured in a matched load impedance at 74 dB L_P).
2. Output in dBm, EIA rating (dBm measured in a matched load impedance at an acoustical level of 0 dB L_P).

The reader can readily appreciate the simplicity and universality of the modern open circuit output voltage rating method.
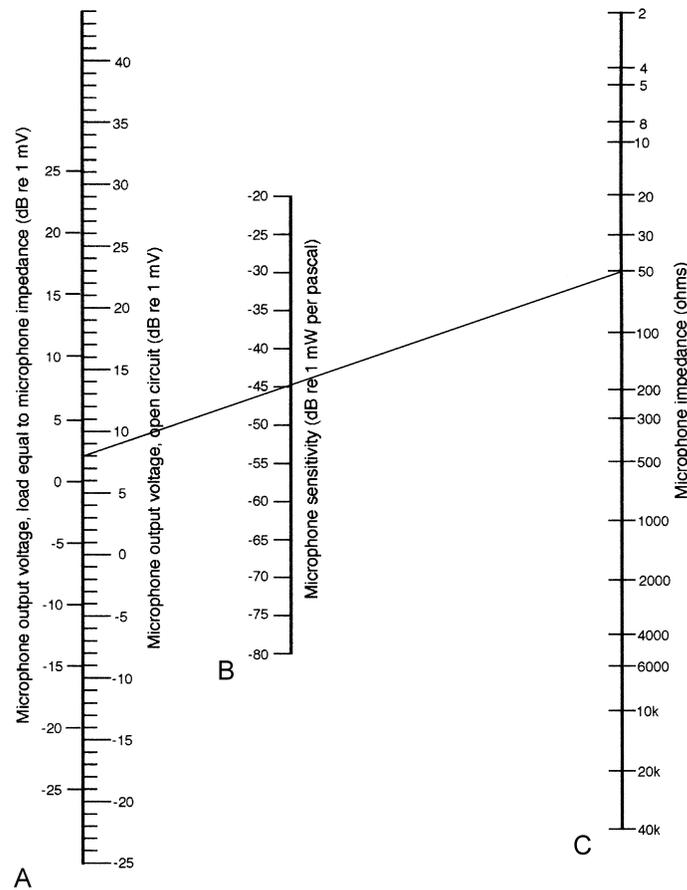
Figure 7.7
Microphone power output nomograph.

Microphone Source Impedance

Virtually all of today's professional microphones, condenser or dynamic, are what may be called "low impedance," as opposed to the high impedance models of decades past. The range of impedance may be typically from 50 to 200 ohms for condenser microphones, or up to the range of 600 ohms for some dynamic models.

The source impedance of dynamic microphones may not be equal at all frequencies in the audio band. Therefore if the ratio of the source impedance to the load impedance is low, particularly if it approaches 1:1, the frequency response of the microphone may change.

Condenser microphones, since they have active amplification in the microphone, typically have a source impedance that stays constant across the audio band. They do have a limit to the

amount of current they can source, which means that below some load impedance the maximum output voltage (and therefore the maximum SPL the microphone can reproduce without distortion) will fall. That minimum load impedance is often around 1000 ohms.

Since the traditional input load impedance seen by a microphone today is in the range of 1500 to 5000 ohms, as long as the microphone is only driving a single microphone input the exact input impedance will typically have little effect on the sound of the microphone. If the microphone output is passively split using either a "Y" connection or a splitter transformer, then the input impedance of the inputs in parallel can easily be low enough to cause problems.

The exact value of a microphone's output impedance is typically of little practical consequence in modern systems layout.

Some microphone preamplifiers have a control for adjusting the input circuitry for specifically matching a wide range of microphone output impedances. (See Chapter 8 under "The Stand-Alone Microphone Preamp.")

Normal Ranges of Microphone Design Sensitivity

In designing condenser microphones the engineer is free to set the reference output sensitivity to match the intended use of the microphone. Table 7.1 gives normal sensitivity ranges.

