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PERFORMANCE™

A Shure Educational Publication

AUDIO SYSTEMS GUIDE

THEATER PERFORMANCES

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Introduction

Proper microphone selection and placement in theater applications can dramatically improve and reinforce the impact of the action and emotion on stage. On Broadway as well as on small community stages, in large productions and small, the theater experience relies as heavily on good sound as on any other feature. In small, acoustically pleasing venues, simply projecting your voice may be all that is necessary for everyone to hear. That was how it was done for hundreds of years before the development of electricity and microphones. However, in modern larger theaters and for more complex productions, microphones and sound reinforcement systems often become absolutely necessary.

While the physical design of the theater environment and its acoustic qualities must be considered in the design of a sound reinforcement system, the topics we will focus on in this book include microphone selection and placement, and wireless microphone systems. This text will examine how microphones, both wired and wireless, can be used to insure that every word spoken or sung is heard while taking into account some of the complexities of costuming or staging. Some of the text in this booklet is pulled from several of Shure Incorporated's Applications Bulletins and educational booklets which can be found on the Shure Inc. website, www.shure.com. It also contains new material, which covers microphone techniques specific to theater productions. These techniques can be useful in all theater applications regardless of venue size.



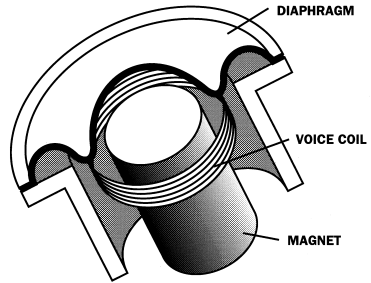
Introduction

MICROPHONE DESIGN

A microphone is a type of transducer, which is a device that converts one form of energy into another. A microphone is capturing acoustic energy, the sound waves of a voice or musical instrument, and converting it into electrical energy. The electrical energy, or the electrical representation of the sound wave, is then transferred to the next device in the audio chain through the microphone cable, or via a wireless system, which sends the audio signal through space using radio waves. There are several types of microphone designs that perform this task using different methods. For our purposes, we will concentrate on the two most common types of microphones used in professional audio today, dynamic microphones and condenser microphones.

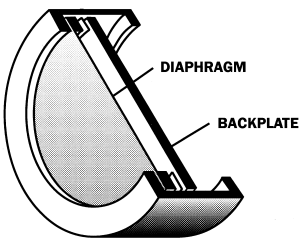
Dynamic Microphones

Dynamic microphones use an assembly consisting of a thin diaphragm, a voice coil, and a magnet. As sound waves strike the diaphragm, which is usually made of a very thin plastic, it causes the attached voice coil to vibrate within the magnet's field. This action, known as electromagnetic induction, generates the electrical representation of the sound wave. This miniature electric generator is a very simple design, yet it is a very cost-effective way of creating an audio signal. Dynamic microphones tend to be more resistant to rough handling, humidity, and temperature change. They can also handle extremely loud sounds and are almost impossible to overload. For these reasons, dynamic microphones are widely, though not exclusively, used in live sound reinforcement.



Dynamic Microphone

Condenser Microphones



Condenser Microphone

Condenser microphones use an assembly consisting of a diaphragm and an electrically charged backplate. The assembly is basically a capacitor, which is a device that can store a charge. In this design, a thin layer called an insulator separates the metal or metal-coated backplate, which is rigid, and the diaphragm, which is flexible. When the condenser element is charged, an electrical field is created between the diaphragm and the backplate. The charge is proportional to the space between them. As sound waves strike the diaphragm and cause it to

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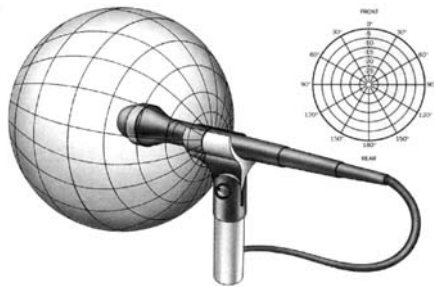
vibrate, the spacing in between the two surfaces varies, affecting the electrical charge in the assembly. This fluctuation creates the electrical representation of the sound wave.

There are two types of condenser microphones, distinguished by the method used to charge the element. Electret condenser microphones have a permanently charged backplate. Non-electret, or "externally biased" condensers require a voltage, called phantom power, which is supplied from another device to charge the backplate. Usually, the next device in the audio chain supplies phantom power that is between 12Vdc and 48Vdc. It is supplied directly through the microphone cable. All condensers have active circuitry incorporated into the design, which is required to supply a usable voltage level to the next audio device, and to convert the microphone output to low impedance. This active circuitry is called the pre-amplifier and is often powered by phantom power as well. Some electret condensers have a provision for supplying the pre-amplifier power by means of a battery held either within the handle of the microphone, or in the case of lavaliers, in a small beltpack. In the absence of phantom power the battery takes over.

Because of their design, condenser microphones can be considerably more expensive than dynamic microphones. They are also more sensitive to temperature and humidity changes or rough handling. However, condensers provide a great advantage over dynamics in theater applications for a couple of reasons. First, they can be made much smaller than dynamics, making them much easier to mount on or hide in costuming. Secondly, they generally have much better frequency response and higher sensitivity, making them better for use in critical sound reinforcement applications, and better for overhead or boundary microphone techniques where the microphones are placed much further from the performers.

Microphone Directionality

Whenever you are choosing a microphone for an application, it is important to consider its directionality, sometimes referred to as its polar pattern or pick-up pattern. There are several directional patterns available, the primary being omnidirectional, unidirectional, and bi-directional. A microphone's directional pattern is usually illustrated on its specification sheet or user guide by a polar graph that shows the microphone's sensitivity to sound arriving from different angles. The graphs show the "receiving" end of the microphone at 0 degrees.

