

OVER 30 YEARS OF EXPERIENCE MANUFACTURING ACOUSTIC PRODUCTS



Microphone Handbook



 **PCB PIEZOTRONICS**^{INC.}
MTS SYSTEMS CORPORATION



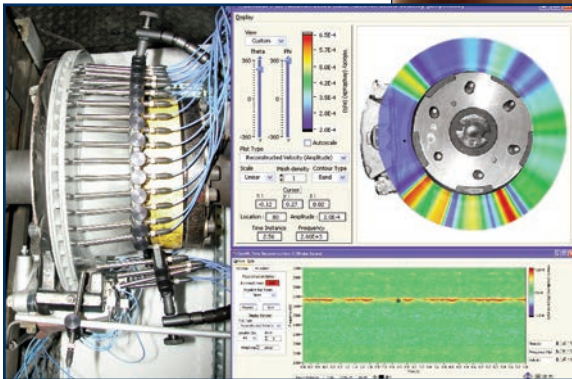
Microphone Handbook

Contents

Page

Introduction	3
Technology Fundamentals and Microphone Types	4
Selecting and Specifying Microphones	6
Dynamic Response	8
Frequency Response	10
Specialty Microphones & Systems	12
Applicable Standards	14
Interfacing and Design Information	16
Applications	17
Maintenance for Microphones and Preamplifiers	18
Latest and Future Developments	19





Introduction

Pressure variations, whether in air, water or other mediums, which the human ear can detect, are considered sounds. Acoustics is the science or the study of sound. Sound can be generally pleasing to the ear, as in music, or undesirable, referred to as noise. The typical audible range of a healthy human ear is 20 to 20,000 Hz. A Sound Pressure Level (SPL) beyond the detectable frequencies of the human ear can also be very important to design and safety engineers. Noise, Vibration and Harshness (NVH) is concerned with the study of vibration and audible sounds. Vibrations represent a rapid linear motion of a particle or of an elastic

solid about an equilibrium position, or fluctuation of pressure level. Harshness is a subjective quality of noise referring to the study of transient frequencies or shock. Usually treatments are employed to eliminate noise, but in some cases products are designed to amplify the sound and vibration at particular frequencies. The sound produced or received by a typical object, which may be above and below the frequencies that are detectable by the human ear, or amplitudes concerning its resonant frequencies, are important to designers, in order to characterize the items performance and longevity.





Technology Fundamentals and Microphone Types



When an object vibrates in the presence of air, the air molecules at the surface will begin to vibrate, which in turn vibrates the adjacent molecules next to them. This vibration will travel through the air as oscillating pressure at frequencies and amplitudes determined by the original sound source. The human ear transforms these pressure oscillations, or sound, into electrical signals that are interpreted by our brains as music, speech, noise, etc. Microphones are designed, like the human ear, to transform pressure oscillations into electrical signals. These signals can be recorded and analyzed to tell us information about the original source of vibration or the nature of the path the sound took from the source to the microphone. This is exhibited in testing of noise reducing materials. Sound pressure must be analyzed in the design stages to not only protect the materials around it, but also to protect the mechanism designed to perceive it, the human ear. Like the human ear, microphones are designed to measure a very large range of amplitudes typically measured in decibels (dB), and wide ranges of frequencies measured in hertz (Hz), which will be discussed on pages 8 & 10.



Microphones measure sound pressure. There are a few different designs for microphones. The most common designs for test and measurement applications are modern Prepolarized Condenser Microphones, Externally Polarized Condenser Microphones, and Piezoelectric Microphones, commonly referred to as Acoustic Pressure Sensors. Other microphone designs include Carbon Microphones, Dynamic, Magnetic Microphones, Fiber Optic Microphones, Laser, Ribbon and Micro Electro-Mechanical Systems (MEMS).

Condenser microphones operate on a capacitive design, shown in figure 1 and utilizes basic transduction (the conveyance of energy from a donor to a receptor) principles and will transform

the sound pressure to capacitance variations, which are then converted to an electrical voltage. This is accomplished by taking a small thin diaphragm and stretching it a very small distance away from a stationary metal plate, called a "backplate." In the presence of oscillating pressure, the diaphragm will move which changes the gap and thus the capacitance between the diaphragm and the backplate. In order to measure the changing capacitance of the microphone due to the sound field, a voltage is applied to the backplate to form the transducer. Changes in the acoustic pressure will deflect the diaphragm and produce a voltage from the capacitor proportional to the original pressure oscillation corresponding to the individual microphone's sensitivity.

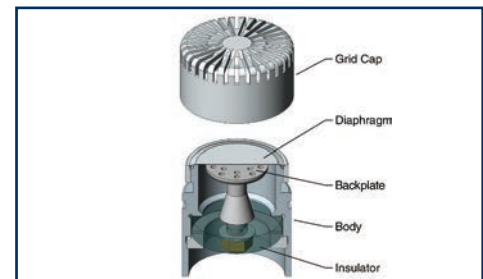


Fig 1. Condenser Microphone Components

In order to convert a change in capacitance to a change in voltage, the charge applied to the backplate can be generated by two different methods. The first is an externally polarized microphone design where an external power supply is used. The voltage source on this traditional design is 200 volts. The second, newer design is called a prepolarized microphone design. This modern design utilizes an electret layer placed on the backplate. An electret is a material in which a constant electric charge is placed. This charged material is what supplies the voltage for polarization. This design, when coupled with an Integrated Circuit Piezoelectric (ICP®) preamplifier can

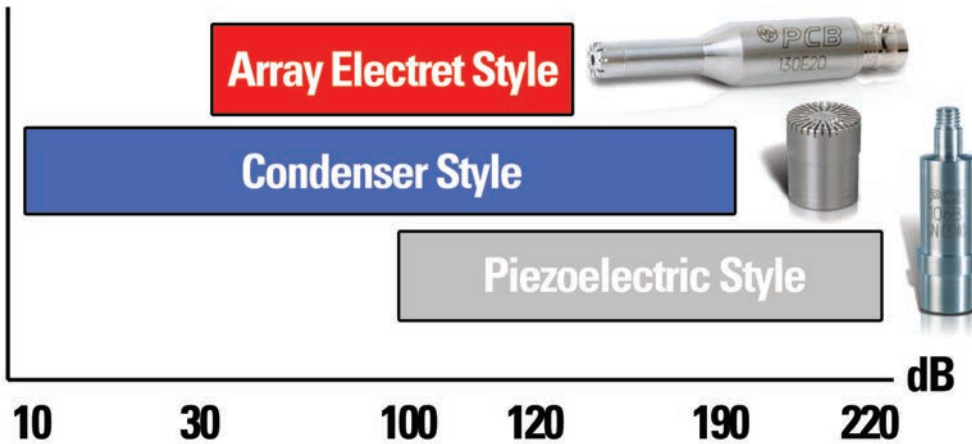


Fig 2. Test & Measurement Microphones

provide great advantages. An inexpensive constant current supply can power the unit, instead of the more expensive externally polarized power supplies. Standard coaxial cables with BNC or 10-32 connectors can be used, instead of LEMO® 7-pin connectors and cables. The coaxial cables can be driven long distances without degradation of the signal. PCB® is the founder of ICP® (Integrated Circuit Piezoelectric) technology, which all the modern prepolarized acoustic designs are based upon. The modern prepolarized designs are becoming increasingly popular for laboratory test and measurement, and field applications, due to low cost, ease of use, and interchangeability with IEPE (the generic trade name for ICP®) compliant accelerometers.

