WIRELESS MICROPHONES AND THE AUDIO PROFESSIONAL

by Jim Brown

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Introduction Wireless microphones have come of age. Once the dream of the wild-eyed producer and the nightmare of the audio professional, properly designed and implemented systems can now be used with excellent reliability. Unfortunately, far too many users try to get by with low cost systems, resulting in poor performance and questionable reliability under real world conditions.

This paper was prepared in 1986 to educate relatively technical minded consumers as to the effective choice and use of wireless mic systems. In the intervening years, the laws of physics have not changed and the basic concepts remain as solid as ever, but some major changes have taken place in wireless mics. First. developments in technology have reduced the cost and increased the quality of systems which use selectable frequencies of operation and which work in the UHF spectrum, as well as those for VHF operation. Second, frustration with the weak performance of inferior systems operating on poorly chosen VHF channels has fueled a shift to the previously empty UHF spectrum and generated a demand for units with selectable operating frequencies. Third, expensive monitoring systems have been designed for clients with high budgets, mostly as a substitute for educated frequency selection. Fourth, both digital television and an increasingly crowded radio spectrum are putting the squeeze on the channels available for wireless mics. As more and more of these new stations come on the air in the next few years, it will become increasingly difficult to find reliable channels for wireless mics in many areas.

Wireless microphone systems are miniature radio transmitters and receivers made to receive only their signal. Some are fixed tuned - that is, they use a quartz crystal for determination of the operating channel. The only way to change channels is to return the receiver and transmitter to the factory and have new crystals put in. Tunable systems add a frequency synthesizer circuit to allow multiple operating channels from a single crystal.

The transmitter has a professional microphone element connected directly to it, and the receiver output is designed for connection directly to the microphone or line input of a mixing console. The radio transmitter and receiver combination acts as a replacement for the microphone cable. If all goes well, the console operator does not know that a radio link is involved.

Wireless Microphones Transmitters come in two basic packages. Handheld wireless microphones have conventional microphone elements mounted to a handle into which a miniature radio transmitter and mic preamp are built. Nearly a dozen good vocal performance microphones elements are available on wireless transmitters from major manufacturers.

Body pack transmitters, (often called "lavalier" transmitters because of the mics with which they are intended to be used) allow the connection of almost any professional electret or dynamic lavalier mic. (A lavalier mic is a miniature mic designed to be pinned or clipped to an article of clothing and worn on the performer. Early lavaliers were much larger, and were worn around the neck - you've probably seen them in old TV clips.) Body pack transmitters are usually a bit larger than a pack of cigarettes, and contain the same electronics as the handheld transmitter. Non-lavalier mics and line level sources may also be used with body pack transmitters with the appropriate wiring adapters -- this can be a good way to send sound outside to an overflow system for special events.

All professional body packs are designed to provide operating power for nearly all commonly used electret lavalier mics. The author has successfully used Sennheiser, Crown PZM, Beyer, Audio Technica, Tram, and Sony electret lavaliers with Shure, Vega, Telex, and Comtek body packs, although some models of lavalier mics are know to have RF interference problems. [Some Shure lavalier microphones are not recommended for use with wireless transmitters other than their own brand, because audio equalization is performed in the Shure power adapter for that fine mic, and the power supply is too large to be used simultaneously with the body pack. A given mic may need different electrical connections to different body pack transmitters.]

Wireless microphone transmitters, like all radio transmitters, must be licensed. In the United States the licensing body is the Federal Communications Commission (FCC). Only a station license is required, and it is obtained simply by filing the appropriate application with the FCC. Neither a licensed operator or a fee is required.

The Receiver By far, the most important single component of a wireless microphone system is the receiver. Wireless microphones should have a reliable operating range of 500 to 1000 feet (150 - 300 meters) under most conditions, but a good receiver is required to take advantage of this range. The most common limiting factors in wireless microphone performance (in order of importance) are 1) Interference, 2) Reflections, and 3) Range. Wireless mics are rarely used in applications which stretch their range -- interference or reflections will nearly always cause system failure first.

Interference If interference (that is, another radio transmitter or noise generated by computers or machines) is on your channel, even the best receiver will not make your system work well. You must either eliminate the interference or change to a new channel. If the interference is close to, but not precisely on, your channel, the receiver's selectivity will help your transmitter thread its way through interfering signals. This is done by tuned circuits and in the best receivers, multiple helical resonators (miniature cavities which act like super-sharp tuned circuits).