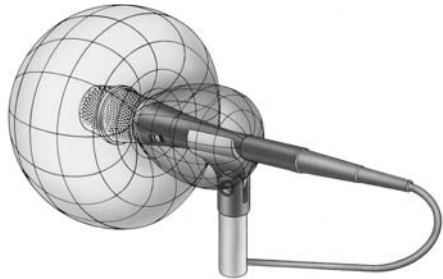


Omnidirectional Microphone

An omnidirectional microphone has equal sensitivity at any angle. Sounds are reproduced equally whether arriving at 0 degrees (on axis) or at 180 degrees (the rear of the mic). The important thing to remember is that omnidirectional microphones will pick up ambient or room sound as well as the sound you intend to amplify or record. This can contribute to feedback issues in a live sound reinforcement system. Feedback is the unwanted, high-pitched squeal or howl produced when sound from a loudspeaker is picked up by a nearby microphone and re-amplified. For this reason, omnidirectional microphones are often used for direct recording and theater applications (most productions rarely employ onstage monitor loudspeakers, so omnidirectional microphones are acceptable).



Cardioid (Unidirectional) Microphone



Supercardioid Microphone

A unidirectional microphone is most sensitive to sound arriving on axis and less sensitive to sound as it moves off axis. Using unidirectional microphones can allow higher gain levels from the sound system before feedback becomes a problem. There are two primary types of unidirectional microphones. Cardioid microphones exhibit an upside down heart-shaped pattern with a 130-degree pickup angle in front. Sound is greatly attenuated at 180 degrees. Supercardioid microphones exhibit a narrower pickup angle of around 115 degrees in front and therefore are even less sensitive to ambient sounds. This can provide still higher gain before feedback. However, they do have some sensitivity directly rear of the microphone at 180 degrees, making placement even more critical. Any unidirectional microphone can be very effective in an application with a high level of undesirable ambient sound. This is of great benefit when trying to achieve maximum gain before feedback.

Since unidirectional microphones pick up less ambient sounds than omnidirectional microphones, they can be used in situations where you may need to mic a sound source from a slightly farther distance yet still maintain the direct to ambient mix of an up close omni. Unidirectional microphones tend to lose high frequency sensitivity first as the sound source moves further off axis. Because of this, the sound may become "muddy" and less bright when the mic is not pointed directly at the sound source. Unidirectional mics also exhibit proximity effect, which is an increase in bass response as the sound source moves closer to

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the mic. This may cause the sound source to sound "boomy" or "bassy". Depending on the application, this may or may not be desired. Omnidirectional microphones do not exhibit proximity effect and are less susceptible to wind and breath noise. This is an important thing to consider when choosing mics for an outdoor performance.

Bi-directional microphones are most sensitive at 0 degrees and 180 degrees, while being least sensitive at 90 degrees (at the sides). The coverage angle at either front or back is about 90 degrees. These mics are used mainly for pickup of two opposing sound sources. They are often used in certain stereo recording techniques, and are incorporated in the design of an MS (mid-side) stereo microphone. They are rarely used in live sound reinforcement or theater applications.

MICROPHONE SELECTION AND PLACEMENT

Choosing the proper microphone for any given application can also be based on several other factors not yet discussed: price, quality, and especially in theater, physical size and color. Whichever microphone is chosen, it is the first step towards an effective sound system. The goal of any sound reinforcement system is to project the program material to an audience in a manner that allows the person furthest away from the performance area to hear sufficiently. An efficient system will allow enough amplification to occur before feedback is a problem. Feedback can be devastating to any production and severely distracting to the audience and the talent, not to mention the damage it can do to the sound system and your hearing. The system's efficiency can be greatly affected by room acoustics, system components, and the performers themselves, but there are several ways to minimize feedback. Solutions include: making the room less reverberant by treating it with absorptive materials, moving the loudspeakers further away from the microphones, and using unidirectional microphones. Some of these solutions are sometimes costly and not practical for smaller venues with limited resources. However, one of the most effective ways of minimizing feedback is to move the microphone closer to the sound source. In theater applications when it is not practical to use a typical handheld vocal microphone, the use of either a lavalier or headset microphone will best allow you to "close mic" the performers. Most modern lavalier and headset designs are lightweight and discreet. Both do an excellent job of increasing potential gain before feedback. Boundary microphones and overhead microphones can also provide good performance. These mics do not get as close to the sound source and, therefore, may not provide the same amount of potential gain, however, they can be less expensive in the long run and still quite inconspicuous. Let's look at each of these types of microphones, their physical qualities, and the techniques involved in their use.

Lavalier Microphones

Lavalier microphones are made of small elements, usually condenser, designed to be mounted via clip or pin to clothing. They are generally connected to an XLR terminated pre-amp assembly, or for wireless applications, they can be terminated with a variety of connector types. The design of these mics makes them inconspicuous enough to be used in TV broadcast, video production, and of course, theater. Early designs used dynamic elements and were usually hung around the neck on a lanyard. Contemporary designs almost exclusively use condenser elements. They can now be as small as a few millimeters in diameter and weigh only an ounce or so (not including the pre-amp assembly). They are often available in several colors such as black, white, and tan. Lavaliers come with an array of mounting clips or pins; some include a magnet mount that will avoid creasing or putting holes in clothing. The same small capsules that are used in lavaliers are often used for wire frame headset microphones as well.



WL50 Subminiature
Lavalier Microphone

In an effort to make lavaliers as flexible as possible for different mounting positions, manufacturers have made some lavaliers available with frequency response caps. These caps do not alter any circuitry; rather, they alter the high-frequency response of the mic in one of two ways. They either provide acoustic resistance to the opening of the cartridge, which attenuates the natural high-end frequency response, or they create an acoustical chamber on the front of the cartridge, which enhances the high-end frequency response of the microphone. Note that only omnidirectional microphones are available with this feature as the acoustical characteristics of unidirectional microphones cause them to sound worse when used with response shaping caps.

Lavaliers allow you to place the mic much closer to the actor's mouth, increasing gain before feedback. Lavaliers, therefore, allow you to minimize pick up of room noise, stage vibrations, and other unwanted sounds. They are also more easily hidden and less cumbersome. When used with wireless systems, they give performers almost unlimited mobility.