Array microphones are an electret style. Although the dynamic range and frequency range are not as wide as the IEC 61094 compliant condenser microphones, as shown in figure 2, it's value oriented design makes it a excellent choice for large channel measurement test and measurement applications concerned with the human audible range. See pages 13 & 17 for additional information and applications.

Piezoelectric microphones use a quartz or manmade ceramic crystal structure, which is similar to electrets in that they exhibit a permanent polarization and can be coupled with an ICP® design. Although these acoustic sensors have very low sensitivity levels, they are very durable and are able to measure very high amplitude (decibels) pressure ranges. Conversely, the noise floor level on this type of microphone is generally very high. This design is suitable for shock and blast pressure measurement applications.

Carbon microphone designs are becoming less popular, but are a low-cost type. This design is a very low quality acoustic transducer type. An enclosure is built. This enclosure houses lightly packed carbon granules. At opposite ends of the enclosure, electrical contacts are placed, which have a measured resistance. When the pressure from an acoustical signal is exerted on the microphone, it forces the granules closer together, which decreases the resistance. This change in resistance is measured and output. A typical use of this item can be seen in early basic designs of a telephone handset.

Magnetic microphones are a dynamic microphone. The moving coil design is based on the principal of magnetic induction. This design can be simply achieved by attaching a coil of wire to a light diaphragm. Upon seeing the acoustical pressure, the coil will move. When the wire is subjected to the magnetic field, the movement of the coil in the magnetic field creates a voltage, which is proportional to the pressure exerted on it.

Microelectromechanical systems (MEMS) microphones consist of etched silicon and are becoming increasingly popular due to their low cost. But their specifications for frequency, amplitude, sensitivity and stability, limit their use for test and measurement applications, for now. Future developments may enable this to be a viable design for use in test and measurement applications.

The most popular test and measurement microphones are the capacitor condenser designs. The focus of the following technical guide will be based on these Prepolarized and Externally Polarized condenser designs.



Model 106B
Pressure Sensor
(Piezoelectric microphone)



Model 130E21B
Array Microphones



Selecting and Specifying Microphones

Microphones measure broadband sound pressure levels from a variety of sources. When the microphone signal is post processed, the frequencies can be correlated with the sound source, and if necessary, related back to the wavelength of the sound. Acoustical measurement of this sound, through the use of high-precision condenser microphones, provides a better understanding of the nature of the sound. In some applications there are a number of microphones that can work and measure the sound pressure level. Common diameters for condenser microphones are 1/4" (6mm), 1/2" (12 mm), 1" (25mm). The key is to determine which microphone will offer the best solution for a required application.

A device called a preamplifier houses the electronics that assist the mechanical microphone in working properly. With some microphone designs, a preamplifier will be housed in the same package as the microphone. In other designs, as is the case with the design which is compliant with the IEC 61094-4 (see page 14) working class standard of microphones, the preamplifier is a separate component. The preamplifier will have an impact on the microphone's characteristics and may limit its use. For example, if you read a prepolarized microphone's specification for temperature, it is rated at 120°C. Some people will misconstrue that and presume that you can perform an acoustic measurement test in environments to that 120 °C, only to find that in real life applications they can not, because the preamplifier is rated at 80 °C and thus the limiting factor. Experienced acoustical engineers check not only the microphone specifications, but also the preamplifier, or microphone and preamplifier system specifications.

A single microphone can be used to measure amplitude and frequency characteristics. The amplitude is sound pressure expressed in pascals (Pa) which can be converted to either psi or decibels, and the frequency is represented in hertz (Hz.) Multiple microphones containing excellent phase characteristics, when combined with the correct software, can be used to analyze the particle velocity and direction of sound making them excellent choices for noise source location.

When choosing the optimum microphone, the parameters to look at include the type of response field, polarization type, dynamic response, frequency response, and temperature range. There are also a variety of specialty type microphones for specific applications. In order to select and specify a microphone, the first criteria that needs to be looked at is the application and what the sound and environment represent.

Microphones Response Types

There are three response types for precision condenser microphones, which are: **Free Field**, **Pressure**, and **Random Incidence** responses. The output of these three different styles will be similar at lower frequencies, but as the frequency becomes higher, it becomes critical to select the right response type in order to obtain the most accurate test results. For any microphone all three responses can be determined, however, the microphone is named for the response for which it has the flattest frequency response.

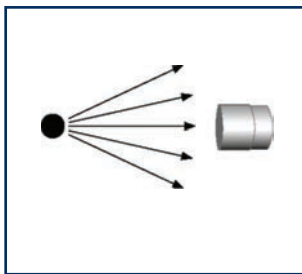
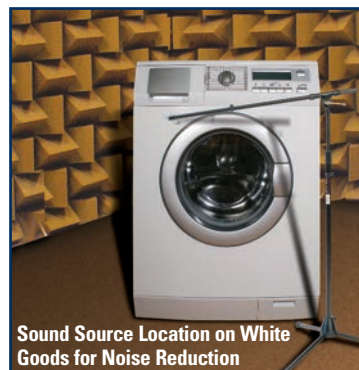


Fig 3. Free Field



The most common is the **free field** type, shown in figure 3. The free field microphone is most accurate when measuring sound pressure levels that radiate from a single direction and source, which is pointed directly (0° incidence angle) at the microphone diaphragm, and operated in an area that minimizes sound reflections. A free field microphone is designed to measure the sound pressure at the diaphragm, as it would appear if the microphone were not present. When any microphone is placed in a sound field, diffraction effects will alter the sound pressure when the frequency is high enough so that the wavelengths are similar in size to the dimension of the microphone. The effect is accounted for in the design of the microphone and calibration to

ensure the most accurate test data. Free field microphones work best in open areas, where there are no hard or reflective surfaces. Anechoic chambers or larger open areas are ideal for free field microphones.



Gun Shot and Blast Testing to Prevent Hearing Damage

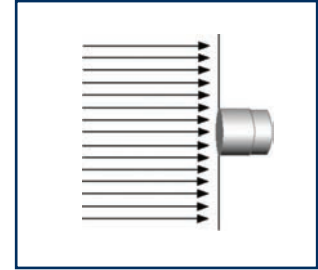


Fig 4. Pressure Field

The second response type is called a **pressure microphone**, shown in figure 4. A condenser style Pressure microphone is used similarly to a piezoelectric or standard pressure transducer in the sense that it is typically mounted in a duct, or cavity to measure acoustic pressure. The pressure response field microphones are commonly flush mounted to a wall or panel and measure the sound pressure that exists in front of the diaphragm, without the need for it to correct for its own presence. A pressure field is described to have the same magnitude and phase at any position in the field. A pressure microphone is commonly used in an enclosure which is small in size when compared to wavelength. Testing of sound pressure exerted on walls, exerted on airplane wings, or inside structures such as tubes, housings or cavities are examples of Pressure Type microphone applications.



