Large Multichannel Wireless Microphone Systems

Introduction

The use of wireless microphones has mushroomed in the past few years. This is due to advancements in technology, a trend towards greater mobility on stage, and the desire to control volume and equalization of individual performers. Consequently, installations in which a number of wireless microphones, referred to as channels, are being used simultaneously, has increased dramatically. In the past, six channels seemed to be the limit. Now theatres and studios with large multi-channel systems, ten to thirty channels, are common. The largest installation to date is 88 channels being used in a theatre in Austria. Systems of this magnitude are a difficult engineering challenge. Careful planning, installation, operation, and maintenance are required.

Frequencies

Manufacturers generally produce wireless microphones on very high frequencies (VHF) and ultra high frequencies (UHF) with specifications outlined by government agencies such as the Federal Communications Commission (FCC). Since the two frequency ranges have different associated wavelengths, they behave differently. The wavelength is inversely proportional to the frequency. Higher frequencies have shorter wavelengths. VHF frequencies (165-216 MHz) have a wavelength of approximately 2 meters. They exhibit good ability to bend around objects. UHF frequencies (450-960 MHz) have a wavelength of less than one meter. They have excellent reflective characteristics. They can travel through a long corridor, bouncing off the walls, losing very little energy. Due to its short wavelength, a UHF wave can sneak through small areas more easily. To take an extreme example, in a jail, the metal bars form a lattice or a "Faradays Cage" that will easily block a VHF frequency while a high UHF wave (950 MHz) is small enough, approximately 30 cm, to escape in between the bars. However, the shadowing effect is more critical in the UHF range. A small solid metal object could block a UHF wave while a VHF wave could probably bend around it.

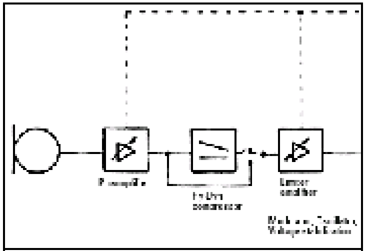
UHF stations are usually located on the outskirts of major cities, and generally have less transmitting power than the stations operating on the VHF channels. There is significantly less potential interference from machinery in the UHF range as well. However, UHF equipment is more expensive than VHF, with little difference in audio quality. It demands highly sophisticated RF design techniques with more stringent tolerances.

To summarize, if the system is to be installed in a fixed location, carefully chosen VHF frequencies are an economical choice. If the system is to be used by a traveling performance company or in a theatre that has saturated the VHF spectrum with wireless equipment, then UHF should be considered.

Frequency bands used by TV Channels				
VHF			UHF	
Channel	Frequency band		Channel	Frequency band
7	174 - 180 MHz		14	470 - 476 MHz
8	180 - 186		15	476 - 482
9	186 - 192		16	482 - 488
10	192 - 198		17	488 - 494
11	198 - 204		18	494 - 500
12	204 - 210		19	500 - 506
13	210 - 216		etc.	

Transmitter considerations

A radio frequency (RF) transmitter works like a miniature FM radio station. First, the audio signal of a microphone is subjected to some processing. Then, the processed signal modulates an oscillator, from which the carrier frequency is derived. The modulated carrier is radiated via the transmitter's antenna. This signal is picked up by a complementary receiver via its antenna system, and is demodulated and processed back to the original audio signal.

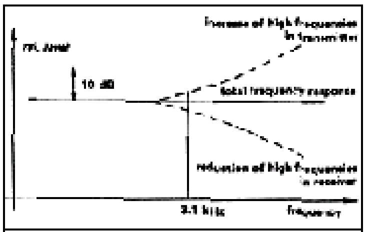


Click here for Figure 1

Frequency deviation

The modulation of the carrier frequency in an FM system greatly influences its audio quality. The greater the deviation, the better the high frequency response and the dynamic range. The trade-off is that fewer channels can be used within a frequency range. However, since audio quality is usually the priority and the UHF spectrum has increased the number of available frequencies, wide deviation is most desirable.

Power

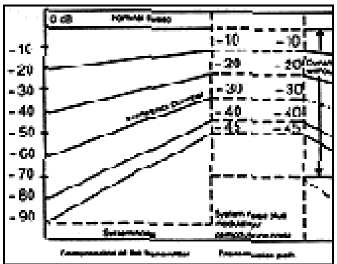


Click here for Figure 2

Transmitter power is a rating of its potential RF signal strength. This specification is measured at the antenna output. The actual transmitted power is influenced by the efficiency of the antenna. Therefore, power specifications are of only limited use in assessing a transmitter's range, considering largely variable antenna conditions. Also, battery life is associated with RF output power. Increased power will reduce battery life with only a moderate increase in range.

