SENNHEISER

# The Evolution of Wireless Innovation
# Part 1

## The transmission technology behind Evolution Wireless Digital microphone systems

## The Evolution of Wireless Innovation — A Four-part Whitepaper Series

The purpose of The Evolution of Wireless Innovation whitepaper series is to give you an inside look at how Sennheiser solved the technical challenges involving digital wireless technology and how Sennheiser developed the Evolution Wireless Digital product line to be the most user- friendly wireless microphone systems in the world. Along the way, you'll also become familiar with the basic terminology and underlying technical concepts of microphone technology and gain practical background knowledge that will benefit anyone interested in professional audio. This series is comprised of four whitepapers:

Part 1 — The transmission technology behind Evolution Wireless Digital. The first whitepaper introduces the main challenges around wireless microphone system design and explores the mitigation measures that were successfully integrated into Evolution Wireless Digital systems.

Part 2 — A comprehensive guide to digital audio performance parameters and Sennheiser's proven approach. The second whitepaper focuses on the topic of digital audio, providing an overview of relevant performance parameters and insights into the way Sennheiser approaches this topic with the Evolution Wireless Digital product family.

Part 3 — Exploring the versatility of Sennheiser's Evolution Wireless Digital microphone systems for various applications. The third whitepaper demonstrates the flexibility of the Evolution Wireless Digital technology platform in various applications. The paper also introduces the three family members in the Evolution Wireless Digital product line: EW-D, EW-DP and EW-DX.

Part 4 — A practical guide to maximizing wireless microphone performance and efficiency in live productions. The fourth whitepaper rounds the series off with a focus on larger productions, an overview of accessories, and practical tips and tricks. It also contains a myth- buster section that debunks some popular-but-false beliefs about wireless microphone systems.

## Introduction

The digitization of our everyday lives — at work, at home and everywhere in between — is advancing at an incredible pace. This digital transformation, along with the myriad challenges and opportunities it presents, has become a constant topic of discussion across nearly every industry.

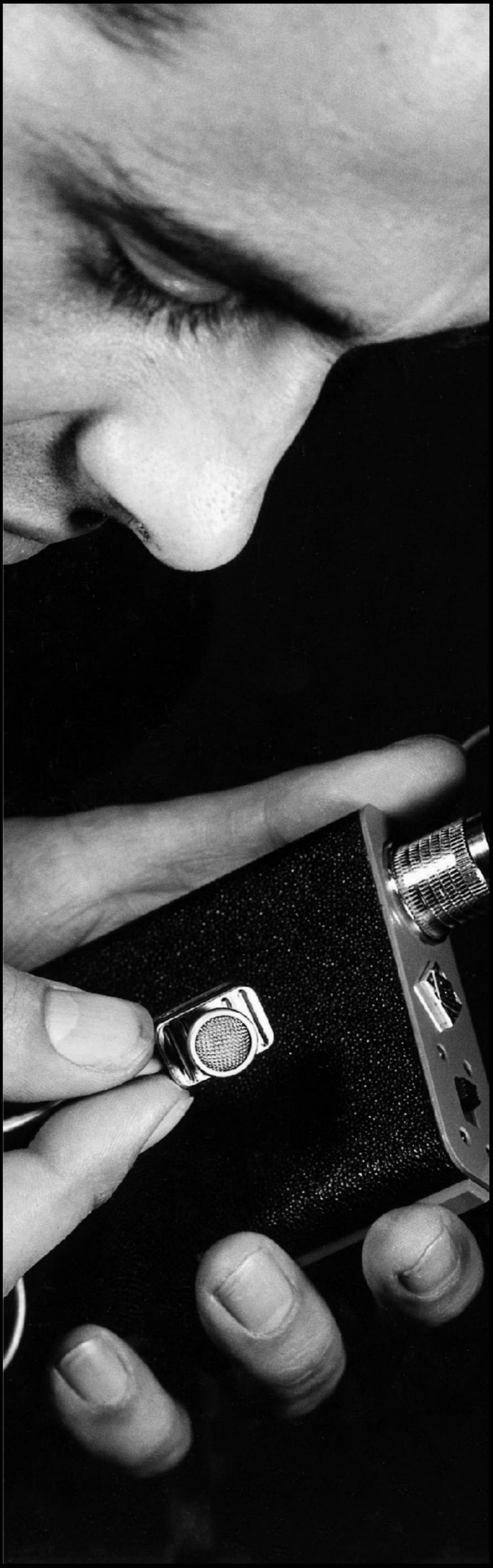
So why, you might ask, has Sennheiser decided to release a whitepaper series on their new digital wireless technology now? Because the professional audio and entertainment industry is and has always been a bit different, and understanding where the digital transformation in our industry came from, and what it means for the future, is a journey worth taking. And it requires looking back farther than you might expect.

65 Years of Wireless Excellence

The success story of wireless audio and Sennheiser dates back more than 65 years and originated in the broadcast sector in 1957. It was then when Sennheiser introduced the “Mikroport” system, a two-channel, analog wireless radio. And that incredible breakthrough paved the way for the first wireless moderation of a Saturday night show on German television.