Cabin Noise Measurement for Operator Comfort

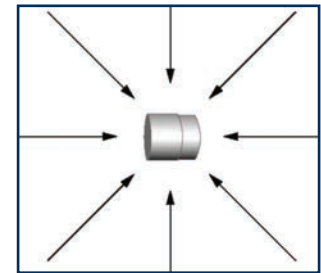


Fig 5. Random Incident Field

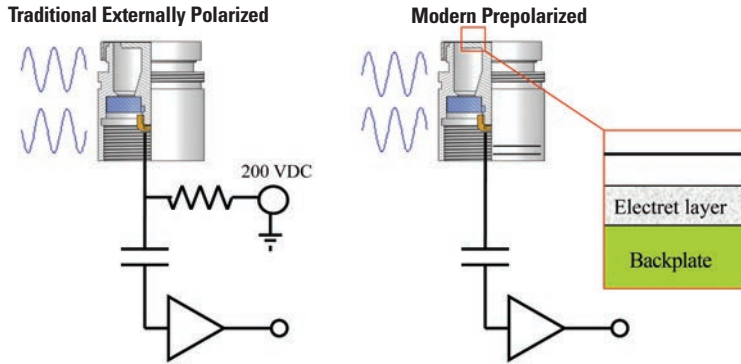
The third type is called a **Random Incidence Microphone**, shown in figure 5. This is also referred to as a "Diffuse Field Type." The Random Incidence microphone is designed to be omni-directional and measure sound pressure coming from multiple directions, multiple sources and multiple reflections. The random incidence microphone will compensate for its own presence in the field. An average of the net effect of all the calibrated incidence angles is taken into account, in order to output an accurate response in a diffuse field. This is accomplished within the design and calibration by the microphone manufacturer. When taking sound measurements in a reverb chamber, church or in an area with hard, reflective walls, you would utilize a Random Incidence microphone, to accurately measure the sound from multiple sources.

Microphone Size (Diameter)

The microphone size plays a part in the selection process. In general, large diameter microphones have higher sensitivity which are better for low frequency and low noise (ie: computers) measurements, while smaller diameter microphones are better suited for high frequency and high amplitude (ie: gun blast) applications.



Polarization Type



Test and measurement microphones can be broken down into two categories, **externally polarized** microphones and **prepolarized** microphones. For most applications either type will work well. The prepolarized are better suited for humid applications. They are recommended when changes of temperature may cause condensation on the internal components. This may short-out externally polarized microphones. Conversely, at high temperatures, between 120 – 150 °C, externally polarized microphones are a better choice, since the sensitivity is more stable in this temperature range, provided that you can isolate the preamplifier or have a preamplifier capable of this same maximum temperature rating.

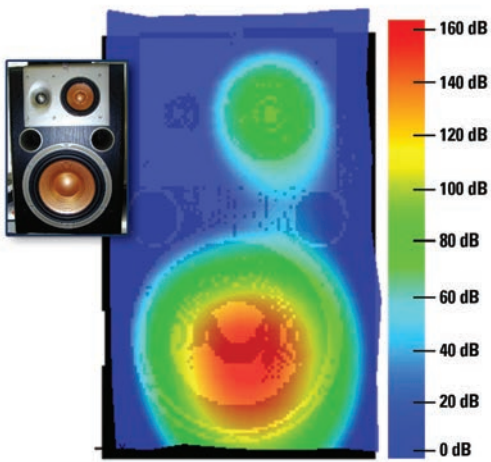
An Externally Polarized microphone set-up requires the use of a separate 200V power source. The most common set-up consists of 7-conductor cabling with LEMO® connectors and in some cases cost effective 5 pin designs are used. Externally polarized microphones are the traditional design. There are more models available and they are still utilized for special applications or for compatibility reasons.

The modern prepolarized test and measurement microphone designs with an ICP® preamplifier are powered by a cost effective and easy-to-operate, 2-20 mA constant current supply. This can be supplied by an ICP® signal conditioner (or directly by a readout that has a 2-20 mA constant current power built-in.) This design, for example PCB's 377 and 378 series, enables the owner to use standard coaxial cables with BNC or 10-32 connectors (in lieu of the multiconductor cabling with 7 Pin LEMO® connectors), for both current supply and signal to the readout device. The prepolarized design also saves set-up time, since it can be used simultaneously with ICP® accelerometers, force, strain or pressure sensors that have built-in electronics. This newer design has become very popular in recent years due to its time and cost savings and ease of use characteristics.

Dynamic Response

One of the main criteria to describe sound is based upon the amplitude of the sound pressure fluctuations. The difference between the highest sound pressure level a microphone can measure to the lowest is called the dynamic range. The lowest amplitude that a healthy human ear can detect is 20 millionths of a pascal (20µPa). Since the pressure numbers represented by pascals are generally very low and not easily managed, another scale is more commonly used, called the decibel (dB). The decibel scale is logarithmic and more closely matches the response reactions of the human ear to the pressure fluctuations. Here are some examples of typical sound pressure levels to use as a reference:

Acoustic Pressure (RMS)	Sound Pressure Level	Equivalent Source
0.00002 Pa	0 dB	Threshold of Hearing
0.02 Pa	60 dB	Business Office
0.2 Pa	80 dB	Shop Noise
1 Pa	94 dB	Large Truck
2 Pa	100 dB	Jackhammer
20 Pa	120 dB	Chain Saw
200 Pa	140 dB	Airplane Take Off



Sound Pressure Levels

Sound pressure can be calculated by using the following formula, where Sound Pressure is Pascals (P), Preamplifier voltage (RMS) is variable V, and Sensitivity is Volts per Pascal (S).

$$P = \frac{V}{S}$$

Once the pressure that the microphone is sensing is determined, this can then be converted to sound pressure level in decibels (dB), using the following logarithmic scale. RMS pressure is in pascals (Pa) and the sound pressure reference is 20μPa (Po).