DC-to-DC converter

Transmitters should be designed to provide constant RF output power and frequency deviation throughout the event being staged. This can he achieved through the use of a DC-to-DC converter circuit. Such a circuit takes the decaying battery voltage as its input and regulates it to have a constant voltage output. Once the voltage of the batteries drops below a minimum level, the DC-to-DC converter shuts off, almost instantaneously. The result is a transmitter that is essentially either off or on. While it is on, the RF output power, frequency deviation, and other relevant specifications remain the same. Transmitters without regulation circuits, once the battery voltage begins to drop, will experience reduced range and the audio quality will start to deteriorate due to a degradation in the modulating signal.



Click here for Figure 3

Companding

Most wireless microphone systems use a companding (compressing/expanding) noise reduction system, similar to those used in recording studios and home stereo equipment, as well as a pre-emphasis/de-emphasis process to maximize signal-to-noise ratio, dynamic range, and transmission reliability. The transmitter pre-emphasizes, or boosts, the higher audio frequencies. The modulated signal is then compressed before being transmitted. This raises low audio levels sufficiently higher than the transmission noise and suppresses overmodulation. The receiver uses complementary expanding to restore the dynamic range and de-emphasis so that the overall response is linear.

Spurious emissions

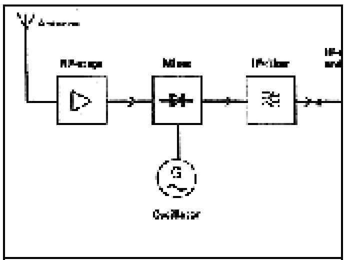
Apart from the wanted carrier frequency, transmitters also may radiate some unwanted frequencies known as spurious emissions. The carrier frequency is obtained by electronically multiplying a crystal frequency. A frequency is generated after each multiple. For example, a 25 MHz crystal is doubled to 50 MHz, which is doubled again to 100 MHz, which is doubled once more to the final carrier frequency of 200 MHz (8 times the original crystal frequency). However, spurious signals every 25 MHz might he generated. For large multi-channel systems these spurious frequencies cannot be ignored. They can be significantly reduced through elaborate filtering and contained by using a well constructed, RF "tight" metal housing for the transmitter. This metal casing should not have any slits, since RF can leak through them. Therefore, it should be one molded piece rather than two half shells screwed together. Small round holes in the casing are acceptable since RF cannot escape through them. They can be employed for access to adjustment locations on the circuit board. Also, an RF tight transmitter is less susceptible to outside interference. Despite this precaution, choosing a frequency for a new channel that falls directly on one of these possible spurious emissions should be avoided.

A metal housing is important not only for its shielding properties, but also its durability. These devices usually experience much more abuse by actors and other talent than anyone ever predicts.

Antenna

A transmitter antenna should be tuned to its carrier frequency. There are generally two types, the long straight "whip" antenna and the coiled "rubber duck" antenna. The whip antenna is tuned by cutting it to 1/4 of the wavelength of the carrier frequency. The duck antenna is used on VHF transmitters to stifle objections to the length of a whip antenna necessary for the VHF range. It achieves its radiating efficiency along its shortened length over a much narrower frequency range. The coiling of the antenna wire concentrates its tuning elements. The tuning is sharply influenced by close proximity to conductors. On body pac transmitters, the duck antenna tends to be stiff and rest against the user's body. Since the human body is largely composed of water and salt, it is quite a good conductor and could easily detune the duck antenna. Therefore, the whip antenna is recommended for body pac transmitters. If a duck antenna must be used, it is recommended to bend it slightly so it does not rest against the performer's body. UHF antennae are short enough that there are generally no objections to the ¼ wave whip antenna.

Handheld transmitters are often designed with their antennae incorporated on their circuit board under the outer housing. This design is not efficient because the performer's hand will absorb some of the radiated energy. It cannot be implemented with a metal, RF-tight housing either.