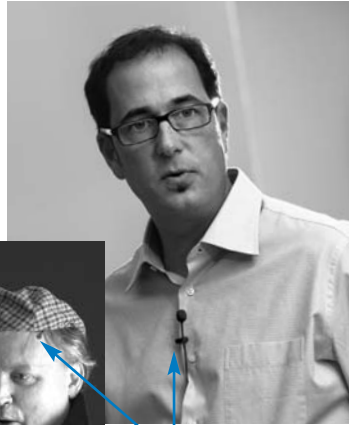
In theater applications where a lavalier is preferred, omnidirectional condensers are the most popular. It is true that using unidirectional microphones is one of the general rules to minimizing feedback due to their rejection of off-axis sounds; however, an omnidirectional in these applications is still very effective because of the improved proximity to the performer's mouth. This distance stays consistent as the performer moves around the stage when using wireless lavaliers. Omnidirectional microphones do not exhibit proximity effect, reducing the need to cut low frequency response at the mixer. Another reason using omnidirectionals can be advantageous, is that the frequency response of the mic stays consistent even if the sound source is off axis, or if the mic is in an unusual position. This is an important attribute given that mic technique in theater productions involves the creative positioning of the microphone on a performer. Wardrobe may not allow for the usual lavalier positioning on the chest.

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Let's examine some lavalier techniques that will help get the best performance out of your microphones:

Placement

- Place the mic at the top of the chest, or above the ear, or along the hairline. Avoid placing the mic too high on the chest by the throat. High frequencies can be blocked by the chin and cause the sound to be muffled or "muddy". Microphones that offer a high frequency boost cap can alleviate this to some extent.



- If placing a lavalier on or near the hairline, consult with the wigmaster to determine the best method to hold it in place. Mics and cables can be secured in the hair using clips, comb clips, bobby pins, or even elastic headbands. You can also sew them into wigs or barrettes. If the actor will be wearing glasses, the mic can be mounted on the temple area of the glasses. A small piece of clear tape should hold it steady.



Tie clip placement and hairline placement of lavaliers

- If placement above the ear is best for your production, you can construct an "ear clip" using a hanger, pipe cleaner, florist's wire, or a heavyweight paper clip. Make a loop on the end that goes over the ear to hold the microphone cartridge. Then, form the wire around the back of the ear and curl the opposite end up around the front of the earlobe to until there is 1/4 of an inch exposed. Cut any excess wire. For added comfort, and to hold the cable, slide some snug fitting surgical tubing or apply heat shrink tubing over the microphone cable and wire.

Keeping them stable

- Never use gaffer tape to affix cable to the skin. The glue on this tape can cause skin irritation and may be too sticky. As an alternative you can use surgical tape, spirit gum, medical adhesive, or clear bandage tape.
- Be sure to provide strain relief for the cable. When mounting a lavalier on the head, the cabling at the point at which the neck bends needs to be the most secure. Make sure there is slack or a sudden movement can pull the microphone out of place. Again, surgical tape is the best choice for securing the cable to the neck.

Care and maintenance

- Be careful not to get makeup into the grill or the element. Use a windscreen to protect the mic whenever possible. Any makeup that gets inside can alter the frequency response or destroy the element altogether. Do not use liquid or soap to clean the mic; this can be more damaging than the makeup. It is generally best to replace the grill of the mic if it becomes covered with makeup. If you must attempt to clean the mic, hold it upside down and brush it lightly with a soft brush or cloth. This will help prevent residue from getting down into the element. To clean adhesives off of the cable, you can use a mix of warm distilled water and no more than 10% alcohol. Check with the manufacturer for any specific cleaning methods for their microphones.
- It is not uncommon for a microphone to "sweat out", which occurs when the cartridge becomes drenched with sweat and ceases to work properly. In many cases this is temporary. Shaking out the sweat can be effective. If more maintenance is necessary, the microphone can be placed in an airtight box containing a silica gel packet. This will absorb moisture in the box.
- Sweat can drip down the cable to the capsule. To prevent this you can affix a small cotton or gauze patch around the cable in an inconspicuous position. Some manufacturers offer "sweat rings", which are small plastic or rubber collars that hug the cable and keep moisture from dripping into the capsule.
- To ensure sweat doesn't enter the connector and cause an electrical short, make sure that the connector has a rubber flex-relief and that it fits snugly around the cable so that there is no opening for the sweat to drip into the connector. Adding a small piece of heat shrink tubing around the cable and over the solder contacts can help close a gap between the cable and the flex-relief, or add an additional level of assurance in active performances.

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- The day-to-day maintenance of your microphones should include letting them thoroughly dry in a cool, dry space after each use. In cases where your microphones are being used extensively in unusually harsh environments like the outdoors, in direct sunlight, in extreme humidity, or any combination of the three, it might be prudent to obtain an airtight box as mentioned above to store and dry your microphones overnight. This is a frequent practice at theme parks and on Broadway.

Getting the best sound

- If the microphone cable is run inside of clothing, tape the cable to the fabric to prevent contact noise, which is caused by cable and clothing rubbing together. Consider sewing a "channel" or "tube" of fabric on the inside of the costume to prevent excess rubbing against the cable. You can also tie a loose, simple knot in the mic cable near the mic, this will help block noise from getting to the capsule.
- Noise from materials in costuming rubbing together can be difficult to prevent. Synthetic materials make more noise than other materials. Consult with wardrobe to see if there is a practical way to isolate the mic and cable from noise.
- If using a unidirectional lavalier mic in the chest area, remember that those types of microphones exhibit proximity effect. Because it is much closer to a resonating chest cavity, it may sound boomy. You can compensate for this by using equalization to decrease the low frequencies.
- Don't be afraid to use equalization. High frequency boost can help brighten a mic that is covered by clothing or positioned in the hairline. Low frequency reduction can help reduce cable noise, breath pops, or wind noise.

Keep spare mics on hand. Lavalier mics may eventually need replacement in an abusive environment like theater. Sweat, makeup, and constant tugging on cables and connectors can take their toll on lavaliers. Inspect your mics on a regular basis by plugging them in and listening for odd noises, crackling, or degradation of frequency response. Wiggle the cables and connectors to check for loose connections. Remember that some damage may not be covered by the manufacturer's warranty so exercise care.