$$dB = 20 \log \left(\frac{Pa}{Po} \right)$$

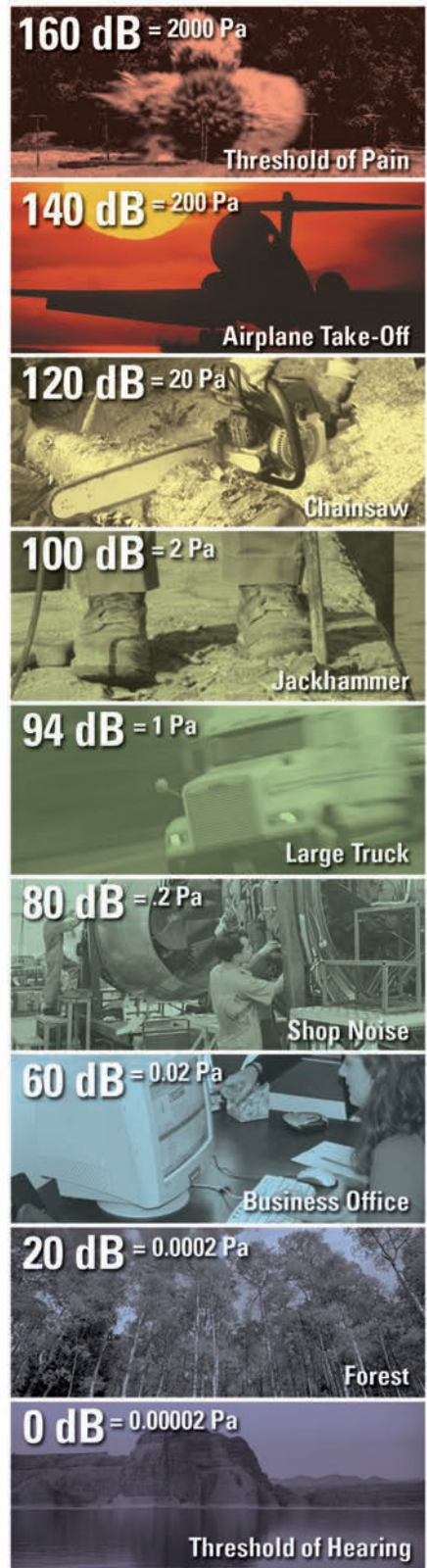
Sound can be represented by sound pressure, sound intensity or sound power. **Sound pressure** is a scalar quantity, and only occurs at a specific location with respect to a specific source (or set of sources). A doubling of sound pressure will exhibit a 6 dB gain in sound pressure level. A doubling of the distance from a sound source to the point of measurement results in a decrease of sound pressure level of 6dB in a free field. To put this in perspective of the human hearing, it takes approximately a 10 dB gain in sound pressure level to be perceived as a doubling of pressure.

Sound intensity is the flow of acoustic energy. Like other flow quantities, it is a vector equal to the sound power over a specified unit area being measured.

Sound power is the amount of acoustic energy released by a source over time. The sound power of a source is measured in watts. A doubling of Sound Power will show an increase of sound power level of 3 dB. Sound power is inherent to the source being measured, and is independent of the location of the measurements. ISO procedures detail methods for measuring the sound power of a sound source using sound pressure level and sound intensity.

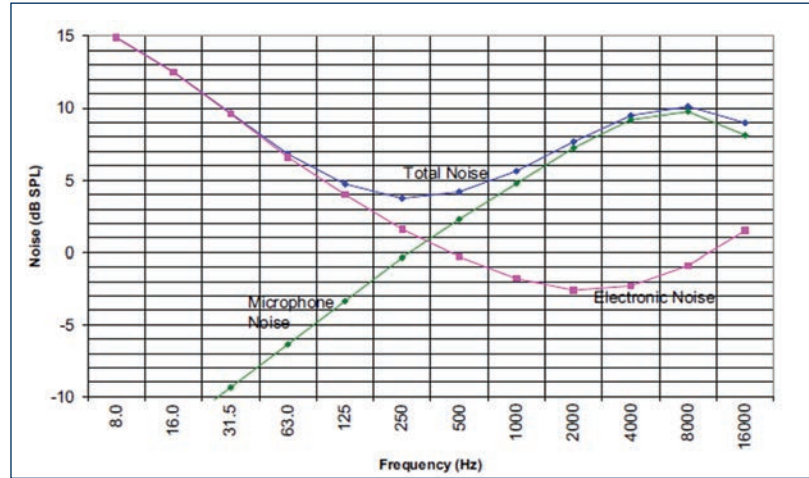
Microphones with smaller diameters are better for measuring higher amplitude sound pressure levels. It is recommended that when you are within a few decibels of a microphone and preamplifiers 3% distortion number, that you (when possible) move to a smaller diameter microphone to provide more headroom and greater flexibility. For extremely high amplitudes above 180 dB piezoelectric pressure sensors designs are a much more viable choice and are great for gunshot, blast and airbag deployment applications.

Manufacturers specify the maximum sound pressure level based on the design and physical characteristics of the microphone. The specified maximum sound pressure level will refer to the point where the diaphragm will begin to deform in a nonlinear fashion, or where Total Harmonic Distortion (THD) reaches a specified amount, typically 3% THD. It is important to note that this 3% distortion number is not the maximum you can measure with a microphone and preamplifier pair, this is simply the microphone's capability that manufacturers standardized for comparison. The absolute maximum decibel level that a microphone and preamplifier will output in a certain application is dependent upon the voltage supplied, and the particular microphone's sensitivity. In order to calculate the maximum output for a microphone, using a specific preamplifier and its corresponding peak voltage, you first need to calculate the pressure in Pascals that the microphone can accept.





For the noise floor level, or minimum amount of pressure measurable, you need to review the Cartridge Thermal Noise (CTN) rating of the microphone and the noise floor of the electronics (preamp). The cartridge thermal noise specification provides the lowest measurable sound pressure level that can be detected above the inherent noise floor of the microphone. Each microphone will have its own noise characteristics, and the diameter of the microphone will have a major impact on the frequencies and noise levels of the microphone. Depending upon the size and design, the microphone can dominate as the inherent noise source at higher frequencies, while the electrical noise of the preamplifier will dominate at lower frequencies. Below is a typical representation of the noise effect at different frequencies for a 1/2" diameter microphone when used in conjunction with a preamplifier.



The inherent noise level of a microphone and preamplifier system, however, will be greatest at both the lower and upper frequency capabilities of the system when plotted as octave bands, shown in figure 6.

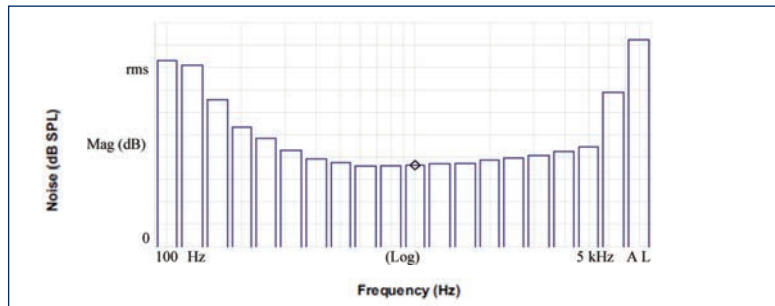


Fig 6. Typical Microphone and Preamplifier Noise Floor Data, 1/3 Octave Band Analysis

Proper selection requires that the sound pressure levels that are to be tested fall between the microphones low-end noise level, called cartridge thermal noise, and the maximum rated sound pressure level of the microphone. In general, the smaller the microphone diameter, the greater the high-end sound pressure level capability. The larger diameter microphones are recommended for low range sound pressure measurements, since the inherent noise or cartridge thermal noise specifications are typically lower.

Frequency Response

Once the type of microphone field response and dynamic range has been taken into consideration, the frequency range of interest for the test requirement should be reviewed. The frequency is the rate at which an oscillating signal completes a cycle by returning to the original value in cycles per second. Frequency is the number of pressure variations per second, measured in Hertz (Hz).



The usable frequency range of a microphone is defined by industry as the -3dB point at the low frequency end, stated for standard pressure (sea level) through the upper range, which is directly related to the resonance of the microphone, and the corresponding roll-off. Upon inspecting the microphone's specification sheet you will find the usable frequency range of the specific microphone. Smaller diameter microphones will usually have a higher upper frequency capability.