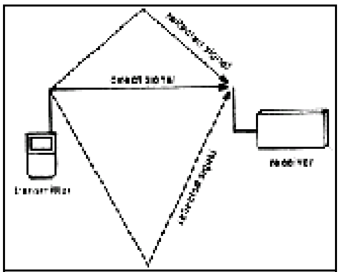
Click here for Figure 4

Receiver considerations

An ideal wireless microphone receiver would capture the carrier frequency of its corresponding transmitter and reject all other signals. Short of this unrealistic expectation, a receiver should be designed to capture its carrier, reject most other signals, and avoid mixing its carrier with the other signals it does pick up. When designing a multi-channel system, the "non-ideal" characteristics have to be overcome. These include widely varying RF signal levels, intermodulation, frequency spacing, and spurious oscillator frequencies.

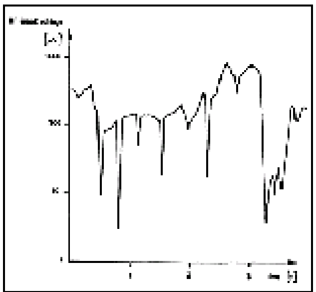
RF signal level

Varying RF signal strength is mainly due to multi-path propagation, absorption and shadowing. These are familiar difficulties also experienced with car radios in cities.



Click here for Figure 5

Audible effects due to low RF signals, known as drop- outs, can occur even at close range to the receiver, due to multi-path propagation. Some of the transmitted waves find a direct path to the receiver antenna and others are deflected off a wall or other object. The antenna detects the vector sum, magnitude and phase, of direct and deflected waves it receives at any particular instant. A deflected wave can diminish a direct wave if it has different phase, resulting in an overall low signal. This difference in phase is due to the longer path a deflected wave travels between the transmitter and receiver antennae and any phase reversal occurring when it hits an object. Obviously, this phenomenon needs to be addressed in an indoor application. It is less critical outside.

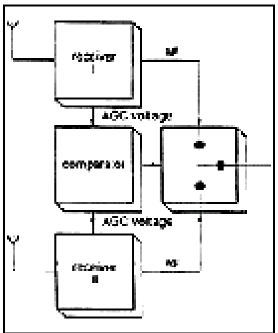


Click here for Figure 6

Considering only the multi-path propagation effect, figure 6 shows a typical curve of the signal strength at a receiving antenna. The variation inside a building with reflecting walls is 40 dB or more.

RF energy can be absorbed by non-metallic objects resulting in low signal strength. As stated previously, the human body absorbs RF energy quite well. It is important to place antennae correctly to minimize this effect.

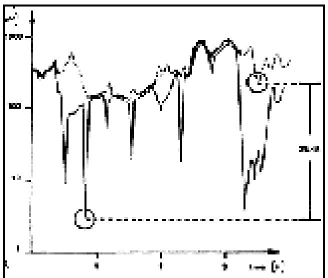
Shadowing occurs when a wave is blocked by a large obstacle between the transmitter and receiver antennae. This effect can be minimized by keeping the receiver antenna a distance of ½ wavelength away from any large or metallic objects.



Click here for Figure 7

These problems are addressed by a diversity receiver. A diversity system is recommended even if only one channel is in operation. Large multi-channel systems are only possible with diversity operation.

Comparing the different diversity systems, the "true" diversity has proven to be the most reliable design. This design has two independent receivers (usually incorporated within a single housing), each with its own antenna, with a logic switch between them. The logic switch constantly monitors the RF field strength as seen by each receiver. The receiver with the highest RF level is used for the audio output. This switching action can occur very fast and often, especially in UHF equipment. It is not audible in a well designed receiver. It is difficult to define an absolute value for the improvement when using this type of receiver. It can only be determined by statistical methods. Figure 8 shows the improvement when using a true diversity system. It has a similar effect of amplifying the wanted signal at least 23 dB.



Click here for Figure 8

Another method of diversity is "antenna" diversity. This incorporates a single receiver with multiple antennae, usually three. Using this method, the signals from each antenna are summed together. It assumes that if a weak signal is detected at one antenna, the sum of the other two will provide a sufficient signal. The problem is that both the phase and the amplitude of the signals are summed. Due to phase cancellation, the summed signal is often lower than the signal seen by a single antenna. Another problem is that each antenna needs an amplifier to keep it electrically independent from the others. These amplifiers can be a source of intermodulation.

A third technique is known as "phase" diversity. With this method, one receiver and two antennae are used. If the signal drops below a certain threshold the receiver switches the phase of one of the antennae. This method assumes that a low RF signal is due to multi-path propagation. However, it may be due to shadowing or absorption. Switching the phase may aggravate a multipath propagation problem.