The design criterion is simple; microphones intended for strong sound sources will need less output sensitivity to drive a downstream preamplifier to normal output levels, while distant pickup via boundary-layer microphones or rifle microphones will need greater output sensitivity for the same purposes.

Microphone Equivalent Self-Noise Level Rating

Today, the self-noise level of a condenser microphone is expressed as an equivalent acoustical noise level stated in dB A-wtd. For example, a given microphone may have a self-noise rating of 13 dB A-wtd. What this means is that the microphone has a noise floor equivalent to the signal that would be picked up by an ideal (noiseless) microphone if that microphone were placed in an acoustical sound field of 13 dB A-wtd. Modern large diaphragm condenser

Table 7.1 Normal Sensitivity Ranges by Use

Microphone usage	Normal sensitivity range
Close-in, handheld	2–8 mV/Pa
Normal studio use	7–20 mV/Pa
Distant pickup	10–50 mV/Pa

microphones generally have self-noise ratings in the range from 7 dB A-wtd to 14 or 15 dB A-wtd. Tube models will have higher noise ratings, many in the range from 17 dB A-wtd to 23 dB A-wtd.

The ultimate limitation on the noise floor of a microphone is the Brownian motion of the air. This is a random noise whose level is determined in part by the temperature of the air. Even a theoretically perfect noiseless microphone will have noise on its output due to the random nature of the Brownian motion. Every time the surface area of the microphone diaphragm doubles, the noise due to Brownian motion increases 3 dB, but the sensitivity of the microphone to sounds arriving perpendicular to the diaphragm surface increases 6 dB. That means that the resultant Signal to Noise ratio (S/N) will ideally increase 3 dB for each doubling of the diaphragm surface area or 6 dB for each doubling of the diaphragm diameter.

As a practical matter, the self-noise of a modern condenser microphone will be about 10 to 12 dB greater than the equivalent input noise (EIN) of a good console or preamplifier input stage; thus, the self-noise of the microphone will be dominant. With a dynamic microphone this is not normally the case; the output voltage of the dynamic microphone may be 10 to 12 dB lower than that of a condenser model so that the EIN of the console will dominate. As a result of this, dynamic microphones do not carry a self-noise rating; rather, their performance must be assessed relative to the EIN of the following console preamplifier.

Some microphone specifications carry two self-noise ratings. One of these is the traditional A-weighted curve and the other is a psophometric weighting curve used with a quasi-peak detector that is more accurate in accounting for the subjective effect of impulsive noise. The two curves are shown in Figure 7.8.
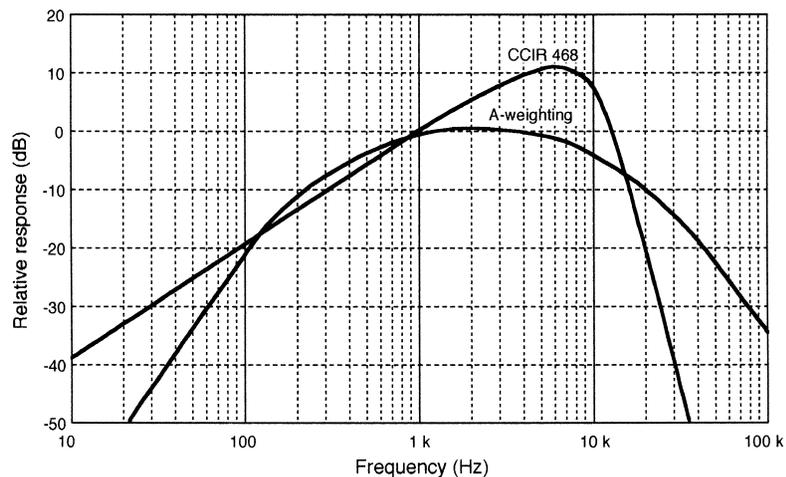

Figure 7.8
Two self-noise weighting curves for microphone measurements.