When the going really gets tough and a very strong interfering signal is present (like a two-way radio transmitter on your block or a broadcast TV tower a mile away), another receiver problem shows up. The first electronic section of the receiver, called the "front end," is designed to amplify (boost) the very weak signals of a wireless mic and separate it from interference on nearby channels. When presented with a very strong signal, it can be overloaded and stop working properly. One common phenomenon, called "***desensitization***", or "***de-sense***", occurs with the strong signal gets rectified in the front end and actually biases the amplifier transistor off. When this happens, the receiver almost stops working -- the desense acts like a gain control and shuts down the signal path! An indication of this problem is fading that occurs with the transmitter at much shorter than normal distances even though no interference is heard. These are non-destructive failures; as soon as the strong signal goes away, the receiver will resume working properly.

Computers and digital audio equipment often produce enough radio trash to seriously reduce the range of wireless mic systems. This interference can take the form of a single carrier frequency, broadband noise, or both.

Intermodulation Interference is the result of the mixing (also known as heterodyning) of two or more strong radio signals to produce radio signals on other radio channels. If one of these new signals (called intermod products) ends up on one of your wireless channels, it interferes with that wireless mic system. This intermodulation can occur in transmitters, receivers, and other radio equipment. It can even occur in nearly any metallic objects which can act like an antenna to pick up and receive these radio signals, and which have a poor electrical connection capable of rectifying these signals. And your own wireless transmitters are part of the interference mix!

What this means in practice is that if there are strong signals around your area, they can be rectified in objects like metal downspouts, building steel, rusted metal, etc., producing interference on your radio channel. Luckily the channels on which these intermod products can occur are predictable using classical (but tedious) mathematics. Computer programs are available which can be used to predict when interference can occur so that those frequencies may be avoided. Comtek has one on their website.

Intermodulation can also occur in your receiver (or an active antenna splitter) when it is overloaded. In this case, the front end becomes the mixer, with new interfering signals being produced by the receiver or amplifier that did not come in on the antenna.

There are other ways in which inadequate receiver design can allow interference to occur. Every receiver contains one or more oscillators which are used to tune it to a given channel. Oscillator harmonics and poor shielding and filtering can allow "spurious responses" only 60 dB below the desired signal. When you realize that interfering signals can be television transmitters operating at 316 KW with an excellent antenna and the wireless mic you are listening for is using only 50 mw with a very inferior antenna, it is obvious that spurious responses of 80-100 dB below the desired signal can cause big problems.

Reflections VHF and UHF radio signals are reflected by any metal objects in our environment. It is common for a direct signal and many reflections to be present at any VHF or UHF antenna. When these signals are in phase, they add together and all is well. If they are out of phase, significant cancellations can occur, causing distortion or noise. If they are exactly 180 degrees out of phase and nearly equal, there is almost perfect cancellation! The exact phase relationships between the reflections and the direct wave will vary with the travel time (and thus the distances) between the transmitter, the reflecting objects, and the receiving antenna. A performer using a wireless mic may move into and out of spots where cancellations occur. These reflection zones will be heard as distorted sound or noise bursts. If the performer is moving rapidly, the bursts will be short. If he or she moves slowly, they may move into a reflection zone and stay there! Note that these are not dead spots - there is plenty of signal, but some of it is out of phase and cancels itself out!

Diversity Reception A solution to the problem of phase cancellation was developed during the 1930's when such fading (caused by multiple signals over varying long paths) plagued international radio transmissions. Two receivers, connected to two different antennas were used, and the operator listened to the one which received the clearest signal. This combination of two receivers and two antennas is called diversity reception. Selection of the cleanest signal is now done silently and automatically by the receiver in a circuit called a "voter". Such systems are sold in this country by Vega, Micron, Shure, Sennheiser, and Sony.

A lower cost, but often effective solution is implemented by Telex in what they call "switched antenna diversity". In this system, two antennas are connected to a single receiver through an electronic switching network. When a weak signal is encountered the receiver tells the switch to try the other antenna in the hope it will be better. The problem with this method is that the switcher can get overloaded, resulting either in desense or intermod. We don't like this method of diversity reception.