Intermodulation

Intermodulation is the result of two or more signals mixing together to produce a sum or difference signal. It is a common misconception that intermodulation is produced by the carrier frequencies mixing within the air. Intermodulation occurs within non-linear active components, such as transistors, exposed to strong RF input signals. This usually happens in the RF section of the receiver or in antenna amplifiers. In multi-channel operation, when several RF input signals exceed a certain level, the intermodulation products grow very quickly. There are different levels of intermodulation defined by the number of addition terms. Each addition term (fl, f2, etc.) represents a carrier frequency:

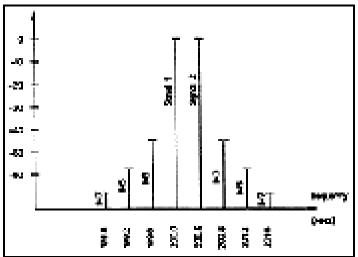
IM2 Products:
f1 - f2 = IM2
where f1 < > f2

IM3 Products:
f1 + f2 - f3 = IM3
where f1 < > f3 and f2 < > f3

IM4 Products:
f1 + f2 - f3 - f4 = IM4
where f1 < > 5, f1 < > f4
f2 < > 5, f2 < > f4

IM5 Products:
f1 + 12 + 5 - f4 - fS = IMS
where f1 < > f4, f4 < > f5
f2 < > f4, f4 < > f5
f3 < > f4, f3 < > f5
...etc.

Only the odd order intermodulation products need to be considered since the even ones are out of the frequency range of concern. Figure 9 shows typical intermodulation products caused by two strong input signals. The frequency of a new channel should be carefully selected to avoid intermodulation products of the other signals.

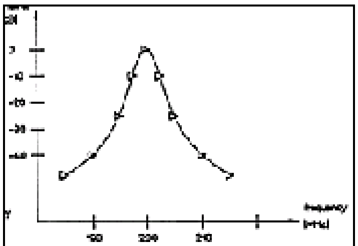


Click here for Figure 9

Equipment can be designed to minimize intermodulation. A specification known as intermodulation rejection is a measure of the RF input threshold before intermodulation occurs. For a well designed receiver, this specification will be 60 dB or greater. An intermodulation rejection of 60 dB means that intermodulation products are generated at input levels of approximately 1 mV. The highest quality multi-channel receivers presently available feature an intermodulation rejection of 80 dB.

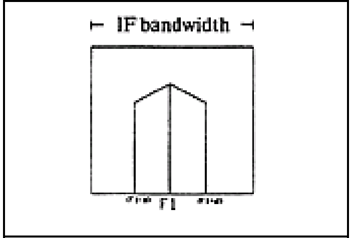
Another important design feature is selective filters. Filtering out signals other than the wanted carrier frequency is no easy task. The filtering "window" should be as narrow as possible. This can be achieved through the use of helical filters in the first stage of the receiver. Figure 10 shows the curve of a third order helical filter of a modern VHF receiver. Strong input signals 5 MHz aside the receiving frequency are attenuated by at least 20 dB.

Despite these precautions, frequency coordination must be done. Only the 3rd and 5th order intermodulation products need to be considered with most equipment. The higher odd ones are too weak to cause problems. If high quality receivers are used, having an intermodulation suppression of 6O dB or greater, only the 3rd order products need to be considered.



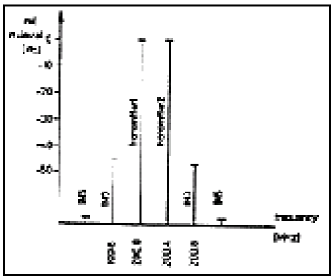
Click here for Figure 10

The distance between an intermodulation product and a carrier frequency should he kept to a maximum. A theoretical minimum safe distance can be determined by considering two criteria. First, an intermodulation product should not enter the final filtering stage, the intermediate frequency (IF bandwidth) of the receiver. Secondly, since the carrier frequencies are being modulated, the bandwidth of an IM3 product, by nature of the algebra listed previously, is three times the bandwidth of the carriers. If full modulation is assumed, the bandwidth of an IM3 product is three times the maximum frequency deviation of the carriers. Therefore, the minimum safe distance regarding IM3 products is three times the maximum deviation of the transmitters plus half the IF bandwidth of the receiver.