Distortion Specifications

For studio quality microphones the reference distortion limit is established as the acoustical signal level at 1 kHz, which will produce no more than 0.5% THD (total harmonic distortion) at the microphone's output. Reference distortion amounts of 1% or 3% may be used in qualifying dynamic microphones for general vocal and handheld applications.

Microphone distortion measurements are very difficult to make inasmuch as acoustical levels in the range of 130 to 140 are required. These levels are hard to generate without significant loudspeaker distortion. A pistonphone (mechanical actuator) arrangement can be used with pressure microphones where a good acoustical seal can be made, but it is useless with any kind of gradient microphone.

It has been suggested (Peus, 1997) that microphone distortion measurements can be made using a twin-tone method in which two swept frequencies, separated by a fixed frequency interval, such as 1000 Hz, be applied to the microphone under test. Since the individual sweep tones are separately generated, they can be maintained at fairly low distortion; any difference tone generated by the diaphragm-preamplifier assembly represents distortion and can be easily measured with a fixed 1000 Hz filter, as shown in Figure 7.9. One problem with this method is that it is difficult to establish a direct equivalence with standard THD techniques.

In many studio quality microphones, the distortion present at very high levels results not from the nonlinearities of diaphragm motion but rather from electrical overload of the amplifier stage immediately following the diaphragm. Accordingly, some manufacturers simulate microphone distortion by injecting an equivalent electrical signal, equal to what the diaphragm motion would produce in a high sound field, and then measure the resulting electrical distortion at the microphone's output. This method assumes that the diaphragm assembly is not itself producing
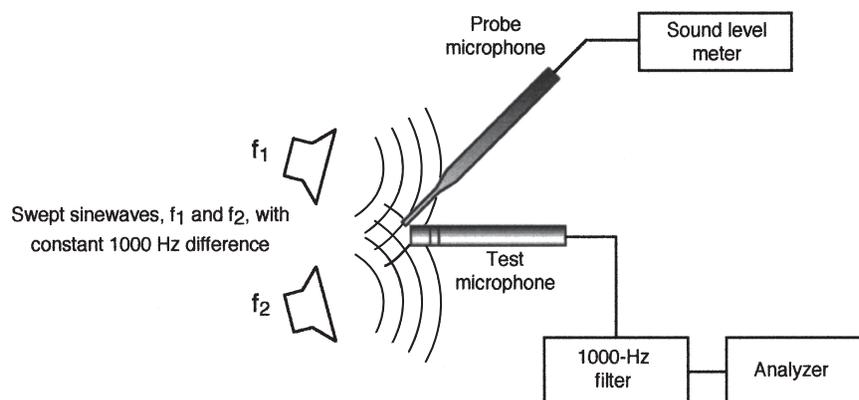

Figure 7.9
Twin-tone method of measuring microphone distortion.

distortion, but rather that any measured distortion is purely the result of electrical overload. We must rely on the manufacturers themselves to ensure that this is indeed the case.

Microphone Dynamic Range

The useful dynamic range of a microphone is the interval in decibels between the 0.5% THD level and the A-weighted noise floor of the microphone. Many studio quality condenser microphones have total dynamic ranges as high as 125 or 130, better by a significant amount than that of a 24-bit digital recording system.

As a matter of quick reference, many microphone specification sheets present nominal dynamic range ratings based on the difference between the A-weighted noise floor and a studio reference level of 94 dB L_P. Thus, a microphone with a noise floor of 10 dB A-wtd would carry a dynamic range rating of 84 dB by this rating method. No new information is contained in this rating, and its usefulness derives only from the fact that 94 dB L_P represents a nominal operating level. Many manufacturers ignore this rating altogether.