A much lower cost method of dealing with reflections is "multiple antenna diversity." Two or more antennas are passively combined into a single receiver, and it is hoped that the statistical probability of cancellation occurring with these multiple antennas will prevent the problems associated with reflection zones. While not as effective as diversity reception, it can often reduce cancellations due to reflections to the point that performance is satisfactory.

Frequency Selection Professional wireless microphone systems commonly operate in five portions of the frequency spectrum. In all cases, these channels are shared with other services. ***The single most important factor in good wireless system operation is how well this sharing arrangement works out.*** Since wireless mics are, by law, always secondary users of channels, they must, by law, accept whatever interference occurs, and not cause any. (Because of their very low transmitter power it is rare for wireless mics to cause interference to other services - I have never heard of wireless mics interfering with anything but another wireless mic.) ***It is common, however for wireless mics to receive interference, and finding channels where that interference will not occur is the key to good wireless mic system performance. This is called frequency coordination.***

Low band VHF channels in the spectrum between television channels 4 and 5 (72-76 MHz) are allocated to wireless microphone use, but one of the sharing services here is common carrier paging systems. If a paging system is on your channel (or later lands there), your wireless system will hear lots of beeps, squalls, and ratchety sounding trash. The other problem with these channels is interference from computers, other digital equipment, and fluorescent lighting. ***For all of these reasons, we discourage their use for wireless mics.***

A handful of high band VHF channels in the 150 - 174 MHz range are legally available to wireless mic users. Many of these channels are shared with commercial two-way radio services in nearly all cities and towns, and have little use for wireless mics. Others are channels shared with government services at locks and dams. Since there are not many locks and dams near most wireless mic users, this sharing arrangement often works well. These are the so-called "hydrological" channels, and are in the range between 169 and 172 MHz. Good receivers are required, however, because 2-way radio transmitters are very close in frequency and Channel 7 television (with much more power) is not far away. When no interference is present, these channels work well for wireless mics. The downside of the hydrologicals is that many wireless systems have been sold for only these few channels, so the chance of touring performers bringing in a system on your channel is greatly increased. ***In general, these are not good channels to use.***

Certain professional users of wireless microphones (broadcasters, and producers of programs for television and motion pictures) are permitted to operate wireless systems on High band VHF television channels (7-13) that are unused in their area. ***Because this frequency spectrum is relatively free of interference, these channels are often good for wireless mics.*** Choice of frequencies for wireless mics in this spectrum is usually performed in conjunction with the frequency coordinator of the local SBE (Society of Broadcast Engineers) chapter.

The same class of pro users who are entitled to use the VHF television channels are also permitted on unused UHF television channels (14-69). In the past ten years, these channels have become quite popular with wireless mic users, and more than half of all new systems operate on these channels. It costs a bit more to manufacture equipment which provides good performance at UHF, so these systems tend to be a bit more costly than equivalent VHF systems, and they tend to have higher battery drain for equivalent performance. Until recently, nearly all UHF wireless systems used television channels 60-69. [Recent developments have changed this, because both commercial and government two-way systems have now been made shared users of channels 60-69. See "New Problems" near the end of this paper.]

Some very low priced wireless microphone systems operate in the 49 MHz band, where they receive interference from cordless telephones, garage door openers, and other consumer devices too numerous to mention. They are also susceptible to interference from CB radio operators. Others allow you to tune them to an open spot on the FM broadcast band. ***Such systems are unreliable and of poor audio quality, and should not be considered for any serious use.***

<u>Finding A Good Channel To Use</u> If you are not experienced in choosing wireless mic channels, contact someone who is, and who understands VHF/UHF spectrum usage in your geographical area. Talking to the SBE (Society of Broadcast Engineers) frequency coordinator is a good place to start. He can usually be found by calling the chief engineer of one of the better broadcast stations in your area. When you think you have found a channel, listen to it on a scanner or other receiver that will tune to it. And make sure to do so during busy periods when the maximum interference is likely to be present.

Especially when many wireless systems will be used, or when wireless will be used in an area where many other strong signals are present, be sure to use a good computerized intermodulation prediction program. The likelihood of problems increases exponentially with the number of strong radio signals present (including your systems and other strong radio and TV transmitters). Once again this is a job for the professional.