With this great innovation came greatly increased expectation. Simply put, it changed everything.

The production requirements for professional audio equipment became increasingly demanding — more simultaneous channels, more range, and more flexibility. Back then, wireless technology was the realm of the elite. There were only a select few audio professionals capable of running such large, demanding productions. It was a time when only a select few technical experts were capable of running these large productions, and a time when engineers pushed the boundaries, strived for technical excellence, and developed products with a “because we can do it” attitude.



The Dawn of Digital Wireless

Fast forward to 2012. With the continuous technological advancements mainly driven by the information technology and mobile telecommunication industry, key digital components became more and more affordable, and the digitization trend increasingly found its way into the relevant elements of the audio production signal chain.

Digital equipment, something that many productions dreamt of but didn't have the budget for, became more accessible for a larger target group. Ecosystem integration became a frequent talking point among professional sound engineers while digital dividends were shrinking the available space in the spectrum globally. Besides excellence in audio, the term spectral efficiency started to gain relevance.

It was into this evolving technological landscape that Sennheiser — leveraging more than fifty years of wireless know-how — made a commitment to push the boundaries further and deliver a world-class digital wireless system. The result was the Sennheiser Digital 9000 system, an innovation that quickly became the wireless solution of choice for globally renowned artists.

But the digital transformation of wireless microphones and in-ear monitoring systems was about more than the pursuit for excellent audio. It was also about creating a more streamlined workflow and seamless integration with other signal chain elements. This pursuit resulted in Sennheiser's introduction of the Digital 6000 system in 2017, which now includes Link Density Mode for reliable operation in even the most crowded RF environments, along with dedicated application interfaces for integration with various world-leading mixing consoles.

## Digital Wireless for Everyone

But there was still more to be done. Consumer wireless audio technologies — such as Bluetooth and WiFi — have become ubiquitous. These technologies have enabled and benefited a new generation of mobile content creators and music lovers — and have also raised the expectations of audiences at live performances and concerts.

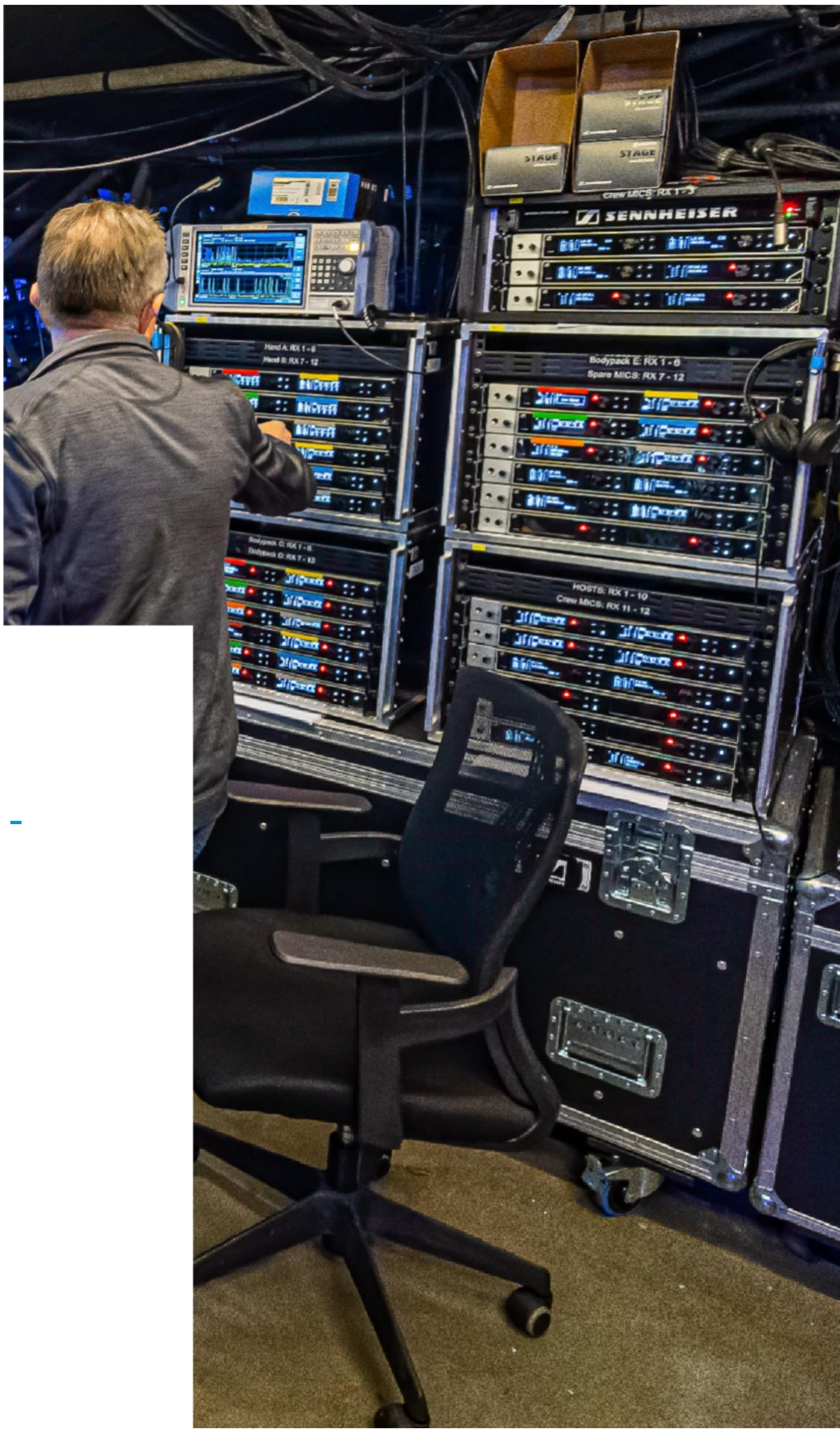
Audiences now expect the same level of production at relatively small performances and concerts that they've experienced at large, high-budget events. But these smaller productions cannot afford to pay top-tier professional sound engineers. Moreover, these productions are often run by one-man-show technicians. All these factors have given rise to increasing demand for digital wireless solutions that offers easier setup, configuration, and operation.