Microphone Hum Pickup

While all microphones may be susceptible to strong "hum" fields produced by stray ac magnetic fields at 50 or 60 Hz and its harmonics, dynamic microphones are especially susceptible because of their construction in which a coil of wire is placed in a magnetic flux reinforcing iron yoke structure. Examining current microphone literature shows that there is no universally applied reference flux field for measuring microphone hum pickup. Several magnetic flux field reference standards may be found in current literature, including: 1 oersted, 10 oersteds, and 1 milligauss. The choice of units themselves indicates a degree of confusion between magnetic induction and magnetic intensity. The specification of hum pickup is rarely given today, perhaps due to the use of hum-bucking coils and better shielding in the design of dynamic microphones, as well as the general move away from tube electronics and associated power supplies with their high stray magnetic fields.

Reciprocity Calibration of Pressure Microphones

Pressure microphones are primarily calibrated in the laboratory using the reciprocity principle. Here, use is made of the bilateral capability of the condenser element to act as either a sending transducer or a receiving transducer, with equal efficiency in both directions. The general process is shown in Figure 7.10.

At A, an unknown microphone and a bilateral microphone are mounted in an assembly and jointly excited by a third transducer of unknown characteristics. From this measurement set we can obtain only the *ratio* of the sensitivities of the bilateral and unknown microphones.
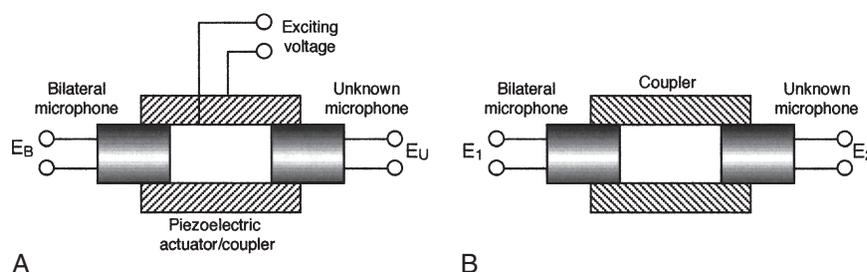
Figure 7.10
The reciprocity process; determining the ratio (A) and product
(B) of microphone sensitivities.

The next step, shown at B, is to measure the output of the unknown microphone by driving it with the bilateral microphone, acting as a small loudspeaker. In this step we can determine the product of the two sensitivities, taking into account the electrical and acoustical equivalent circuits. The sensitivity of either microphone can then be determined by algebraic manipulation of the ratio and product of the sensitivities, taken on a frequency by frequency basis. Standards laboratories use the reciprocity technique to plot the frequency response of a very stable microphone capsule. Most frequency response measurements are made by comparison to a reference microphone whose response is traceable to that of a microphone calibrated by reciprocity.

As a secondary standard for microphone level calibration a *pistonphone* is normally used. The pistonphone is a mechanical actuator that can be tightly coupled to the capsule assembly of a pressure microphone and produces a tone of fixed frequency and pressure amplitude. Those interested in further details of microphone calibration are referred to Wong and Embleton (1995).

Impulse Response of Microphones

The impulse response of microphones is rarely shown in the literature because of the difficulties in achieving a consistent impulse source and interpreting the results. A spark gap discharge can be used, but it has been shown that at high frequencies the spectrum is not consistent. Figure 7.11 shows the spark gap response of both a condenser and a dynamic microphone, and it can clearly be seen that the condenser is better behaved in its time domain response.

Most impulse responses today are obtained by convolution from swept sine wave measurements, referenced ultimately to a microphone capsule calibrated by reciprocity.
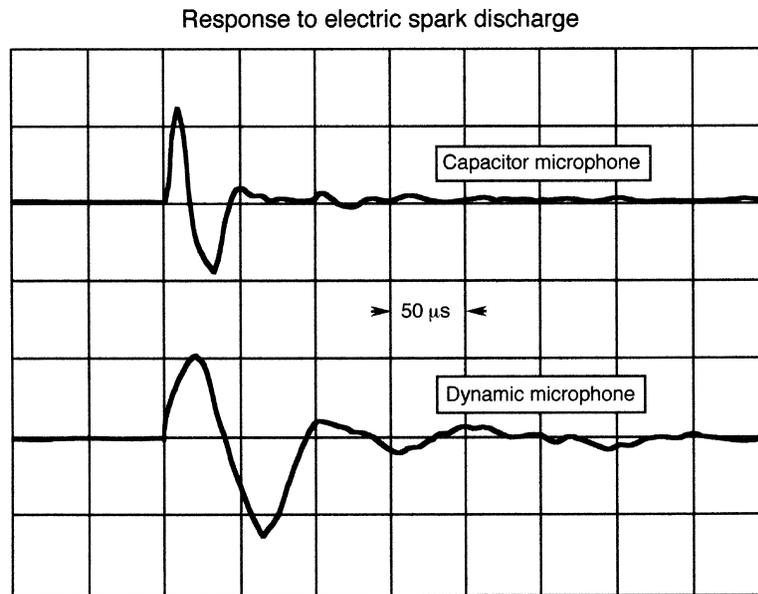
Response to electric spark discharge