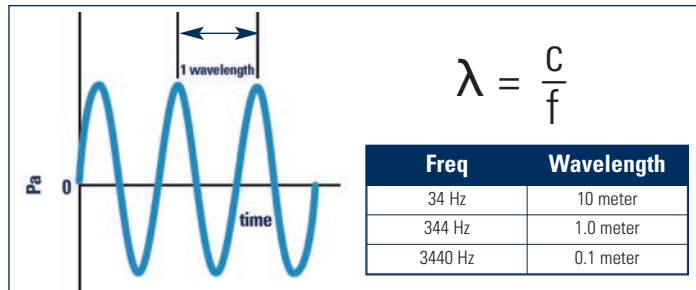


Fig 7. Wavelength as a Function of Frequency

Frequency corresponds to a wavelength and is calculated by the following formula, shown in figure 7 where Wavelength (λ) is in meters, Speed of Sound is m/s (c), and Frequency (f) is in Hz. The speed of sound is 344 m/s at room temperature.

Manufacturers will specify a tolerance of +/- 2 dB (and in some cases also +/- 1 dB) on the frequency response specifications, as directed by industry standards. When comparing microphones, make sure that you check the frequency range and the tolerance associated with that specific frequency range. If an application is not critical, you can improve the usable frequency range for that microphone, if you are willing to increase your allowable decibel tolerance. You can check with the manufacturer or look at the individual calibration sheet for a particular microphone in order to determine the actual usable frequency range for specific different decibel tolerances.

Perception of Sound and Weighting

While in many cases it is important to understand the linear (or un-weighted) measurement of sound, many of today's manufacturers are sometimes interested in how the human ear perceives sound at specific frequencies. A doubling of sound pressure represents a 6 dB increase, but the human ear does not perceive all frequencies the same. As we stated earlier, a young and healthy human ear can hear sound ranging from 20 Hz to 20 kHz. It is not uncommon for test engineers to be interested in sound pertaining to frequencies below the capability of the human hearing, called Infrasonds, or above the human hearing range, called Ultrasounds. In other cases, where manufactures are attempting to design their products either quieter or more pleasing to the human ear, these manufacturers are most interested in the net effects of the human ears perception of these sounds. With results from tests where equal loudness contours were generated, we know that the human ear is most sensitive for frequencies ranging from 1 kHz to 5 kHz, and our ears attenuate signals above and below these frequencies. Weighting designations were created to address the amplitude changes that the human ear perceives at different frequencies. The most common is called "A" weighting, which refers to how human hearing perceives sound pertaining to the most frequently used sound pressure levels. Other weighting networks B, C and D, which deal with higher sound pressure levels, are less common.

Temperature Range

Temperature will have an effect on the microphone's performance. Sensitivity can be directly affected by extreme environmental conditions. As the temperature approaches the maximum specifications of the microphone, its sensitivity may shift, which may result in less accurate data. The owner will need to be aware of not only the operating temperature, but also the storage temperature of the microphones. If operated and/or stored in extreme conditions, the microphone can be adversely affected and should also be calibrated more often. Most manufacturers state a temperature coefficient as part of the specifications on their microphones.

An experienced acoustician is aware that it is important to review not only the microphone specifications, but also the required preamplifier specifications because the preamplifier in most cases is the limiting factor for operating temperature capability. While most microphones are capable of operating to 120°C without any loss of sensitivity, the preamplifiers which are required for these microphones are typically in the 60°C to 80°C range. PCB's industry exclusive HT426E01 preamplifier addresses this deficiency and is the only preamplifier on the market that is specified to compliment (not limit) the microphones 120°C capability.





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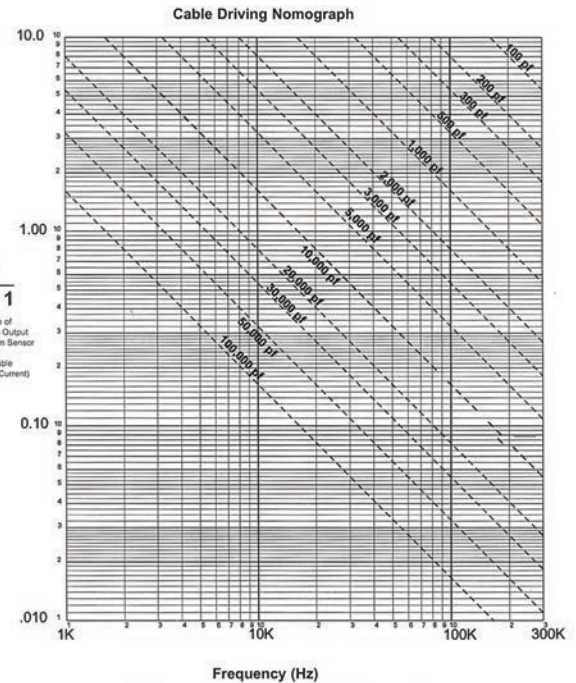
Should you require additional assistance, PCB has application engineers available 24 hours a day where they can assist you in determining the maximum recommended cable length.

Cable Length Determination (ICP®)

The maximum Cable Length depends upon a number of criteria. The quality of the cable and its capacitance in pF (C), the current being supplied from signal conditioning (Ic), the maximum frequency required of the measurement (fmax), and the maximum amplitude required (V). The equation and nomograph showing the capable frequency range of cabling are:

$$f_{\max} = \frac{10^9 (I_c - 1)}{2\pi CV}$$

$\frac{V}{I_c - 1}$
(Ratio of Maximum Output Voltage from Sensor to Available Constant Current)



f_{max} = Maximum frequency given the following characteristics
C = Cable capacitance (pF) I_c = Constant current level from power unit (mA)
V = Maximum output voltage from sensor (volts) 10⁹ = Scale factor to equate units



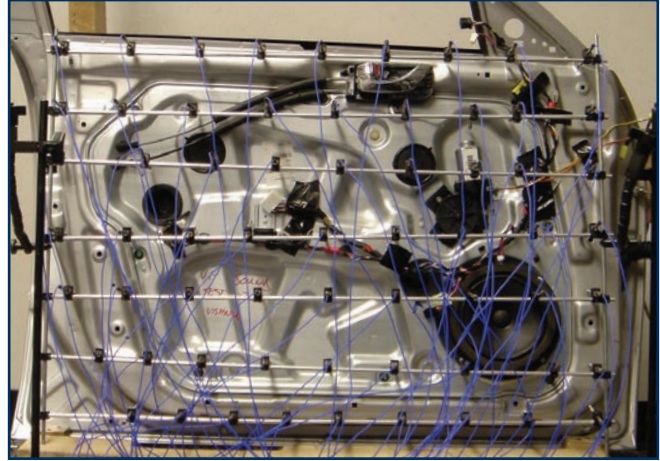
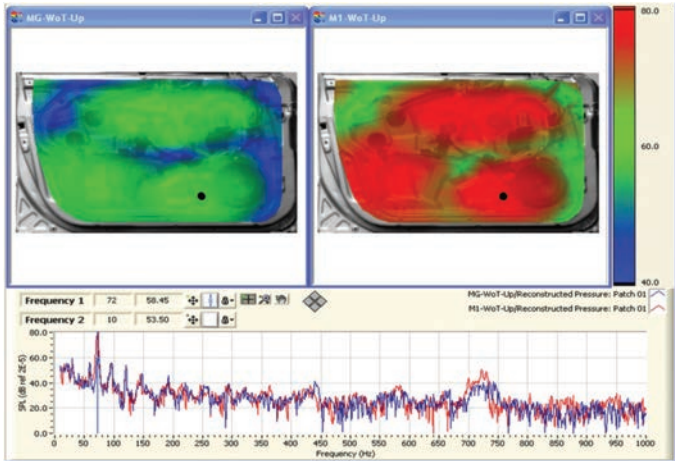
Specialty Microphones and Systems

When high temperature becomes a concern, a probe microphone offers an alternative solution. The **probe microphone** was designed for sound pressure measurements in harsh environments. It combines a microphone with a probe extension tube and heat sink. This enables the user to get very close to sound sources. The probe tip will send the acoustic signal to the microphone inside the probe housing. By placing some of the critical components in the separate housing, this microphone type can be used in extremely high temperature applications, or where access to the sound source is too small for a typical condenser microphone.