Headset Microphones

Let's revisit the concept of mic'ing a sound source as closely as possible to increase gain before feedback. In most theater applications, the actor's mouth is the sound source. A lavalier does a good job of close mic'ing, especially when mounted in front of the ear or on the hairline. However, the ultimate position would be at the performer's mouth. The only way to do this is with a headset microphone. While not quite as discreet as a lavalier, most modern headsets are very lightweight and comfortable for the wearer. Many headsets have a frame that goes over the head but most professional quality headsets have a lightweight wire frame that sits on the ears and wraps around the back of the head, with a short boom arm that holds a condenser element at the corner of the mouth. They are available in various colors so that they can be less obvious to the audience. Condenser headsets have the required pre-amplifier assembly or are terminated in some manner for use with a wireless transmitter. There are omnidirectional headsets and unidirectional headsets, the choice of which can be determined by reviewing the characteristics of each and determining which is best for your application.

All headsets should be stable enough to maintain the microphone position at the mouth regardless of the head movements of the actors. More and more large-scale productions are using headsets, especially in high-energy musical performances; and manufacturers are consistently updating their designs to maintain the best performing mix of comfort and sound quality.



Beta 53™
Headworn Microphone

Overhead Microphones

The microphone techniques we've been covering up to this point have involved the use of one microphone on every performer. However, this can be cost prohibitive in many smaller theaters, schools, community theater, or church pageants. An alternative method uses overhead or hanging microphones, sometimes called choir microphones. These capture sound by hanging down from above the stage. Overhead mics usually are comprised of a condenser element mounted on a short gooseneck, which then leads to a thin cable. The length of cable can be up to 20-30 feet long, and ends in the necessary pre-amplifier assembly. They can be found in various colors and polar patterns. A high quality probe style or "end-address" condenser microphone can also be used, although they are quite a bit larger. There are adapters available that will suspend these more traditional microphones by the cable for overhead use and maintain their position.



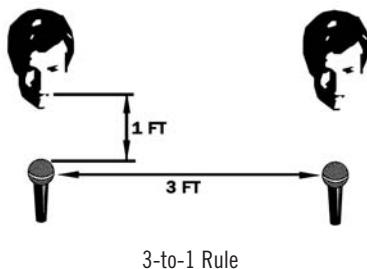
Illustrative example of overhead
microphone placement being used to
provide area coverage

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Using overhead microphones to capture sound from above can provide decent sound reinforcement, but you should be realistic as to what to expect. These microphones are further away from the sound source than even a microphone on a floor stand would be, and will pick up more ambient sound than preferred. This, in addition to the possibility of these mics actually being closer to loudspeakers than to the sound source, can lead to significantly reduced gain before feedback. Another factor contributing to feedback is the number of open microphones being used. The more open microphones in a sound reinforcement system, the less potential gain before feedback. Therefore, the idea to put in more mics to cover the area better or to "make it louder" will in fact worsen the situation. It is a must to use as few overhead microphones as necessary.

Other things to remember when using overhead microphones:

- Placement of these microphones is often dictated by the constraints of the stage set. Take into consideration when possible, the position of the actors on stage and install mics accordingly. Planned scenery for a production may make installed overheads unusable due to scenery changes, space limitations, or reflection of sound.
- Remember that most actors project their voice to the audience. An overhead microphone, if pointed straight down, is pointed at the top of someone's head. Speech is not as intelligible from that vantage point as the high frequency content is lost. At the same time, the microphone can be picking up both the reflected sound off the surface of the stage, as well as mechanical or air handling noise from above. When combined with direct sound, this will provide poor audio quality.
- For most reinforcement applications, you should stick with a unidirectional polar pattern. Whenever possible, you should hang an overhead mic 2 to 3 feet in front of the nearest actor downstage. The capsule should be aimed slightly upstage. These mics work best when installed 2 to 3 feet above head level. Increasing this variable will reduce your potential gain before feedback.
- Always observe the 3-to-1 Rule when spacing multiple microphones to cover a larger area. The 3-to-1 Rule states that the microphone to microphone distance should be three times the microphone to sound source distance. This will reduce interference effects such as comb filtering. Remember that overhead microphones will not give you the same performance as a lavalier



Boundary Microphones

Boundary microphones are an alternative to miking each individual performer, and an alternative to overheads. These mics are designed to be laid flat on an acoustically reflective surface, in this case the stage itself. Again, these mics are usually condenser elements in a low profile housing. The necessary pre-amp can be self-contained or the in-line type found in overheads. They should be placed along the lip of the stage, with a unidirectional polar pattern aiming back at the action on stage. They obviously need to be out of the actors' way as far downstage as possible. You should follow the 3-to-1 Rule with these mics as well.

The drawbacks to these microphones are some of the same drawbacks we have seen with overhead mics, primarily the distance from the sound source and the proximity to the loudspeakers. Add to this, the pickup of stage noise from the actors' feet, scenery movements, etc. You can alleviate some stage noise by placing a soft felt or foam pad in between the mic and the stage, and decreasing the low frequencies on the EQ. Small boundary microphones can be hidden in permanent scenery, such as on a table in the center of a room scene. Polar pattern for this method is dictated by the microphone's position relative to the actors.



Example of unidirectional boundary microphones being used to provide area coverage for an on-stage application



Overhead and boundary microphones work best with experienced actors whose voices project well. People with softer voices and some children do not have the ability to project their voices enough for overhead or boundary microphones. In many cases with overhead or boundary mics you may be tempted to turn up the system volume to compensate for the increased distance from the actors, but beware that this can push the system into feedback. A headset or lavalier may still be the best answer for your production because they allow for greater gain before feedback than either overhead or boundary microphones.

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WIRELESS MICROPHONE SYSTEMS

To achieve the ultimate in mobility and still maintain the highest potential gain before feedback requires the use of wireless lavalier microphones. Without wireless lavalier microphones in larger productions, movement would be restricted, scene and wardrobe changes would be difficult, and walking or dancing around stage would just become dangerous. Through advances in wireless microphone technology, and the availability of more affordable systems, stage productions now have freedom of movement onstage and off. Bodypack transmitters are easy to conceal, and many wireless systems can be used simultaneously. There are rules to using wireless however, which you must follow. Most of these rules are regarding frequency selection and antenna usage. Much of what has been learned about placement of mics and bodypack transmitters has been learned through years of trial and error. Every production yet to come will no doubt present new challenges and solutions.