To meet this demand, Sennheiser leveraged key innovations of Digital 9000 and Digital 6000 systems to develop a successor to the analog evolution wireless systems, which served as the wireless workhorse for artists and performers all over the world for two decades. This new digital wireless solution would offer even greater performance for musicians, creators, and audio professionals, including a simplified setup process, proven and reliable UHF connection, and the superior sound quality of 24-bit digital audio. And it would make digital wireless technology accessible to more creators, performers, and audio professionals than ever before.

This was the vision that ultimately became Evolution Wireless Digital.

# The Evolution of Wireless Innovation

## Part 1




Credit: Ralph Larmann

### Wireless Transmission Technology - Challenges & Mitigation Measures

The main challenge in wireless microphone system design is to guarantee a highly reliable wireless audio link with reasonable range for mission-critical performance within the allocated crowded unlicensed spectrum.

As in every wireless system, the dependency of important performance parameters on each other requires compromises for the system. This is well illustrated for wireless microphone systems in Fig. 1. Here in particular the audio performance, operation time and latency are important to mention, as those maybe have a less critical role, for example, in cellular systems for mobile telephony. One can imagine that especially for live events or professional audio productions it is very critical if one of these is not matching customer requirements or degrades throughout operation. Imagine low performance on either of these during long or important live events like the Eurovision Song Contest or Superbowl. In particular the demanding latency and reliability requirements are core to system design. These performance parameter dependencies make life even harder, as system design itself has several challenging intrinsic trade-offs to be dealt with. On top of this, there is the challenging environment a wireless system must work in: the radio channel.

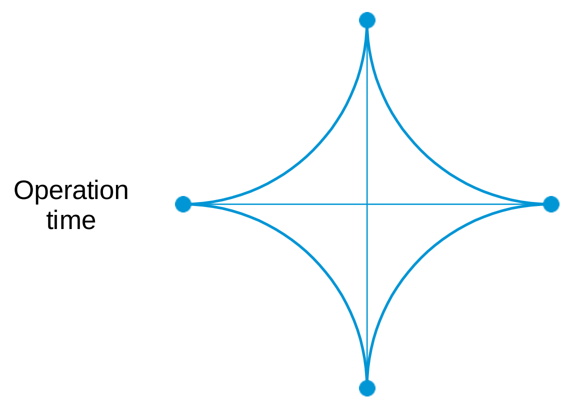



Fig. 1: Visualization of critical performance parameter dependencies

## Challenge - Fading of the Radio Channel

Wireless system design always starts with the radio channel. Knowing the influence of the channel on the transmission signal enables the designer to develop a more robust wireless link. And it also helps users to get the best possible performance from their equipment.

One of the most severe effects of the radio channel is known as “small-scale fading”. In this context, small-scale does not mean negligible; quite the contrary. It means channel fading effects due to small-scale movement (e.g. a few centimeters) of the transmitter or receiver. These channel fading effects can cause the received signal at the antenna to drop by 40 dB (1:10,000) to 50 dB (1:100,000)! It is easy to explain why:

A transmitter (e.g. a microphone) sends a sinusoidal radio frequency wave (the RF carrier) from its antenna. When no obstacles exist between the transmitter and receiver, some waves travel directly to the receiver antenna (line-of-sight component). Another part of the waves is reflected at obstacles like walls, the floor, or trusses (see Fig. 2). Since each wave travels an individual distance between the transmitter- and receiver antennas, the waves arrive at the receiver antenna with an individual delay. When all the waves superimpose at the receiver antenna, their amplitudes are simply summed up. In the worst case, the delay between two sine waves amounts to precisely 180° phase difference, so they completely cancel out each other. This case is shown in Fig. 3 below.