<u>Dealing With Overload</u> Receiver overload problems can often be solved by reducing the signal presented to the receiver. This may seem like a contradiction - how do you improve performance by attenuating the signal? Well, remember that performance is rarely limited by system range, but rather by interference and reflections. An RF pad (attenuator) of 6 - 10 dB will often get a receiver below the overload point without letting the signal fall into the noise. Pads are readily and inexpensively available from your local MATV (master antenna television system) supplier. I also see them at hamfests.

<u>Antenna Systems</u> Getting the right antenna in the right place, and connecting it properly to your wireless receivers can do a lot to give your systems greater range and better reliability. Antennas should always be located close to the transmitter (i.e., the performer's mic). This gives the maximum pickup of the radio signal from the performer. Antennas should also be as far as possible from sources of interference -- other radio or TV equipment, computers, digital equipment, light dimmers, fluorescent lighting fixtures, etc. And, in general, antennas for wireless mics should NOT be high in the air -- all that does is increase the likelihood of overload and other interference from TV stations and other transmitters outside your building!

It is generally a good idea to locate the wireless mic receiver close to the console operator, so that he or she can monitor the signal strength lights and be alerted to problems. In this arrangement, the best approach is to place the antenna close to the performer, and extend it to the receivers by means of good quality, low loss coaxial cable. If there is more than one receiver, use a good quality passive (non-amplified) splitter. We specify the Mini-Circuits Labs ZFSC-4-175 (718/934-4500), www.minicircuits.com, and Belden 1505A or 9100 coaxial cable. This combination will provide very good performance for cable runs of up to 200 ft and at all frequencies up to and including television channel 69. A larger cable, Belden 1223A or 9114, will get you up to 300 ft, and an even larger one, Belden 9011, offers the lowest loss and can help with longer runs.

What's all this "RG" stuff mean? RG cable specs go back to military electronics in the first half of the 20th century. RG-58/U is a .2" diameter 50 ohm cable, RG-59 is a .24" diameter 75 ohm cable, RG-8 is the "big" 50 ohm cable and RG-11 is the "big" 75 ohm cable. Later, RG-6 a slightly oversized 75 ohm cable, has become quite popular because it provides premium performance but is only slightly larger. These RG-specs cover a VERY broad range of cable types. For example, there are hundreds of RG-59 cables, some of which are optimized for video, some for low power rf, some for high power rf, some for computer data, etc. RG-59 simply defines the 75 ohm impedance and the approximate size (and even the size varies).

50 Ohm or 75 Ohm Cable? It has been common practice for wireless mic systems to be sold and used with 50 ohm coaxial cables. While there is nothing inherently wrong with 50 ohm cable, 75 ohm cables offer much better performance at much lower cost. Some users mistakenly believe that wireless systems are better matched to 50 ohm cable, and that they must use 50 ohm cable to prevent an impedance mismatch. In practice, this is not the case. Real world receivers vary widely in input impedance -- all that most engineers who design these systems can tell you is that they are somewhere in the 50-75 ohm range. The same is true of the antennas themselves -- their impedance is strongly affected by surrounding objects and varies with frequency. So a real world system is just as likely to be well matched to 75 ohm cable as it is to 50 ohm cable. More important, the TV antenna and cable industry have standardized on 75 ohm cables, making the quantity and quality of these cables much higher, and their prices much lower for equivalent quality.

Here are loss data for the best 50 and 75 ohm MATV cables I know of, in dB/100 ft. Prices are typical for a 1,000 ft spool from an industrial electronics vendor. Note that you have to go to the biggest, most expensive RG-8/U to get performance in a 50 ohm cable which is better than the best RG-59/U cable! And even if there is some mismatch, the extra loss it causes is much less than the advantage the 75 ohm cables start out with!

Cable	1000 ft	Diameter	Impedance	200 MHz	500 MHz	700 MHz
Belden 9100 (RG-59/U)	$93.50	.237"	75 ohms	3.5 dB	5.6 dB	6.7 dB
Belden 9114 (RG-6/U)	$105	.27"	75 ohms	2.7 dB	4.35 dB	5.2 dB
Belden 9011 (RG-11/U)	$195	.40"	75 ohms	1.7 dB	2.75 dB	3.25 dB
Belden 9310 (RG-58/U)	$267	.193"	50 ohms	5.4 dB	9 dB	11.1 dB
Belden 9258 (RG-8X)	$300	.242"	50 ohms	4.5 dB	7.2 dB	9.1 dB
Belden 9913F (RG-8/U)	$774	.405"	50 ohms	2.0 dB	3.2 dB	3.9 dB