ULX Wireless Systems

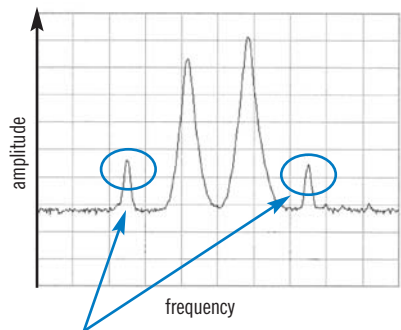
Frequency Coordination

The process of optimizing wireless performance begins before the product is designed and manufactured. Manufacturers carefully design all components within transmitters and receivers to minimize unfavorable interaction between systems and their environment. Available operating frequencies for wireless systems are also carefully selected to allow users to use their systems with relative peace of mind. However, care must always be taken to choose systems according to the potential benefit to the application, and with advance knowledge of possible sources of radio frequency (RF) interference. By observing a few guidelines when choosing wireless systems, you can minimize the risk of poor performance:

- A receiver can only demodulate one radio signal at a time. In other words, a wireless receiver on any given frequency can only receive a signal from one transmitter on that frequency. If there are two signals present on the same frequency, the stronger of the two may block out the other, or the output of the receiver will be unusable noise. The analogy most often referred to in explaining this concept is commercial FM radio. In any city, only one station is broadcasting on any given frequency. Many receivers (e.g. car radios) may be tuned to say, 97.9FM, but only one station is broadcasting on that frequency. If you reach an area between two cities, both having stations on 97.9FM, the signal reception is poor and very noisy.

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- Broadcast TV channels, whether analog or digital, must be avoided. The great majority of wireless microphone systems operate within the radio frequency range of broadcast television, per FCC regulations. However, FCC regulations prohibit the use of wireless microphone systems on occupied TV frequencies. The strength of RF from broadcast TV antennas can be millions of times stronger than wireless microphone signals. If systems are on an occupied TV frequency, the systems will not operate properly. Manufacturers of wireless microphones can assist you in determining your proximity to TV broadcast antennas and determine which frequencies are open for use and compatible with each other in your area.
- In multiple system set ups, each wireless system must operate on its own frequency. It is generally recommended that each system's carrier frequency be at least 400 kHz (.4 MHz) apart from the next system's carrier frequency. However, this is dependent on the ability of the receiver to "listen" only to its own transmitter. It should never be assumed that simply choosing systems that are each 400 kHz apart from each other is improving the set up. In fact, doing so is actually guaranteeing interference problems due to the harmonics generated at multiples of the carrier frequency.
- Operating frequencies for multiple system set-ups must also be chosen to avoid Intermodulation Distortion, or IMD. Intermodulation is the collective of frequencies produced by combinations of other (non-carrier) frequencies present in wireless components. The use of non-linear circuits in wireless system designs causes the generation of new, weaker radio signals on various multiples of the operating frequency. These can combine with the operating frequency of another system, or that other system's own new signals. The IMD products that are created by two or more systems can be very complex and difficult to calculate. Manufacturers have proprietary computer programs that can calculate these possible interactions for you.



IMDs created by two transmitters

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Bodypack Transmitters

Bodypack placement is often a test of the imagination and innovation of the sound designer and wardrobe master. While lavalier microphones are small and easily hidden, wireless bodypack transmitters are much larger and not as easily fastened to the actors, let alone hidden. Add to this the need to coordinate sometimes harried costume changes, and you have a logistical challenge.

Most bodypack transmitters are of the same general shape and size. They are a few inches high, a few inches wide and maybe half an inch thick. With a little ingenuity and creativity they can be mounted almost anywhere. Since most come with a standard

belt clip, the obvious easy option is to clip the bodypack onto an actor's clothing at the beltline or on the hip area. They can also fit into pockets of shirts, jackets, or pants with little hassle. Even so, it is important to allow the antenna to be unobstructed and fully extended. Extra pockets of fabric can be sewn into costuming when the bodypack needs to be as unobtrusive as possible without using the clip. When costuming prohibits normal positioning, or if you cannot sew more pockets into the wardrobe, there are other options to consider. The small of the back can be used for placement if a fanny pack or similar harness is used instead of a clip. A bodypack can be held between the shoulder blades and under costuming using a shoulder harness made up of a pouch for the pack and a couple of loops to go around the shoulders. Maintaining stability in some odd locations can require the use of cloth or elastic straps, which can be stable enough to hold bodypacks on to arms and thighs. Affixing a large safety pin to a bodypack with gaffers tape can allow smaller, lighter bodypacks to be affixed to hats or wigs, although this may not be the best choice for physically active performances or dancing. Creative ways of affixing bodypacks to actors are being developed at all levels of theater everyday, because every situation is unique. Here are some useful tips to remember:

Here are some useful tips to remember:



Examples of transmitters
(left to right: handheld, bodypack)



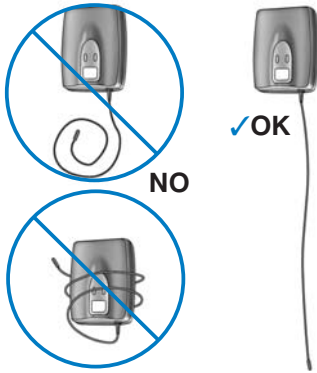
fixed



portable

Receiver examples

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Proper and improper antenna positions

- RF signal can be blocked and reflected by metallic surfaces. This can include any costuming that has metal threading or metal plating, the extreme case being your knight in shining armor. Wearing a bodypack under this material will severely degrade RF performance.
 - Antennas of bodypacks should always be kept as clear as possible from obstructive surfaces or materials. As stated earlier, an antenna should never be curled up and stuffed into pockets.
- Allow for strain relief on the mic connector and antenna, so that movement of the actor will not crimp the cable or antenna with their movements. Repetitive strain on the cable will cause failure sooner rather than later. Remember to check cables thoroughly before each performance.
 - You can utilize the lock out features of some bodypacks to make sure the actor cannot accidentally power off the transmitter during a performance, or in the case of frequency agile systems, accidentally change the operating frequency.
 - Make sure to leave the battery as accessible as possible, as you may need to do a quick change unexpectedly.
 - The human body, because of its composition, can cause some RF transmission issues with bodypack transmitters. In certain cases, the body of the actor can potentially inhibit RF transmission. Repositioning the bodypack or the receiving antennas (or both) can overcome this occurrence.
 - Sweat can be potentially harmful to the electronics of a bodypack transmitter. There are many methods sound designers have created to protect bodypacks from sweat. A simple solution is to wear a Neoprene transmitter pouch when practical. While not completely waterproof, it will protect the bodypack from low-level sweat and moisture. Another more protective method is to use a dry condom to cover the bodypack. As unusual as it sounds, it is fairly effective when used properly. An un-powdered, dry surgical glove can also be used. Remember that there are people allergic to latex or other materials, so check with the talent ahead of time before using any method of covering a bodypack next to skin.