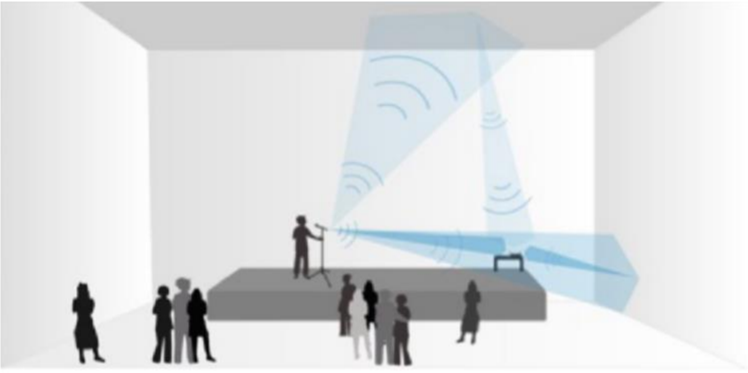


Fig. 2: Typical reflections of the transmit signal on its way to the receiver

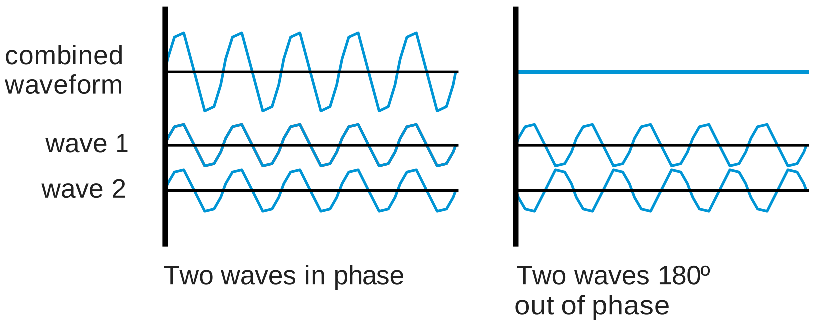



Fig. 3: Superposition of sine waves

Since the outcome of this superposition depends strongly on the delay between the individual waves, the amplitude (i.e. signal strength) on the receiver antenna changes with the position of the antennas. So if the transmitter or the receiver moves, the amplitude can change strongly. For example, in the UHF frequency range, the amplitude can change by more than 10 dB within a few milliseconds.

As can be guessed from Fig. 3, the resulting amplitude also depends on the superimposed waves’ wavelength (i.e. RF carrier frequency). A given delay causes a different phase change on another frequency. So a look at the received signal on an antenna over several MHz of the frequency band and over time gives quite a picture of hills and valleys, cf. Fig. 4.