Times LMR195 (RG-58)	$320	.195	50 ohms	5.2 dB	8 dB	10 dB
Times LMR-240 (RG-8X)	$440	.240	50 ohms	4.5 dB	6.5 dB	8 dB
Times LMR-400 (RG-8)	$530	.400	50 ohms	2 dB	3.3 dB	4 dB

Getting Antennas Closer to the Transmitter -- A Practical Example Let's say we've got a mix position that's 100 ft from the stage, we want to move our antennas from the mix position to a point that's only 20 feet from the stage, it takes 150 feet of coax to get from the antenna to the mix position, and that we're working at about 600 MHz. Belden 9114 will burn about 7 dB, a 1x4 splitter will lose another 7 dB, for a total loss of 14 dB. But because the antenna is only 1/5 the distance, we gain 13 dB, so the receivers get only 1 dB less signal than before. And any interference is reduced by that same 14 dB, so we have a 14 dB improvement there. Not only that, but the digital equipment at mix positions (and in equipment racks) will often generate a lot of RF noise that interferes with wireless mics. Just by moving the antenna away from all that mess we are likely to help performance even more!

Problems At Short Range When your wireless system experiences noise and dead spots within 50-200 feet of its receiver, something's wrong. If it's a good system and all your connections are good, you are probably receiving interference. Interference may not necessarily be heard as noise -- it may simply make your system have poor range or dead spots. Again, there may be plenty of signal from the mic, but it may be getting overwhelmed by the noise. Look for interference sources (noted above) around your antenna. Move the interference source away from the antenna or move the antenna away from the interference source and closer to the performer's mic. Or do both.

If this doesn't make things better, suspect desense. Receivers for channels A and B can be overloaded by a transmitter for channel C within 10-30 feet. This is more often a problem with cheapies, but I've seen it with a few good systems too. Try taking the antenna off the receivers which are having problems and using a paper clip or short piece of wire instead. If reception improves, you're experiencing overload. As a permanent fix, insert a 10 dB pad or passive splitter (described above) between the antenna and the receiver.

Extending Range Most good wireless systems should be good for at least 300 ft if there's nothing in the way and nothing to interfere with them. When it is necessary to extend the range of a wireless system beyond 500-1000 feet, several tools are available. Wireless receivers operating in or near TV channels work very well with antennas designed for the MATV service. A good multi-element antenna having 8 dB of gain can double the working distance. Raising the antenna height can also help considerably (if it doesn't increase interference). With some receivers a low noise pre-amplifier will also help extend the range. And, when you are going for long range, use the lowest loss cables you can find. ***But try all of these things cautiously if you are in a strong signal area - all of these techniques can cause receiver overload if they increase the strength of the interference!***

Improving Audio Performance Most wireless mic systems use noise reduction systems (known generically as companders). They ***comp***ress the audio level before transmitting and ex***pand*** it again in the receiver. When this is done well, the audio is not changed by the total process, but noise in the radio link is greatly reduced. dbx and Dolby noise reduction are other examples of compansion systems. Most of the better quality wireless systems use companders, and are capable of dynamic range on the order of 105 dB. Some brands and models work much better than others. This is another area where low cost systems tend to be inferior -- their cheapie compansion circuits produce very audible pumping.

All wireless microphones, including those using compansion, must also use peak limiters to prevent overmodulation according to FCC rules. While these limiters can help improve the signal to noise ratio, it is important that they be adjusted so that they are not overused. Most wireless mic transmitters have preamp input gain control accessible as a screwdriver adjustment which can be accessed through a hole in the transmitter case. It should be adjusted so that peak limiting is not audible in normal operation. Excessive peak limiting will be audible as a pumping of background room noise and, in severe cases, as a loss of high frequencies.

An interesting operational problem with wireless systems occurs when there are intermittent metallic connections in the immediate vicinity of the wireless mic transmitter. When such intermittent connections exist, a static-like noise is heard in the receiver output. One condition that can cause this is the performer wearing costumes containing conductive materials. The exact mechanism causing the problem is not clear, but several are possible. If rapidly changing reflections are produced by the metal object, they could be detected at the receiver as amplitude or phase modulation. Intermodulation could also be taking place.