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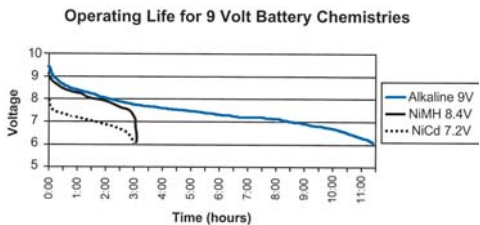
- It is a good idea to clearly label your bodypacks in some manner to identify the intended user. Any mix-ups can destroy the continuity of the show and cause the sound engineer to search for the right mixer channel to operate.
- Do not leave transmitters bunched together on a table or in a bin when they are on. The proximity of the transmitters to each other can increase the likelihood of intermodulation distortion (IMD) manifesting itself on one or more receivers. The same effects can occur when poorly chosen frequencies are used on bodypacks that are then worn on actors that are very close to each other on stage. Proper selection of frequencies is a must.

Bodypacks can come equipped with a variety of input connectors, depending on the manufacturer. Most will supply bias voltage for condenser elements. Using one manufacturer's wireless lavalier microphone with another manufacturer's transmitter and receiver is not out of the question. It is a matter of contacting the manufacturer of either and getting the proper "pin outs" of the connector types. It may require purchasing a mic with no connector, or rewiring the proper connector on to the lavalier to match the bodypack. Do not assume that if the connector is the same between manufacturers the mic will work. There are several ways of wiring any given connector.

Regarding output power of transmitters, it should be noted that output power is not only regulated by government agencies, but it is also carefully determined by the manufacturer. It is true that higher output power may increase the transmission range of the RF signal (antenna efficiency can also affect range), however it can also cause a higher likelihood of IMD in multiple system setups. Typical range of wireless systems is usually listed on the specification sheet available from the manufacturer. Most theater applications dictate the use of lower power transmitters (5mW-50mW) for greater multi-system compatibility. Also, lower output power can translate to longer battery life.

Batteries

Battery life varies from model to model and manufacturer to manufacturer. Bodypack transmitter features that can affect battery life are tone key squelch, output power, LED or LCD displays, and antenna efficiency. The battery type required can vary as well, with transmitters using 9V, "AA", or "AAA" batteries. Alkaline batteries provide the best performance for wireless microphone transmitters. They last much longer than basic carbon-zinc batteries, and they maintain a voltage usable to the transmitter



Alkaline vs. rechargeable batteries

until much closer to the end of their life. For maximum battery life, a lithium battery can be used. They can last two to three times longer than an alkaline battery, but they can also be much more expensive. Rechargeable NiCd (Nickel Cadmium) and NiMH (Nickel Metal Hydride) batteries are generally not recommended because they do not have as much power density as alkaline, and in the case of some 9V's, they may in fact only be providing 7.2V, which is not enough for the transmitter to function properly. Rechargeable alkaline batteries are the best choice if rechargeable batteries are absolutely necessary, however, no 9V rechargeable alkaline is available yet.

Receivers and Antennas

Setup of wireless system receivers involves first the antenna-to-receiver interface and then antenna placement. The simplest setup involves a receiver with the antenna(s) permanently attached. Receivers with non-detachable antennas should be placed on an open surface or shelf, in line-of-sight to the transmitter, for proper operation. They are often not suitable for rack mounting except perhaps as a single unit at the top of a rack and then only if the antennas are mounted on the front of the receiver or if they can project through the top of the rack.

A receiver with detachable antennas offers more versatility in setup. In most cases these antennas are attached to the rear of the receiver. If the receiver is to be mounted in a metal rack the antennas must be brought to the outside of the rack. Some designs allow the antennas to be moved to the front of the receiver, while others provide an accessory panel for front mounting. Again, the receiver should be mounted high enough in the rack so that the antennas are essentially in the open.

Here is a review of general rules concerning setup and use of receiver antennas:

- Maintain line-of-sight between the transmitter and receiver antennas as much as possible. Avoid metal objects, walls, and large numbers of people between the receiving antenna and its associated transmitter. Ideally, this means that receiving antennas should be in the same room as the transmitters and elevated above the audience or other obstructions.



1/4 wave and 1/2 wave antennas UHF range

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- Keep the receiver antenna at a reasonable distance to the transmitter. The maximum distance is not constant but is limited by transmitter power, intervening objects, interference, and receiver sensitivity. Closer is preferable, but a minimum distance of about 10 feet is recommended to avoid potential intermodulation products in the receiver. Ideally, it is better to have the antenna/receiver combination near the transmitter (just off stage), and run a long audio cable back to the mix position, than it is to run a long antenna cable or to transmit over long distances.
- Use the proper type of receiver antenna. A 1/4-wave antenna can be used if it is mounted directly to the receiver, to an antenna distribution device, or to another panel that acts as a ground-plane. If the antenna is to be located at a distance from the receiver, a 1/2-wave antenna is required. This type has somewhat increased sensitivity over the 1/4-wave and does not require a ground-plane. For installations requiring more distant antenna placement or in cases of strong interfering sources it may be necessary to use a directional antenna suitably aimed. They are sensitive to RF in the forward direction and much less sensitive to RF at the rear.
- Select the correctly tuned receiver antennas. Most antennas have a finite bandwidth making them suitable for receivers operating within only a certain frequency band. When antenna distribution systems are used, receivers should be grouped with antennas of the appropriate frequency band as much as possible. Telescoping antennas should be extended to their proper length.
- To get the best RF reception from a diversity receiver (those with 2 antennas), the minimum separation between its antennas should be 1/4 wavelength (about 16 inches for VHF, 4 inches for UHF). The effect improves somewhat up to a separation of about one wavelength. Diversity performance does not change substantially beyond this separation distance. However, overall coverage of very large areas may be improved by further separation.
- Locate receiver antennas away from any suspected sources of interference. These include other receiver antennas as well as digital equipment like CD players, digital effects units, lighting control systems, etc. All of these devices have the potential to emit electromagnetic interference, which can result in poor RF reception, noise, and other problems.
- Mount receiver antennas away from metal objects. Ideally, antennas should be in the open or perpendicular to metal structures such as racks, grids, metal studs, etc. They should be at least 1/4 wavelength from any parallel metal structure. All antennas in a multiple system setup should be at least 1/4 wavelength apart.