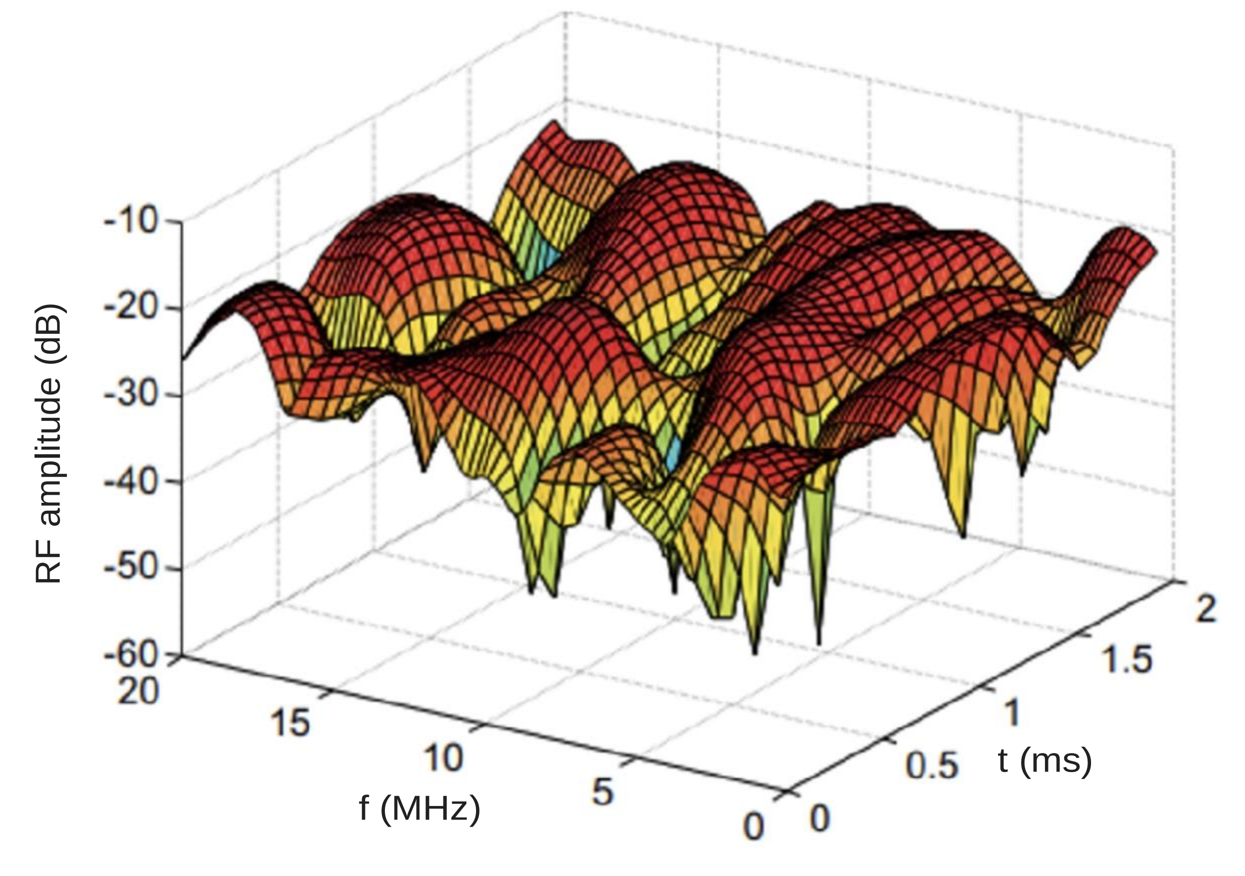



Fig. 4: Change of RF amplitude over time and frequency

The above picture shows that the described channel fading effects are frequency-selective. This aspect is also connected to the maximum delay between two waves: In a large sports arena or concert hall, the time delay between the line-of-sight wave and the arrival of the last reflected wave is much longer than in a small jazz club. If the delay is “long” (1 or 2 microseconds in a large hall), the complete cancellation of a wave happens only on very distinct frequencies. If the delay is “short” (50 - 100 nanoseconds), a small band of frequencies are cancelled out.

According to European regulations, narrowband wireless microphones can transmit signals inside a fixed bandwidth of 200 kHz. Therefore, if a signal of this bandwidth is transmitted inside the small club, signal cancellation at the receive antenna due to reflections will most likely suppress the complete 200 kHz bandwidth of the transmitted signal. If, on the other hand, the same signal is transmitted and reflected inside a large arena, only some part of the transmitted bandwidth will probably be cancelled out.

This effect influences the applicable countermeasures. Suppose the complete signal bandwidth is cancelled out at the antenna. In that case, it is still possible to keep up flawless reception by using a second receive antenna at a slightly separate location, also known as antenna diversity. This approach works with both analog FM (Frequency Modulation) and digitally modulated wireless systems.

If only parts of the transmitted bandwidth are cancelled out, antenna diversity can also help. Still, it is generally hard for the receiver to decide which of the two received antenna signals is better because the partly cancelled signal might still show a sound signal amplitude. This decision is incredibly challenging in analog FM systems. In the case of a digital wireless link, partial signal cancellation can be detected and mitigated by a channel equalizer. The channel equalizer removes the influence of a reflected wave (and thus signal cancellation) from the received signal, resulting in clear reception – even in highly reflective environments like large arenas. In general, large halls and arenas (in contrast to small venues) present such a challenging environment for wireless microphones. But this can be mastered with digital technology.

## Mitigation of Channel Impairments with Digital Transmission

Suppose the wireless microphone link experiences a substantial loss of signal strength due to channel fading or disturbances from noise, distortion or interference and nothing is done about it. This impairment manifests itself differently depending on whether an analog FM- or a digital wireless microphone is used. In both cases, the wireless link’s signal-to-noise ratio (SNR) is momentarily reduced. Traditional analog FM systems degrade gradually with disturbances and react to this with a corresponding reduction in audio SNR, which is perceived as a distinct short “hissing” sound in the audio. While this may be somehow acceptable in consumer wireless technologies, like Bluetooth or WiFi applications, it is not acceptable for mission-critical live applications or professional audio productions. Here, digital radios have an advantage as the audio SNR is constant, until the wireless SNR drops below a certain minimum threshold, SNRmin, resulting in a short audio dropout. Hence, a digital system is operating perfectly without any continuous signal degradation up to the point of a drop out. Avoiding these dropouts or disturbances in audio is the topmost priority of the wireless microphone designer. Fortunately, there are many more ways to prevent these disturbances in a digital wireless link than in an analog one.

Another very specific effect of wireless microphone systems somehow related to the wireless channel that needs to be explained is the so-called reverse intermodulation distortion (RIMD) of the transmitters (IM = intermodulation). Here two transmitters which are placed close together are coupling with each other over the antennas. This generates non-linear distortion signal components, usually at the transmitter output amplifier. Due to this “self-made” disturbance, manufacturers of analog FM systems traditionally had to calculate and publish tables (or a computer program) showing allowable combinations of “intermodulation- free” frequencies that can be used. The more channels simultaneously in use, the more frequencies that become unavailable because of generation of unwanted intermodulation signals. It is important to mention that transmitter intermodulation increases exponentially with an increasing number of wireless links (remark: not every IM-product automatically results in an unusable channel, usually the focus is on products arising from 3rd order non-linearities). So the challenge in analog FM systems is to balance the risk of audible audio artefacts versus the available number of channels that can be used in the continuously shrinking available spectrum. Hence, spectral efficiency is becoming more and more important.