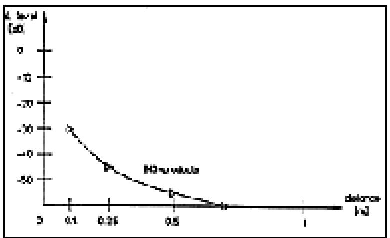


Click here for Figure 11

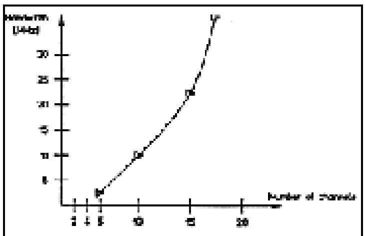
This is the theoretical ideal, however. Often, full modulation in the transmitters is not achieved. Therefore, the IM3 products would not be as wide. The practical minimum safe distance is often a debated subject. Nevertheless, it is recommended that IM3 products should be 250 KHz away from any carrier frequency. If IM5 products are to be considered, they should be assumed to have a bandwidth of five times the maximum deviation of the transmitters.


Click here for Figure 12

Intermodulation products are not only generated in receivers. Transmitters also have antennae which tend to pick up other signals. When these signals pass in a reverse fashion across the output filter of the transmitter, they are fed to a non-linear component: the output stage transistor. In this way, transmitters can generate intermodulation products themselves. Figure 12 shows the intermodulation products of two hand-held transmitters (30 mW each; 200 MHz; 200.4 MHz) used at a distance of 1 meter from each other. With body pac transmitters the problem becomes less critical since the antenna is close to the body. Figure 13 shows the transmitter intermodulation products of two body pac transmitters (30 mW each; 200 MHz; 200.4 MHz) when the distance is varied. This shows that actors with body pac transmitters can come rather close to each other without significant problems of transmitter intermodulation products. The situation changes dramatically, if several transmitters, still in operation, are put side by side on a desk. This mistake must be avoided. A highly selective output stage in the transmitter should be incorporated to minimize these problems.


Click here for Figure 13

Frequency coordination can be extremely complex. It requires an appropriate computer program. For a six channel system, for instance, 90 IM3 products have to be taken into consideration. For twenty channels this figure grows to 3,500. As shown in figure 14, the necessary RF bandwidth rises exponentially as the number of channels is increased. This graph only considers IM3 products. The other constraints that need to be considered make the graph even more dramatic.


Click here for Figure 14

External disturbing sources such as TV transmitters, taxi services, police services, digital equipment, etc., also have to be taken into consideration. Fortunately, the screening effect of buildings is rather high (30 to 40 dB for VHF carriers). For indoor applications, this effect keeps strong outside signals at low levels. A significant problem can occur when poorly screened digital equipment is working in the same room. These wideband disturbing sources are able to interfere with all VHF channels. The only solution to this problem is to replace the poorly screened piece of equipment with a better one.

Spacing

In order to have a defined channel, without crosstalk and with an intermodulation safety gap, a minimum spacing of 300 KHz between carrier frequencies should be employed. A wider spacing is even more preferable since many receivers often exhibit desensitized input stages in the presence of closely spaced signals. However, caution should be used when linking receivers with widely spaced frequencies to a common set of antennae. The frequencies need to be within the bandwidth of the antennae.

Local oscillator

Receivers contain one or two local oscillators (single conversion or double conversion). In most VHF systems it is 10.7 Mhz below the carrier. A small part of the oscillator energy could be radiated via the antenna or via the housing. Although this energy is small it is not negligible. When the receivers are connected to each other through an antenna system, this potentially dangerous frequency will find access to the input stages.

This must be considered in the computer program. The difference between two carriers should never be equal, or even close to this oscillator frequency. A safety margin of 200 KHz is recommended. Another related frequency, the image frequency, two times the local oscillator, should be avoided in the same way. To minimize this problem, high quality receivers apply a double screening. Inside an all-metal housing, hermetically sealed metal boxes contain the complete RF circuitry. This technique reduces the spurious emission by 20 dB.

Antennae

A good receiver antenna system is extremely important. There are several types of receiver antennae available. Similar to microphones, there are omnidirectional antennae and directional ones. There are far more omnidirectional antennae in use presently. However, in areas that are saturated with RF equipment, directional antennae become more attractive.

Omnidirectional antennae are generally tuned by cutting them ¼ wavelength of the operating frequency. This type includes the "rabbit ears" seen in the majority of systems. These are attached directly to the receiver. This is simply a monopole or Marconi type of antenna and is generally reliable.