- Orient receiver antennas properly. If transmitter antennas are generally vertical then receiver antennas should be approximately vertical as well. If transmitter antenna orientation is unpredictable then receiver antennas may be oriented up to 45 degrees from vertical.
- Use the proper antenna cable for remotely locating receiver antennas. A minimum length of the appropriate low-loss cable equipped with the proper connectors will give the best results. Because of increasing losses at higher frequencies, UHF systems may require special cables and active antenna amplifiers. Refer to the manufacturer's recommendations for antenna extension cables and amplifiers.
- Use an antenna distribution system when possible. This will minimize the overall number of antennas and may reduce interference problems with multiple receivers. For two receivers a passive splitter may be used. For three or more receivers active splitters are strongly recommended.

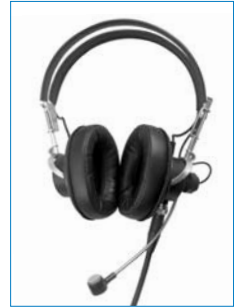
Automatic Frequency Selection

A new technology being introduced into wireless microphone receivers is the automatic frequency scan and set capability. With this technology, the receiver can be instructed to scan a set of frequencies and determine the most appropriate frequency for that particular set up. The receiver scans the set of frequencies while measuring RF signal strength. The RF signal can be other RF sources such as local TV broadcast, wireless microphone systems, or RF "noise". In any case, the manufacturer has programmed into the receiver an acceptable threshold level for RF strength from these outside sources. When the RF signal strength on a scanned frequency is below the threshold, the receiver determines that the frequency is usable. It then sets itself to that frequency, or the user acknowledges the frequency scan result and sets the receiver manually. The transmitters may still need to be manually set to the receiver's chosen frequency, although some newer systems can also set the transmitter frequency via an infrared communication link. For multiple system set ups, the procedures can vary according to the scanning abilities of the receiver. Some receivers may be able to scan pre-programmed groups of frequencies to determine which group has the greatest number of compatible systems. This automatic frequency scanning technology can simplify and shorten the set up process, however, it may take time for the technology to be widely available.

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INTERCOM SYSTEMS

Intercom systems are communication networks designed to allow production staff to talk to one another from different areas of the venue. These systems are separate from any sound reinforcement equipment reproducing the performance. To monitor the performance itself, these systems can provide for an input from the main sound reinforcement system so staff can synchronize cues. Intercom systems most often are permanently installed systems that have individual stations located in different key areas of the venue. They are found at the front of house (FOH) mix position, spotlight positions, backstage, dressing rooms, etc. To allow two-way communication, intercom stations may have a built-in speaker/mic, or provide inputs for headsets and microphones. Some stations may be in bodypack form for easy use by semi-mobile staff, or for use in portable systems. Other stations can be wall mounted, rack mounted, table top, or telephone handset type.



SM2 Headworn Microphone.
An example of a microphone used in intercom systems

Intercoms can be configured in many different ways, from a simple 2-station system, to systems of 60 or more with digital control panels and switching systems for multiple channels. There are wireless intercom systems available, which often work in the same frequency range as wireless microphones. In these cases wireless frequency coordination becomes even more critical to avoid compatibility issues.

ASSISTIVE LISTENING SYSTEMS

Assistive listening systems are generally used to provide improved sound to individuals with hearing impairments. They may also be used to provide simultaneous translation of the program into other languages. They consist of a single transmitter and as many receivers as necessary. The transmitter is about the same size as a typical wireless microphone receiver with an attached antenna and is AC powered. The receivers are small, battery operated packs with an attached earpiece or headphones, or in some cases they can be adapted to the user's hearing aid. These systems are operated in the 72MHz-76MHz range, which is reserved specifically for them. No license is required. The source is most often a feed of the overall mix from the main sound reinforcement system.



StarSound 600® System.

An example of an
infrared assistive listening device

(photo courtesy of Phonic Ear Inc. – www.phonicear.com)

An alternative technology uses infrared transmitters and receivers. Again, a single transmitter is used with multiple receivers. The transmitter is usually placed at an elevated location at the front of the theater where listeners facing forward can see it.

The receivers are sometimes a small clip-on pack with an IR sensor at the top or occasionally a headset with an attached IR sensor. Since these are not radio systems, there is no concern for frequency, licensing, or radio interference. The only operating concern is to avoid strong, direct sunlight on the receiver IR sensors. IR systems will only work in a single room. The infrared signal is unable to travel through walls to an adjacent room. This can be either a benefit or a hindrance depending on the application.

Assistive listening systems are a reliable and relatively inexpensive technology, widely used in theaters, houses of worship, and schools. In fact, the Americans with Disabilities Act (ADA) requires their use in many public facilities. Receivers are generally made available to people at the performance by the venue. However, since the receivers are fairly inexpensive and transmitters are standardized, some individuals may purchase their own receivers to carry with them to performances.

PERSONAL MONITOR SYSTEMS

Personal Monitor Technology was born out of concert sound applications but is now becoming more popular in some theater applications. These systems are used to provide monitoring or foldback directly to the ears of a performer. The system parts are essentially the same as an Assistive Listening System: an AC powered transmitter, a battery powered bodypack receiver and earpieces. However, in-ear monitor systems are engineered to provide full range, high quality stereo sound to listeners with "normal" hearing. In addition, the earpieces are designed to seal out ambient sound to provide greater control of the mix and a fair degree of hearing protection.