Digital systems are not IM-free, as often wrongly stated. The same RIMD mechanism as described above, caused by the user own multi-channel system, is still there. But it has no immediate effect on the output signal as no continuous degradation will be heard at the output. This enhanced tolerance to disturbances in conjunction with digital mitigation techniques results in a very important but maybe not obvious advantage of digital systems: Being able to use channel frequencies adjacent to each other and deploy an equidistant channel grid without the requirement for IM-free channel tables or software.

After this introduction of some of the main challenges to a robust wireless transmission, the ways to mitigate or master these will now be focused on. To avoid audio dropouts arising from fading, noise or interference, various signal-processing techniques can be exploited, thanks to technological advancements of digital key components like FPGAs, DSPs and micro-processors as explained in the next paragraph.

## Mitigation Toolbox of Digital Signal Processing

Since there is no common standard that defines wireless technology for microphones, the designer is solely responsible for determining a transmission system that meets the customer's needs as well as possible. Therefore, the developer is free in the choice of tools and methods to achieve this goal. The toolbox contains the following (and many more) items to avoid audio dropouts due to the disturbances mentioned in the above sections:

- Antenna Diversity (usable in analog FM- and digital wireless)
- Channel Equalizer (usable in digital wireless only)
- Robust Modulation Scheme (usable in analog FM- and digital wireless)
- Forward Error Correction (usable in digital wireless only)
- Audio Error Concealment (usable in digital wireless only)

All these items are used in the Evolution Wireless Digital family, and some will be explained in more detail in the following chapters. At this point, a brief explanation of all items is given on how they counteract channel fading and interference in principle:

Antenna diversity directly counteracts channel fading by exploiting the fact that in a reflective environment the received amplitude at the antenna changes significantly with the transmitter antenna position. Thus, a receiver can use multiple (in general, two) antennas to increase the possibility of getting a strong signal at least on one antenna. Antenna diversity can be used in analog and digital wireless links. More details on this topic are given on page 12.

A channel equalizer is another means to mitigate fading effects. It estimates and processes the individual properties of the two superimposed waves (amplitude and delay) from the resulting received wave. Of course, this only works well when some substantial waves are received, and the signal is not cancelled out altogether. Due to particular reasons, an equalizer helps best in large halls and not so much in open fields or small rooms. To extract two individual waves from a single received one, providing the waves with some distinct features known in advance is helpful, which is more manageable in digital wireless microphone systems.

The modulation scheme of a wireless microphone defines how the audio signal is transmitted via the RF carrier. In the case of analog schemes like FM, the analog audio signal directly and continuously changes some property of the RF carrier, namely its frequency. In digital schemes, a sequence of binary digits is impressed on the RF carrier using mapping bits to discrete symbols, which change the RF carrier in predefined steps. More details on this topic are given on page 14.

Forward error correction mitigates disturbances in the transmission by inserting additional (redundant) bits into the audio data at the transmitter. These redundant bits are calculated by sophisticated algorithms from the original audio data so that the receiver can detect and correct errors that might have happened on the wireless link.

Digital audio error concealment is the last measure to improve the link robustness because it is only used when errors have already happened on the wireless link. The concealment process directly works on the received audio data and continuously calculates a running substitute audio signal based on previous audio data. If the receiver detects a low reception quality, the substitute audio is crossfaded into the original audio. Thus, the audio need not be muted when the reception is completely lost due to a strong fading loss. With Evolution Wireless Digital, the maximum concealment duration is 40 milliseconds, but the actual concealment duration is usually much shorter depending on the channel fading characteristic.

After this concise introduction to the microphone designer's toolbox, two tools are explained in more detail because they influence the performance of the wireless microphone directly. At the same time, they give the manufacturer's development engineer a lot of opportunities to tailor the system according to the customer's needs: These tools are known as antenna diversity and the modulation scheme.

## Mitigation by Antenna Diversity

In wireless microphone systems, antenna diversity at the receiver is a well-known tool to improve link reliability. It can be used in analog FM systems as well as in digital systems. In principle, antenna diversity can use an unlimited number of antennas. Still, most microphone systems use two antennas since the performance gain from additional antennas is neglectable.