Tunable Wireless Systems Frequency synthesizers offer an alternative to the quartz crystals used to set transmitter and receiver operating frequencies. Rather than being locked into a single frequency determined by the quartz crystal in the transmitter and receiver, the synthesizer (which also uses a single quartz crystal) may be set to produce any of up to several dozen operating frequencies. The user may tune the system just like a modern digital FM tuner.

On the surface, this would appear to be the greatest thing for wireless mic operation since sliced bread. There is, unfortunately, more to getting these systems to work well than meets the eye. Careful frequency selection requires avoiding those channels where intermod products can render the systems unreliable. Synthesized systems don't always allow the flexibility required to avoid intermod, especially when a lot of wireless systems are in use, or when the systems are used in a very difficult rf environment.

Most users are not aware of the problem until they run into interference and change one system's channel to avoid interference. What they find is that the problematic system is now clean, but another system (or even several other systems) are now experiencing intermod caused by the transmitter they changed!

Digital Wireless Systems Several years ago, a manufacturer introduced a wireless system which uses spread spectrum digital transmission. While spread spectrum techniques offers the promise of good coexistence with other interfering signals, including digital television systems, the more systems of this type are in use the greater will be the interference between them. Moreover, this particular system is "not nearly ready for prime time." The vendor promises flawless interface to anything from lavalier mic elements to a guitar output, but audio performance doesn't even begin to live up to data sheet promises -- it varies from "kind of ok" to awful. Stay tuned, but don't buy this one yet.

Digital And Analog Squelch Radio systems have long used sub-audible tones and digital codes to allow one receiver to recognize one transmitter and reject all others. These systems have been applied to wireless mics with varying degrees of success. The advantage is that if their own transmitter is overridden by another signal using no code (or a different code), you won't hear the interfering signal. The disadvantage is that you won't hear your wireless mic transmitter either. In other words, an interference event which would have been a burst of noise becomes dead silence.

Wireless Intercom Systems A wireless intercom system consist of two or more wireless mic systems wired for two-way communication between two or more crew members. In these systems, the base station functions as a repeating transmitter, picking up transmissions from each remote (or "walkaround") and retransmitting them on a channel where all remotes can hear. The base station is also usually tied into a conventional wired intercom. The wireless intercom can be set up so that all remotes are on the same channel and operate "push-to-talk", or may be on individual channels and operate "full duplex" (i. e. listening and talking at the same time). In either variation, everyone hears everyone else, rebroadcast through the base station.

Such systems are currently marketed by Cetec-Vega, Comtek, Telex, and Clear-Com, and have range capabilities roughly comparable to that of wireless mics. Frequency coordination is important, since these systems can use up frequencies very quickly (including those you'd like to use for wireless mics). Receivers are generally not as good, particularly in the area of overload performance, but noise that would not be tolerated with wireless mics is more acceptable in intercom operation. System costs are about the same as an equal number of wireless mic transmitters and receivers.

New Problems Two rather serious new problems have reared their ugly heads in the past few years, both of which are likely to require the redesign of new and existing installations. First, television **channels 60-69** have been allocated to use by both commercial and government entities for two-way radio communications. This means that if there is no television station assigned to a given channel in your area, there may be two-way radio systems (police and fire dispatchers, trucking companies, bus companies, plumbers, etc.) on that channel. These new two-way systems will come on the air slowly over a period of years, more each year until each channel is full. The greatest impact will be in and around larger cities.

Second, the advent of **digital television** has brought new television channel assignments, one for every existing licensee. This means that a lot of channels which used to be available for wireless will be no longer. These assignments are made in two phases. Beginning in 2000, stations began transmitting both analog TV on their existing channels and digital TV on their new channels. Eventually, the existing analog transmitters will be shut down and new assignments will be made for digital only television. In addition to using up more channels, digital television is much more likely to interfere with wireless mic systems than existing analog television, but it is less likely that interference will be recognized as such. Here's why.

With analog television (what we have now), nearly all of the transmitted energy is concentrated around three frequencies for each channel -- the picture carrier, the sound carrier, and the color sub-carrier. A skillful frequency coordinator can find frequencies in between to put wireless systems that won't have intermod products to cause interference.

With digital television, the energy is distributed almost equally throughout the channel. So when intermod products are produced, they also spread over entire channels. The result is broadband hash which is likely to drastically reduce the range of wireless systems. It may not sound any different from the noise that appears between stations in any radio receiver, but because its a lot stronger, it will reduce the reliable range of wireless mics.