Hydrophones are used to measure sound in water. They were designed to detect underwater sound pressure signals. Industrial and scientific underwater testing, monitoring and measurements are accomplished with this corrosion resistant design. Different models are available for different sensitivities, frequencies, decibel levels and operating depths. Test and measurement condenser microphones should not be submerged in water.

Sound Level Meters are designed by manufacturers to provide a fast and convenient way to obtain a sound pressure level reading. This small handheld design contains all the components necessary to take a sound pressure reading, including the microphone, preamplifier, power source, software and display. This is an excellent choice for taking a dB measurement in an industrial setting, for community noise assessment, noise exposure measurements, artillery fire measurements, and many other applications. The Sound Level Meter can be provided with a number of options, including A-Weighting, real time analyzers, and software options.





When measurements involving the magnitude and direction of the sound need to be captured, as is the case when attempting to detect noise sources, an intensity probe is an excellent tool. By taking two phase matched microphones and placing a spacer between them, a user can not only tell the pressure level, but also the speed and direction of the propagating sound waves. Different sized spacers are available for measuring the particle velocity at different frequencies. The higher frequencies typically require a smaller spacer. Larger spacers are suitable for lower frequencies.



For Near Field Acoustic Holography (NAH) applications where three dimensional field values are to be studied, an Array microphone set-up is recommended. By taking a number of array microphones and spacing them out in a predetermined pattern, and combining them with the appropriate software, spatial transformation of a complex sound pressure field is projected to effectively map the acoustic energy flow. Array microphones are an excellent choice for large channel count acoustic testing. Transducer Electronic Data Sheet (TEDS) is recommended option for arrays, since they enable the user to quickly and easily identify a particular microphone. These TEDS chips and software enable the user to store information on the microphones model, serial number, calibration date, along with the specifications of the microphones sensitivity, capacitance, impedance, etc... that can be read by the measuring system software for gain or sensitivity adjustment to ensure accurate test results.

Outdoor preamplifiers have been developed to help microphones withstand the rigorous environmental exposure that these microphones will be subjected to. Airport noise, or highway traffic noise has become increasing popular spots for test and measurements, to provide safety for humans. The Environmental enclosures and outdoor preamplifiers provide different levels of protection for the internal components, while maintaining their high-accuracy specifications. Microphones should not be used in condensing environments without environmental protection.





Applicable Standards

Prior to selecting a microphone or other acoustic test hardware, the consumer should determine whether there are certain standards that the product must comply with, for the application in which the product will be used. Whether for legal purposes, or for quality assurance programs, these standards will help determine the quality, accuracy and consistency of the products. Standards have been set for sound level meters, calibrators, microphones, or other related measurement components. There are numerous standards that correspond to the performance requirements, dimensions and characteristics of acoustical components. The most popular organizations for establishing these standards are the American National Standards Institute (ANSI) and the International Electrotechnical Commission (IEC.)



IEC 61094 deals specifically with the condenser microphone. It establishes specifications on the mechanical dimensions and certain electroacoustic characteristics for working standard microphones, which are to be used as laboratory reference microphones. These condenser microphones require the highest accuracy, due to the fact that these units will determine the accuracy of other microphones in primary calibrations by the reciprocity method.

The above IEC standards define both dimensional sizes and tolerances along with electroacoustical specifications for the most common selection criteria: sensitivity, frequency range, dynamic range and more. Defining the dimensional sizes and tolerances ensures interchangeability between acoustic manufacturers microphones. The IEC 61094 types include WS1P/F/D, WS2P/F/D and WS3P/F/D, where the WS1 pertains to 1" (25mm) diameter microphones, while the WS2 is for the most common 1/2" (12mm) diameter models, and the WS3 is for the 1/4" (6mm) models. The P/F/D represents the field response type, where "P" is for Pressure, "F" is for Free-Field and "D" is for Diffuse Field (commonly referred to as Random Incidence.)

ANSI S1.4 is the American National Standards Institute's standard for Sound Level Meters. It deals with the specifications for this product, and was originally written in 1983 and later amended to S1.4A in 1995, and is currently used today. ANSI S1.43 established in 1997 deals with setting a standard for compliance for Integrating-Average Sound Level Meters.



IEC 60942 was created with the specifications on sound calibrators in mind. There are three classes concerned with the standards of sound calibrators. The most stringent is the Laboratory Standard (LS). The LS class has the tightest tolerances and is designated for calibrators that will be used only in the laboratory. Both Class 1 and Class 2 instruments are considered for field usage applications. A Class 1 calibrator is intended to be used with a Class 1 sound level meter, while a Class 2 calibrator is designed to be used with a Class 2 sound level meter.

IEC 61672 was instituted to replace 60651 and 60804. 61672 provides electroacoustical performance standards for Sound Level Meters. There are standards that range from the simplest integrated sound level meter which measures sound exposure levels, to sound level meters that measure time-average sound levels, to conventional sound level meters that measure exponential time-weighted sound levels. A sound level meter can have one, all, or a combination of the previously mentioned measurements. There are several classes for the sound level meters. The standards are based around the same design characteristics, but differ in the tolerance limits and operational temperature specifications. To conform to a certain class, a specified frequency response for sound incident on the microphone in a free field or diffuse field must meet the IEC standards. Class two tolerances are more liberal, compared to class one standards.



There are certain classifications that are commonly referenced. Types ranging from Type 0 through Type 2 dictate the tolerance and accuracy of the system. These standards were created for Sound Level Meters, and get commonly referred to when mentioning components of the system,



such as the microphone cartridge and the preamplifier. Type 0 refers to Laboratory reference. It is not required to satisfy the environmental requirements for field instruments, but must be extremely accurate, since this is what other sound level meters will be judged against or tested to. Type 1 is a working class standard for both laboratory use and for use in the field. The Type 1 standard is extremely accurate and durable. It is designed to take the challenges of the environment and still compile highly accurate and reliable acoustic measurements. This is a very popular type for research and design engineers. Type 2 sound level meters have standards that are more relaxed.

The Type 2 is a general-purpose type. These microphones do not have the high-frequency response, low cartridge thermal noise levels, or accuracy as the first two types, but offer a less expensive alternative for when the measurement accuracy is not as critical.