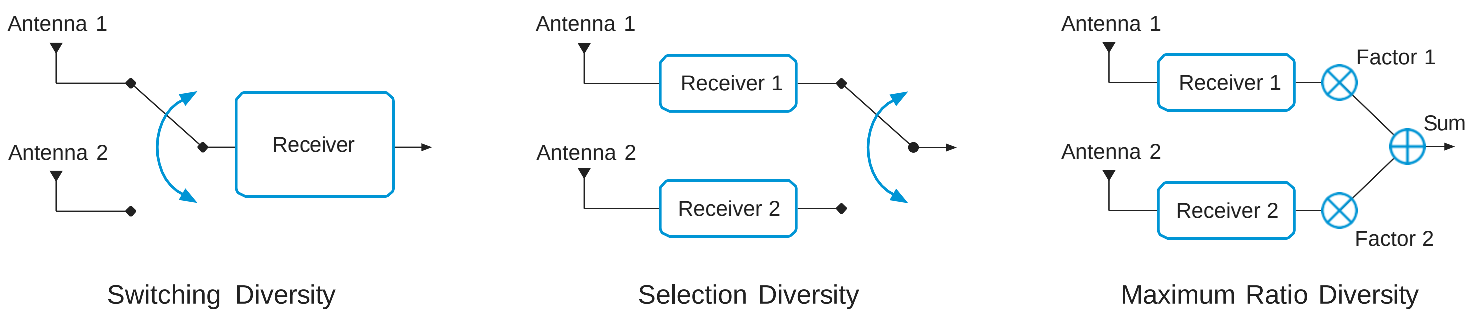



Fig. 5: The three main antenna diversity techniques

What can be confusing is that each manufacturer uses its own marketing name for their diversity technique. Therefore, it is hard for users to compare the diversity techniques between products and manufacturers. However, the three main diversity techniques are shown in Fig. 5. All actual implementations of antenna diversity are variations of these three:

Switching or Scanning Diversity
A single receiver scans multiple antennas or switches between two antennas. When a strong signal is found on a particular antenna, the receiver stays on until it drops below a preset threshold. Then it switches to the other antenna.

Selection Diversity
An individual receiver is attached to each antenna so that the signal strength is monitored on each antenna simultaneously. The system selects the best signal from all receiver paths at any given time.

Maximum Ratio Diversity

This scheme also employs one receiver per antenna. In this case, however, all signals from the receivers are summed up or combined. Thus, this scheme is also called Maximum Ratio Combining. The combining is done so that each signal is weighted by a factor proportional to the signal strength. If the signals are combined regardless of their strength, this scheme is called Equal Gain Combining. The diversity technique used in the Sennheiser Digital 6000 system is based on the latter.

The diversity scheme used in the Evolution Wireless Digital family is based on Switching Diversity and is called “Intelligent Switching Diversity”. The term “intelligent” refers to the fact that, in principle, it sounds easy to stay on an antenna until the signal becomes weak and switch to the alternative antenna. Still, it needs some intelligence to assess the signal quality and make a switching decision that improves the link’s reliability.

In Evolution Wireless Digital this is done as illustrated in Fig. 6: The receiver constantly tracks multiple channel parameters at the current antenna (e.g. amplitude change, modulation quality) and does a prediction of the channel quality. In the example picture, the receiver tracks antenna 2 (red). The receiver stays on the current antenna if the quality prediction is good. If the quality prediction degrades, the antenna is switched.

In contrast to analog FM systems, in Evolution Wireless Digital, the antenna switching takes place in predefined gaps between the audio data (see Fig. 6), and thus the actual switching is inaudible. These gaps are placed at regular intervals inside the data stream, allowing rapid adaption to the changing channel quality. Should the channel quality on both antennas be low, digital error concealment keeps up the audio output until the channel quality improves again.