In most localities, all (or nearly all) digital TV stations are being assigned to UHF channels, because nearly all existing VHF channel assignments were used up many years ago. This means that most new and existing VHF systems are unlikely to be affected by digital television systems, and are likely to be the most reliable in the near future.

Multipath (Reflections) A recent thread on the Theater Sound Mailing List caused me to write this explanation of multipath and some common interference phenomena that occur with wireless mics. The thread started when someone asked about using wireless mics on a theatrical production where the set would include a large, complex framework made out of aluminum.

Any conductive object can pick up radio waves (act as a receiving antenna) and re-radiate them (act as a transmitting antenna). Here's what happens.

A radio wave is an electromagnetic field -- i.e., the simultaneous combination of an electric (voltage) field and a magnetic field at right angles to each other. An antenna is simply a conductive object this is producing or receiving that field. An electromagnetic field causes current to flow in a conductive material. And the closer the size of the conductive object is to a multiple of a quarter wave length of the radio signal involved, the more current will flow.

When radio frequency current flows in a conductive object, that current sets up a new radio signal (another electromagnetic field) which is then radiated by that object back out into space. If there is nothing non-linear happening, this new field is directly related to the original field that produced it, and it will be indistinguishable from the original field. But at any point in space, a radio antenna will pick up both fields, and those fields will have traveled different distances to get to the antenna. Because of the different distances, the travel times will also be different. This will put the original field out of phase with the new re-radiated copy of itself. The total voltage the antenna sees is the sum of that produced by the two fields. (Note that this is different from polarity, which is a reversal of the field or the voltage, and this difference is why it is so important to say polarity when you mean polarity!).

If we move the antenna, the time relationships will change. This is exactly what you hear when you drive down the road and hear "multi-path" distortion of an FM signal -- at some points the reflection is precisely in phase (zero degrees, or a multiple thereof), at some points it is precisely 180 degrees out of phase (or an odd multiple thereof), and at every other point is some random number of degrees out of phase. [Another time you'll hear this is when you're listening to a distant FM station and an airplane flies through the path between you and the station. You'll hear slow additions and cancellations as the phase relationship between the direct and reflected signals change with the plane's position.]

When the two signals are precisely in phase, they add together perfectly, and the result is equal to the sum of the two fields. When they are precisely 180 out of phase, they subtract from each other. If they are precisely equal, they cancel each other. If they are not, the result is simply less signal. Something similar happens when they are a random number of degrees out of phase -- there is a partial addition or partial subtraction, depending on the phase relationship, and that phase relationship changes as the antenna is moved. Exactly the same thing happens when you move the transmitting antenna (i.e., the wireless mic).

>This vibration, with a pure piece of metal, not only sends off frequencies at 400Mhz, but it
> sends 800Mhz, 200Mhz and so on.

NO, NO, NO. It re-radiates exactly what it receives.

>But since we aren't dealing with a pure piece of metal, the frequencies it sends off are insane.
>If there is a bar of metal attached to another bar of metal, it can vibrate that one too.

New frequencies are produced by poor electrical connections which cause rectification, not metal alloys. Some connections of dissimilar metals can cause rectification too. When this happens it causes intermodulation distortion (see above).

Paul Peterson noted:

>I've heard several designer's mention RF interference when there's pieces of metal rubbing or
>scraping together. In one case, the metal pins in an actor's reconstructed knee created inter-
>ference every time he flexed his knee.

What's happening here is pretty complex. Those pieces of metal are simply re-radiating the radio signal as in the above discussion. But when they rub together, their length changes, and so does their electrical conductivity (at the connection). That change produces a change in the strength of the re-radiated field, and that change can be detected as amplitude modulation of the signal. That change in amplitude is what you are hearing as noise.

And Paul Johnson correctly observed

>diversity systems with close spaced aerials give marginal diversity performance. The problem
>seems to be reflections. If you just connect one aerial and wander over the set, the signal
>strength varies far more than a non-metalic set. Watch out for strange nulls. Spacing the
>receiving aerials to both sides of the stage pretty well cured the problem.