The source for in-ear systems is usually a combination of auxiliary mix outputs and/or direct channel outputs from the main sound reinforcement system, depending on the requirements of the listener. It is possible to customize a different mix for individual performers if each has his or her own transmitter/receiver. These systems are easily integrated with conventional mixers or dedicated monitor consoles. In theater applications, a director's feed can be mixed into the signal the performer is hearing in-ear. The director can then talk directly to the talent to provide cues, direction, and even dialogue prompts, all without the knowledge of the audience. If there are live musicians accompanying the show, they can use personal monitors to hear director's cues as well as monitor their own performance. In addition, the sound designer will be able to improve the overall sound in the house due to the lack of interference from monitor loudspeakers normally used by live musicians.



PSM 400
Wireless Personal Monitor System

CONCLUSION

The subjects of microphone design and selection, wireless microphone application, and associated audio processing are no doubt going to continue to evolve and expand. Each new production will require a new set of requirements and parameters that the sound designer or sound engineer will need to meet. New technologies will lead to perhaps more affordable and user-friendly products, but the principles of microphones and audio systems will remain the same. The topics that were covered within this book provide the foundation by which you can address your theater's microphone and wireless system needs.

Reference Information

Recommended Shure Microphone Models

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Category	Model	Pattern
Wired Lavalier	MC50B	Omnidirectional
	MC51B	Cardioid
	MX183	Omnidirectional
	MX184	Supercardioid
	MX185	Cardioid
	SM93	Omnidirectional
Wireless Lavalier	WL50	Omnidirectional
	WL51	Cardioid
	WL183	Omnidirectional
	WL184	Supercardioid
	WL185	Cardioid
	WL93	Omnidirectional
Wired Headset	Beta 53	Omnidirectional
	Beta 54	Supercardioid
	WH30XLR	Cardioid
Wireless Headset	WBH53	Omnidirectional
	WBH54	Supercardioid
	WH30TQG	Cardioid
Overhead	MX202	O, C or S
Overhead (probe style)	KSM141	O and C (dual)
	KSM137	Cardioid
	KSM109	Cardioid
	SM81	Cardioid
	PG81	Cardioid
Boundary	MX393	O, C or S
	MX391	O, C or S

Key: O = omnidirectional, C = cardioid, S = supercardioid

OTHER RECOMMENDED READING

Yamaha Sound Reinforcement Handbook

Davis, Gary & Jones, Ralph. Hal Leonard Publishing Co.

The Microphone Book

Eargle, John. Focal Press.

Sound Design in the Theater

Bracewell, John. Prentice Hall Publishing

Architectural Acoustics

Egan, M. David. McGraw Hill Book Co.

ABOUT THE AUTHOR

Crispin Tapia

Crispin Tapia is an Applications Specialist at Shure Incorporated. He has been active in the Chicago music scene for many years as a performer, and has experience in live sound and studio recording. He has earned both a B.A. in Psychology from the University of Illinois at Chicago, and a B.A. in Audio Engineering from Columbia College Chicago. His responsibilities at Shure Incorporated include conducting product training seminars to Shure dealers, Shure staff, and end users across the country.

3-to-1 Rule – when using multiple microphones, the distance between microphones should be at least 3 times the distance from each microphone to its intended sound source.

Ambient sound – local or background sounds.

Bias voltage – a fixed DC voltage which establishes the operating characteristic of a circuit element such as a transistor.

Boundary microphone – a microphone designed to be mounted on an acoustically reflective surface.

Cardioid microphone – a unidirectional microphone with moderately wide front pickup (131 degrees). Angle of best rejection is 180 degrees from the front of the microphone, that is, directly at the rear.

Comb filtering – the variations in frequency response caused when a single sound source travels multiple paths to the listener's ear, causing a "hollow" sound quality. The resultant frequency response graph resembles a comb. Can also occur electronically with multiple microphones picking up the same sound source.

Condenser microphone – a microphone that generates an electrical signal when sound waves vary the spacing between two charged surfaces: the diaphragm and the backplate.

Demodulation – the recovery of the original modulating information from a radio signal.

Diversity – receiver design which picks up a radio signal simultaneously at multiple locations and intelligently switches or combines to yield the best continuous signal.

Dynamic microphone – a microphone that generates an electrical signal when sound waves cause a conductor to vibrate in a magnetic field. In a moving-coil microphone, the conductor is a coil of wire attached to the diaphragm.

Electret – a material (such as Teflon) that can retain a permanent electric charge.

Feedback – in a PA system consisting of a microphone, amplifier, and loudspeaker, feedback is the ringing or howling sound caused by amplified sound from the loudspeaker entering the microphone and being re-amplified.

Gain – amplification of sound level or voltage.

Gain-before-feedback – the amount of gain that can be achieved in a sound system before feedback or ringing occurs.

IM – intermodulation, frequencies produced by combinations of other frequencies in non-linear devices.

IMD – intermodulation distortion, another name for IM.

Impedance – in an electrical circuit, opposition to the flow of alternating current, measured in ohms. A high-impedance microphone has an impedance of 10,000 ohms or more. A low-impedance microphone has an impedance of 50 to 600 ohms.

Lavalier microphone – generally a small, condenser element worn on the chest area and mounted via a lanyard, clip, or pin.

Omnidirectional microphone – a microphone that picks up sound equally in all directions.

Phantom power – a method of providing power to the electronics of a condenser microphone through the microphone cable.

Receiver – device that is sensitive to radio signals and recovers information from them.

RF – radio frequency.

Sensitivity – a rating to express how "hot" the microphone is by exposing the microphone to a specified sound field level.

Supercardioid microphone – a unidirectional microphone with tighter front pickup angle (115 degrees) than a cardioid, but with some rear pickup. Angle of best rejection is 126 degrees from the front of the microphone, that is, 54 degrees from the rear.

Transducer – a device that converts one form of energy to another.

Transmitter – device which converts information to a radio signal.

Wavelength – the physical distance between successive complete cycles of a wave, inversely proportional to frequency, dependent on properties of medium.

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