Some manufacturers will designate their microphone, preamp or filter as a certain type or to meet a particular standard. In order to conform you must look at the complete system. The whole system must meet the standard, not just one specific component. PCB designs each individual component to exceed the specifications, so that when installed it meets the Type 1 specifications, even after the accumulation of tolerances of each component is taken into consideration. For more information on the above standards, please contact the above organizations. They can answer your questions and send you documentation on the specific standards that you may have an interest in.



Interfacing and Design Information

After proper selection of your microphone, the corresponding preamplifier and ancillary equipment must be specified and installed. The necessary cabling, power supply, signal conditioning and data acquisition selections are to be made. Not all of these components are required for all test set-ups. Figure 8 represents the typical set-up for prepolarized system.

With a newer Data Acquisition System (DAQ) which has a constant current power built-in, the microphone and preamplifier combination can be directly connected to the DAQ via a coaxial cable, making the set-up easier and more cost effective.



Fig 8. Modern Prepolarized set-up

The diagram for the externally polarized system is shown in Figure 9 below.



Fig 9. Traditional Externally Polarized set-up

Prepolarized microphones are versatile and can be used in either setup and can be used with a power supply that is designed for externally powered microphones and its associated preamp, provided that you set the supply voltage to zero, and the power supply can provide the constant current supply. Externally polarized microphones can only be used in the setup shown in Figure 9, and only with a 200V power supply.



Applications

Acoustical testing is performed for a variety of reasons, ranging from designing new products, to monitoring products, to predictive maintenance functions, to personal protection. Some typical applications for acoustical studies that require microphones may include:

Research and Product Design – Excessive sound pressure can cause damage to products or human hearing. Microphones are used to measure the pressure level exerted on a surface. Sound pressure can shake plaster off walls or cause damage to an airplane wing. Sound measurement is used in a variety of applications including: the study of door slams, clutch engagements, starter impact and sunroof noise. The automotive market will utilize high precision microphones for “Squeak and Rattle” tests in order to provide a quieter ride. Analysis of engine noise in a cabin or car interior, or sound exhibited from consumer appliances are tested to extend the lifespan of the product and keep the external noise minimal, for the comfort of the user.

Preventive Maintenance – Increased sound levels or changes in frequency can indicate that a product is not working to its capacity. Motors, gears, fans, bearings, blades, or other industrial components can all experience changes in decibel level or frequency shift when not working properly. High precision microphones can be utilized to confirm that a product is experiencing a problem, or can be used to predict failure of a component.

Audiometric Calibration – Universities, governments and independent companies have audio testing equipment to perform hearing tests and research projects. Microphones are used to test and calibrate the systems to ensure the accuracy of the test equipment.

Compliance – Microphone tests can be performed and recorded for verification of pressure levels on products, and can be utilized in legal situations. Companies will use high precision microphone tests for proof of sound pressure levels during design. Microphones are used on sound level meters to ensure compliance with national standards for shop noise.

Environmental Noise Analysis – There are certain sound pressure levels that the human ear can be subjected to for specific amounts of time before ear damage can occur (dose) as suggested by OSHA (Occupational Safety and Health

Administration). Exposure to high amplitude sound pressure, for example loud machinery, industrial noise, airport noise, highway noise, etc., can have adverse effects on the human hearing. These effects can range from annoying noise to permanent loss of hearing. Acoustic testing is performed so that a better understanding of the sound levels that are experienced in these surroundings is achieved, and the necessary adjustments can be made in order to provide greater personal protection.

Noise Source Identification – Acoustic holography, beamforming, and other pressure mapping techniques are areas where microphone use has been increasing. Grids consisting of multiple microphones, sometimes used in conjunction with acoustic cameras, can be set-up to tell the difference in the sound pressure at different points around an engine or a car tire well. Calculations can be made per zone or spectrum. Some applications include seismic activity monitoring, satellite tracking, automotive and industrial noise source identification. Microphones can be utilized to transform 2-dimensional complex sound pressure information into 3-dimensional acoustic fields using basic wave equations to indicate surface intensity and radiation patterns.

Array microphones are Free Field Type microphones, which are designed to offer a cost-effective solution for multiple channel sound measurement. This makes Nearfield Acoustic Holography (NAH) measurements practical. Grids can be constructed to take 2D mapping measurements. The 130E20, 130E21 and 130E22 have an integrated Microphone and Preamplifier. The 130 series utilizes the Prepolarized microphone design and incorporate ICP® type circuitry powered by a constant current signal conditioner. The 130 series provide an inexpensive alternative to the 377 series. The 130 series are accurate for frequency responses and great for trending, but are more sensitive to changes in temperature and less accurate than the 377 series of high precision condenser microphones, when the most accurate decibel amplitude measurements need to be made.





Maintenance for Microphones and Preamplifiers

Microphones are very stable over long periods of time, provided that they are handled and stored properly. Components of the microphone are fragile and can get damaged by misuse. The diaphragm is made up of a very thin proprietary material that should be kept clean of dust, dirt, moisture and any type of imperfection (scratch, dent, etc.) The grid cap is designed to let through the true sound pressure level. The only function for the grid cap is to prevent items from coming in contact with the diaphragm. We do not recommend that you ever remove the grid cap or clean the microphone. If you take the precautionary measures to keep it clean and dry, it should not be necessary. In the event that you absolutely must take off the grid cap and clean the microphone diaphragm, we recommend using a blow bulb or light pressure clean and dry air hose to blow away contamination off the diaphragm. Do not touch the microphone's diaphragm with your fingers or let it come in contact with any sharp or pointed object. Please note that any contact to the microphone's diaphragm can negatively impact the sensitivity and long term stability of the microphone.

Accessories, like windscreens and desiccants, will help keep moisture off the microphone and help maintain the specified sensitivity level. Nose Cones will help keep turbulence off the microphone diaphragm and still let the sound pressure level come in unobstructed.

Dust, rain, oil or moisture may adversely affect the microphone and the preamplifier's performance. If you should get contamination on the backside of the microphone, or inside the connection area of the preamplifier, use a light pressure rubber bulb to blow clean, dry air into the unit in order to remove the dust.

Keep the microphone and preamplifier assembled while preparing for testing. Keep the maintenance caps on the preamplifier's electrical connector and store your microphones and preamplifiers in their protective cases, when not in use. With proper maintenance, your microphone and preamplifier should provide stable and accurate results for years to come.