A more sophisticated antenna is a remote ground-plane antenna connected to the receiver by a coaxial cable. Besides having a main radial to pick up the signal, it has at least three others that form a virtual ground plane which protects the main radial from potentially interfering deflected waves bouncing off the closest large reflective surface, usually the floor. If the antenna is mounted from the ceiling, it should be turned upside down, since the ceiling is more of a threat than the floor.

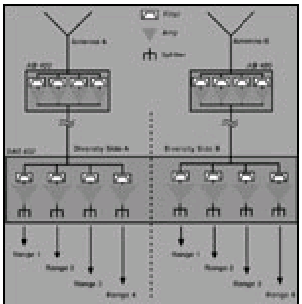
An antenna has a bandwidth. It is sensitive to the frequency that it is tuned to while it attenuates other signals. For a single receiver, it is desirable to have a very narrow bandwidth. For larger systems where several diversity receivers are linked to one set of antennae, it is necessary for the antenna to have a bandwidth that includes all the frequencies in operation. The bandwidth of an omnidirectional antenna can be broadened by increasing the diameter of its radials.

A directional antenna, similar to a cardioid microphone, is more sensitive to signals arriving from the front and attenuates signals from the rear. This is an excellent choice for a fixed installation where other nearby venues have wireless systems as well. An example is a theme park, especially if it has outside theatres. By carefully aiming these antennae, one can provide RF pick-up of the intended stage and reject the potentially interfering signals from other areas. This type of antenna is also tuned but generally has a broader bandwidth, an advantage with a large multichannel system. However, correct installation is critical. They are larger than the omnidirectional type, need to he distanced farther from potentially blocking objects, and aimed in the correct direction. They can not be disassembled and neatly packed like omnidirectional ground plane antennae. These disadvantages are more pronounced with a VHF version. A UHF version is much more compact.

Polarization refers to the direction of the electric field of a transmitted wave. It is best to have the transmitter and the receiver antennae polarized, which means oriented in the same direction, both horizontal or both vertical. However, reflected waves often change their polarization slightly. This is why the receiver antennae in a diversity system are often angled approximately 45 degrees. The worst condition, the transmitter antenna and the receiver antennae at a 90 degree angle to each other, should be avoided.

To prevent the receivers from getting unacceptably high input levels, the receiving antenna must be installed at a minimum distance to the transmitters. The receiving antennae should be positioned at a minimum distance of 6 meters (20 feet) from the transmitters. This condition is of high importance for good operation of large multichannel systems.

Splitter systems



Click here for Fig. 15

Ideally, each diversity receiver should have its own set of antennae tuned to the frequency that it operates on. However, this is often cumbersome and unnecessary. One can still obtain optimum performance by operating several receivers from one set of antennae within the same frequency range. To accomplish this, a splitter system needs to be used. However, signal loss between the antennae and the receivers needs to he considered.

The two major sources of signal attenuation are line loss and splitter loss. As a signal travels down a cable, some of its energy dissipates. The amount of the signal loss is directly proportional to the conductivity and the length of the cable, as well as the carrier frequencies traveling through it. Higher frequencies in the UHF range are attenuated more than VHF frequencies. Therefore, if long antenna cables are needed, low-loss cable or an in-line amplifier, or both is recommended. If amplification is to be used, usually 10 dB will be sufficient. Higher amplification invites stray signals to be picked up and can aggravate intermodulation. The amplifier should be positioned near the antenna to obtain the best signal-to-noise ratio. Splitter loss should also be addressed. Each receiver that is added to the antenna system requires another split to be made. Every time a split is made, some signal is lost. Therefore, an active splitter should be considered, especially if no previous amplification was used. An active splitter as opposed to a passive one, is a powered device that incorporates amplification. Any amplifiers used must be of high quality, and should just compensate for the cable and splitter losses.

For additional security from interference, selective filters should be used in the splitter system. If an RF bandwidth of 40 MHz is available for a twenty-four channel system, the bandwidth can be divided into four subgroups of six channels. The subgroups can be separated from each other by highly selective Rf filters, The subgroups then become nearly independent of each other. In this way, any non-critical coordination violations between frequencies in different subgroups can be ignored.

Conclusion

Large multi-channel systems demand excellent planning, especially in the initial phase, and good technical support. Observing all the above mentioned items, perfect operation of a system can be guaranteed, even under difficult conditions.

Figure graphics by Hans Kuhn, Sennheiser electronic KG, Wedemark Germany.