Note that all of these effects are VERY dependent on the size of the conductive objects and the openings between them. If the objects are large enough in comparison to a wavelength, there can also be significant shielding effect -- i.e., the large object prevents signals from getting past it. The large framework which is the basis of this thread could do that. But if the openings are large in comparison to a wavelength, it will act less like a barrier. For that reason, UHF mics, which use shorter wavelengths, might be expected to perform better than VHF mics.

My advice: Definitely use diversity receivers and good, well separated antennas. Try both VHF and UHF systems, and see which works best. As with any multiple wireless show, be careful about frequency coordination for intermod. And don't play cheap if you want a reliable show.

>I've heard about the polarization of radio waves. Could you explain that and how it affects wireless systems?

A vertical antenna sends out vertically polarized waves, and receives vertically polarized waves better. Likewise, a horizontal antenna sends and receives horizontally polarized waves. [This isn't an on/off relationship, it's a continuously variable function -- the received signal strength is multiplied by the cosine of the angle between the antenna's polarization and the angle of the radio wave. When the angle is 0 degrees, the cosine is 1, and when it's 90 degrees the cosine is 0.] But the antennas in wireless transmitters are typically the arm of the performer holding a handheld transmitter, and the cable connecting the lavalier mic to the body pack. It's hard to say what the polarization of the radio waves will be that are transmitted by these antennas! Moreover, any time a radio wave bounces off of any object, its polarization can be changed. Thus we must think of the polarization of our wireless systems as random.

>What should be the orientation of the receiving antennas, especially with a diversity system?

This is generally much less important than having them well located (and in a diversity system, well separated). If you must put both diversity antennas in the same spot, do put them at right angles to each other (for example, one 45 degrees in one direction, one 45degrees to the other). This is the best way to deal with the randomly polarization of the transmitter. If he antennas are separated, I'd go with whatever orientation provides optimum directivity to the area where transmitters will be.

SUMMARY AND RECOMMENDATIONS

- It costs money to build wireless systems which are good sounding and reliable under real world conditions. $800 - $1,400 should be a minimum "street" price for wireless systems. Stick with major manufacturers like Comtek, Shure, Telex, Lectrosonics, and Vega. All are designed and manufactured in the US. Buying cheaper systems is asking for trouble, either now, or in the future.
- The more wireless mics you plan to use at one time, the more you should plan on paying for them. If you're in a small town, need only two or three wireless, and there are no other churches (or interference sources) nearby, you'll have a good chance of being happy with something in the $800 range.
- The bigger the city, the more the mics you need to use, or the closer you are to big TV transmitters, the more likely you are to need mics in the $1,200 - $2,000 range.
- Never accept any manufacturer's "stock" frequencies. This will make it far less likely that a "star" will bring in a system which wipes out one of yours!
- Always have frequency coordination done by a professional who understands the radio environment in your area. These professionals should know the television transmitters in your area and exactly how close their transmitters (not their studios) are to your facility.
- Never use amplified antenna splitters, amplified combiners, or antenna pre-amplifiers.
- When you buy electronic equipment that will be used anywhere near your wireless mics (computers, monitors, mice, digital audio and video, ballasts for fluorescent lighting, etc.) insist that it be FCC Class B approved, and make sure the interconnecting cables are shielded. And don't believe it's Class B unless you see the sticker on the product. (The more lax FCC Class A standard allows equipment to put out much more radio trash).
- Keep antennas away from computers, digital equipment, dimmers, fluorescent lighting, other radio equipment, and accessories for all of the above. When you buy lighting equipment, insist that it conform to FCC Part 15 Class B or FCC Part 18 Residential Use.

- Locate antennas "low to the ground" and close to the performer.
- If you use transmitting antennas (for wireless intercom, hearing impaired systems, or two-way radio) DO locate them high and in the clear, and keep them away from your receiving antennas.
- Use good quality coax (see table above) and passive antenna splitters (Mini-Circuits Labs ZFSC-4-175).
- Avoid UHF channels 60-69, which will be plagued by interference from new two-way radio systems in a few years.
- Make sure you understand how the new digital TV stations will affect the radio environment in your area, and consider buying good VHF systems when you need more wireless mics.
- If your systems are unreliable within about a 300 ft range, something is wrong, probably interference. Work on finding the source of the problem by moving your antenna away from known interference sources. (But expect wireless systems to lose range when going through walls which contain a lot of metallic elements -- it's normal for this kind of construction to block the signal.)