Calibration

Test and measurement condenser microphones are used to very accurately measure sound. These high quality microphones come with a calibration certificate, shown in figure 10, stating the individual microphones sensitivity under certain laboratory temperature, pressure and humidity conditions. Changes in atmospheric pressure, temperature or humidity can affect the microphone's sensitivity. It is recommended to use a handheld

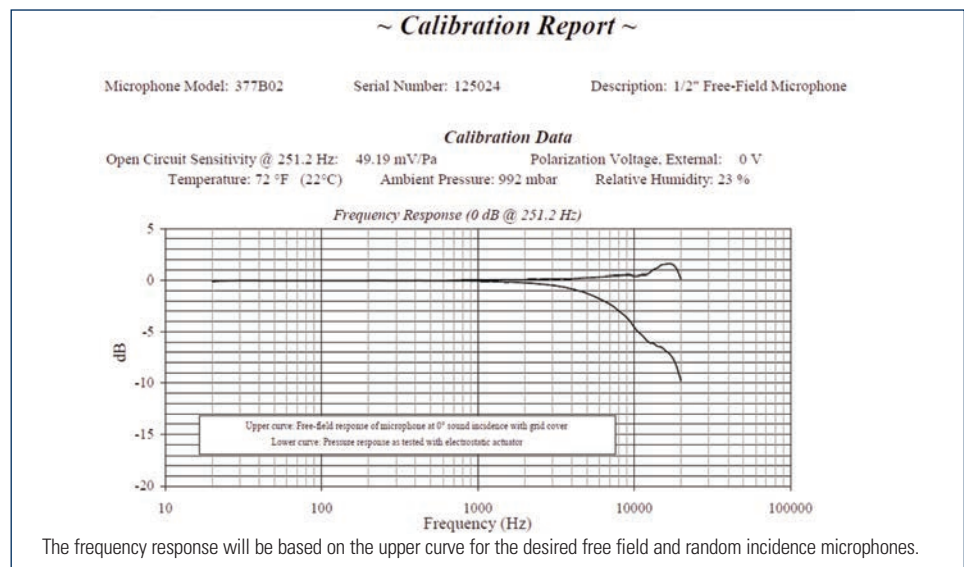


Fig 10. Calibration Certificate



calibration device to provide the most accurate sensitivity in the actual test environment. This is done with a speaker or mechanical pistonphone for a single frequency (typically 250 Hz or 1 kHz). In some applications, for instance measurements related to Legal Metrology, it is required to calibrate in the test environment both before and after the measurement is performed. This is a recommended practice for all tests due to the fact that it ensures a high level of confidence in the test results.

Most end users will also send their microphones into a qualified calibration service center to verify the microphone and preamplifier are in good working condition and meet original manufacturer's specifications. This is typically done once every 1-

2 years, depending upon a number of factors including how often the microphone is used, how rough the environmental conditions are, if the units have been misused and dropped or simply to comply with internal or external quality programs.



This above calibration differs from the "in-field" single point check in the fact that the service center will test the microphone through the whole frequency spectrum capability (called a sweep) to not only verify the sensitivity at the single point, but also the linearity or consistency of the sensitivity through the whole frequency range of the original manufacturer's specification.

Latest and Future Developments

Due to the ease of use and the cost savings mentioned earlier, consumers have been dictating where research and design time be spent. Manufacturers have been coming up with more diverse prepolarized microphone designs, so that end users have a larger selection to match that of the traditional microphones for different applications.

The rise in applications concerning Nearfield Acoustic Holography (NAH) has driven manufacturers to not only come with array microphone designs for large channel counts, but also the ancillary equipment to be enhanced. Array grids, both stationary and linear guided systems, are becoming increasingly popular. This in turn has also promoted new designs in software systems designed for sound pressure mapping, large channel signal conditioning units, and newer readout and data acquisition designs that can handle the increased inputs and necessary data output.

Advanced designs of Sound Level Meters are very popular in both the industrial sector and for health related measurements. End users want items that are both mobile and easy to use. These products come complete in a battery-operated handheld unit that does not require any assembly for daily usage. Sales of this product group continue to be strong, due to its convenient design. Future developments will be in the expanded software systems, extended battery life, greater storage capability, easier transfer of data, and designs made for specific target applications.



Transducer Electronic Data Sheets (TEDS) are becoming increasingly popular with the rise of large channel count tests and for obtaining accurate results on a consistent basis. This system makes it easy to manage a number of microphones by enabling the user to locate a specific microphone within a group of microphones. Data storage, calibration, historical information, and physical characteristics of each individual microphone and preamplifier are easily retrieved, with the TEDS set-up. Software companies and data acquisition companies are placing a higher emphasis to manufacture designs to take advantage of this technology, so that the end consumer can reap the rewards.

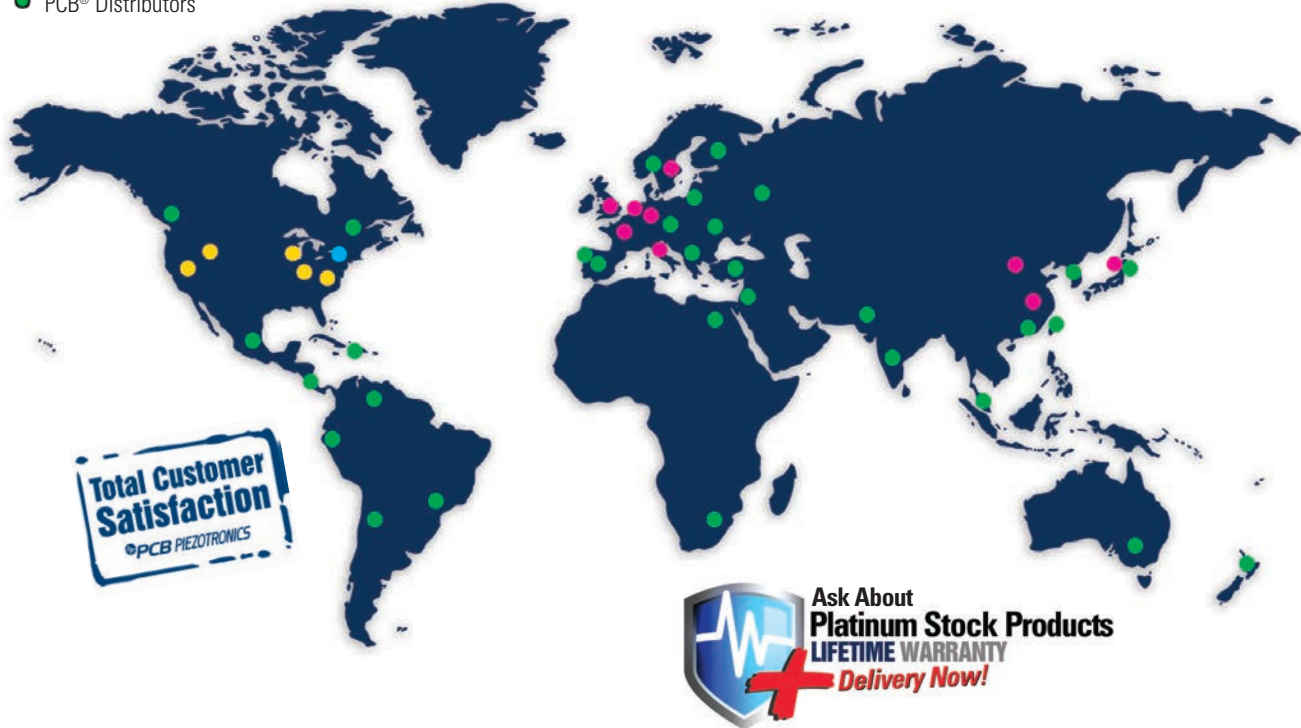
In general, consumers are looking for smaller packages that will accurately measure sound pressure levels and make their jobs easier and quicker in both the set-up process and data recording areas. They also want the costs to be minimized. The manufacturers will continue to look at designs that will offer the customer the best value for the application.

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