Figure 7.11

Impulse responses (spark gap) of condenser and dynamic microphones. *(Figure after Boré, 1989.)*

Extending the Microphone Frequency Response Envelope

As higher sampling rates have been introduced into modern digital recording, the desire for microphones with extended on-axis frequency response capability has increased. Figure 7.12 presents on-axis response curves for the Sennheiser multi-pattern Model MKH800 microphone showing response out to 50 kHz—an example of what can be accommodated through careful design and amplitude equalization.

Standards

The primary source of microphone standards for normal audio engineering applications is the International Electrotechnical Commission (IEC). IEC document 60268–4 ed4.0 (2010) specifically lists the characteristics of microphones to be included in specification literature, along with methods for performing the measurements. IEC document 61094-2 ed2.0 (2009) specifically covers reciprocity calibration of 1-inch pressure microphones.

In addition, many countries have their own standards generating groups that in many cases adopt IEC standards, often issuing them under their own publication numbers. See Gayford (1994, Chapter 10) for additional discussion of microphone standards.
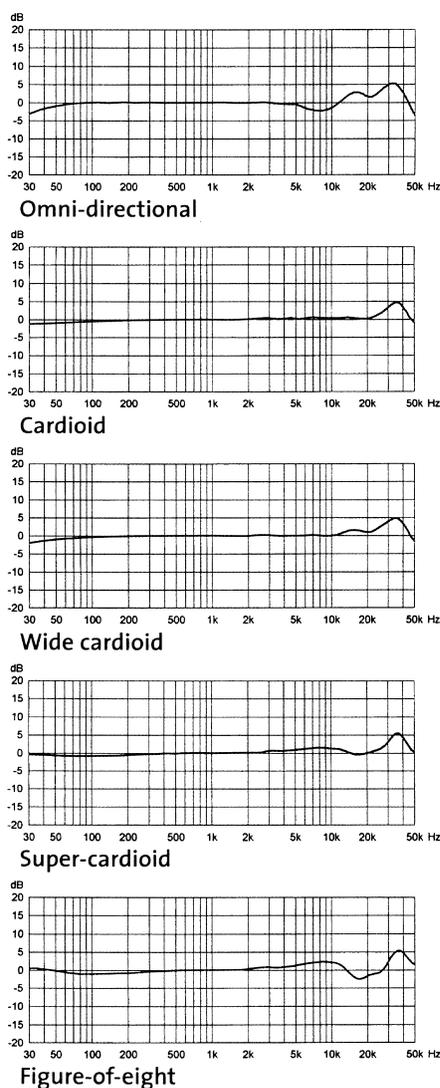
Figure 7.12
On-axis frequency response of Sennheiser model MKH800 microphone for five directional settings.
(Figure courtesy of Sennheiser Electronics.)

Microphone standards working groups including AES SC-04-04 are working on getting manufacturers to adopt consistent methods of characterizing microphones, and of presenting that data to microphone users. The attempt here is to define, far better than before, those subjective aspects that characterize microphone performance in real-world environments and applications, and to allow data from multiple manufacturers to be directly compared. We eagerly await the outcome of these activities.