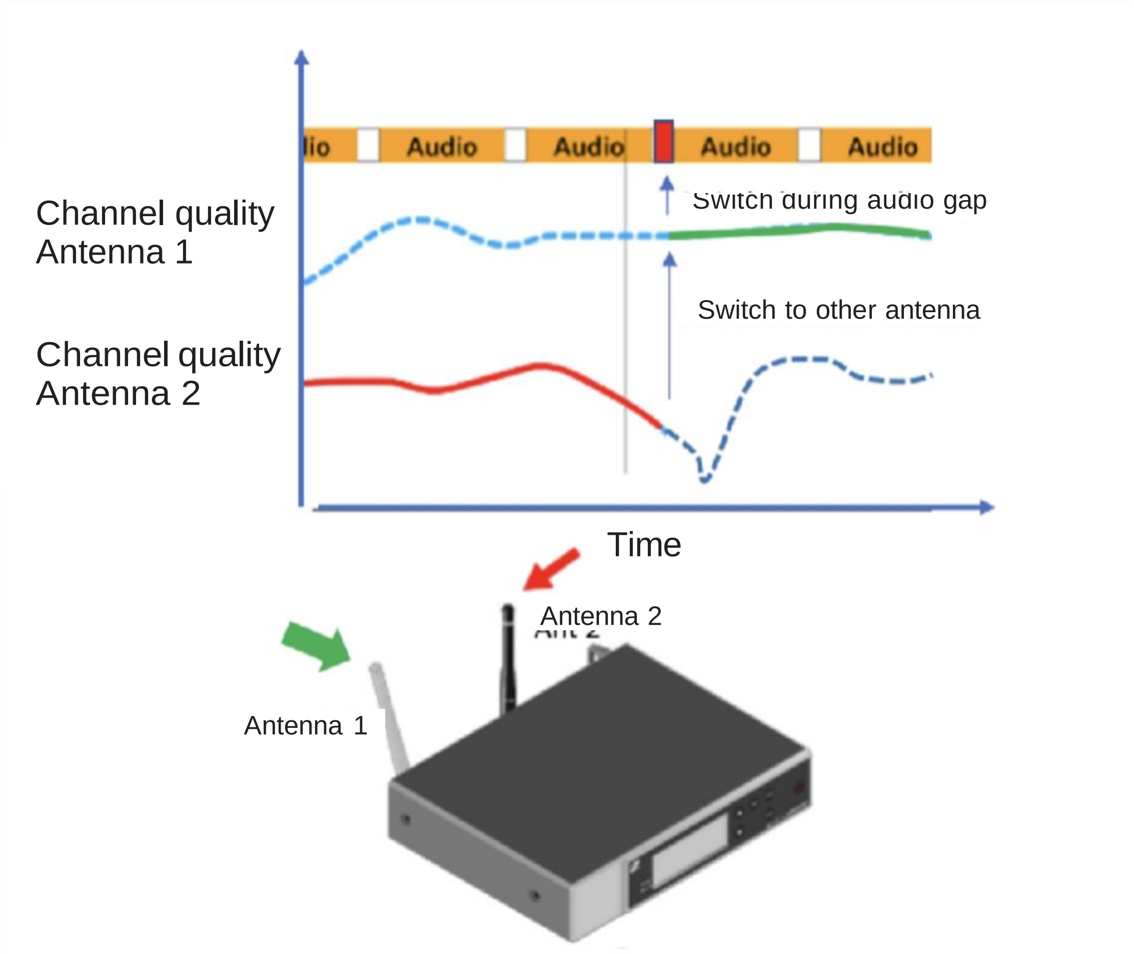



Fig. 6: Example antenna switching sequence used in the Evolution Wireless Digital family

Watch the video

## Mitigation by Applying Robust Modulation Schemes

Many ways exist to modulate an audio signal onto a radio frequency (RF) carrier and transmit it over the air. Before the advent of digital technology, the most robust way to do that was using analog frequency modulation (FM). What is the principle of FM, and why is it so robust against noise and channel fading effects? This is explained in the following chapter. Also, the principles and benefits of digital modulation and its application in the Evolution Wireless Digital line are covered.

### 1) Analog Frequency Modulation

Analog frequency modulation can be explained by looking at Fig. 7. An analog audio signal (a sine tone, blue) modulates the RF carrier (red) by changing the RF frequency of the carrier proportional to the audio amplitude. So, the transmit frequency is continuously changed (modulated) by the “rhythm” of the audio signal. The receiver can reconstruct the audio by observing the momentary frequency, i.e. the positions of zero crossings of the RF signal.

This principle is what makes FM so robust against noise and other disturbances. Because as Fig. 8 shows, added noise on an FM-modulated RF signal does not much disturb the positions of zero crossings (left). Only much stronger noise (right) will change that situation, leading to a graceful degradation of received audio quality on a noisy FM link.

But despite its robustness and simplicity, FM shares a disadvantage of all analog modulation schemes: All disturbances from the radio channel — although slight — will be incorporated into the received audio and can never be removed again (see Fig. 8). This effect can be avoided using digital modulation, as explained in the following.

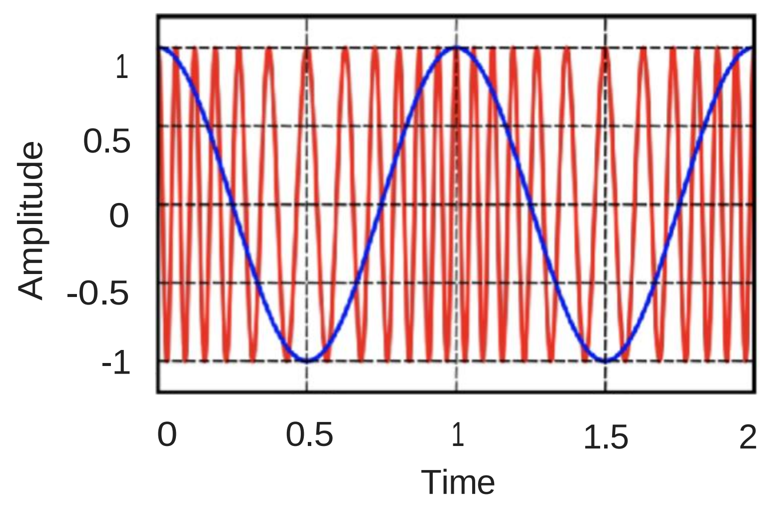



Fig. 7: Frequency modulation (red) using a source analog sine signal (blue)

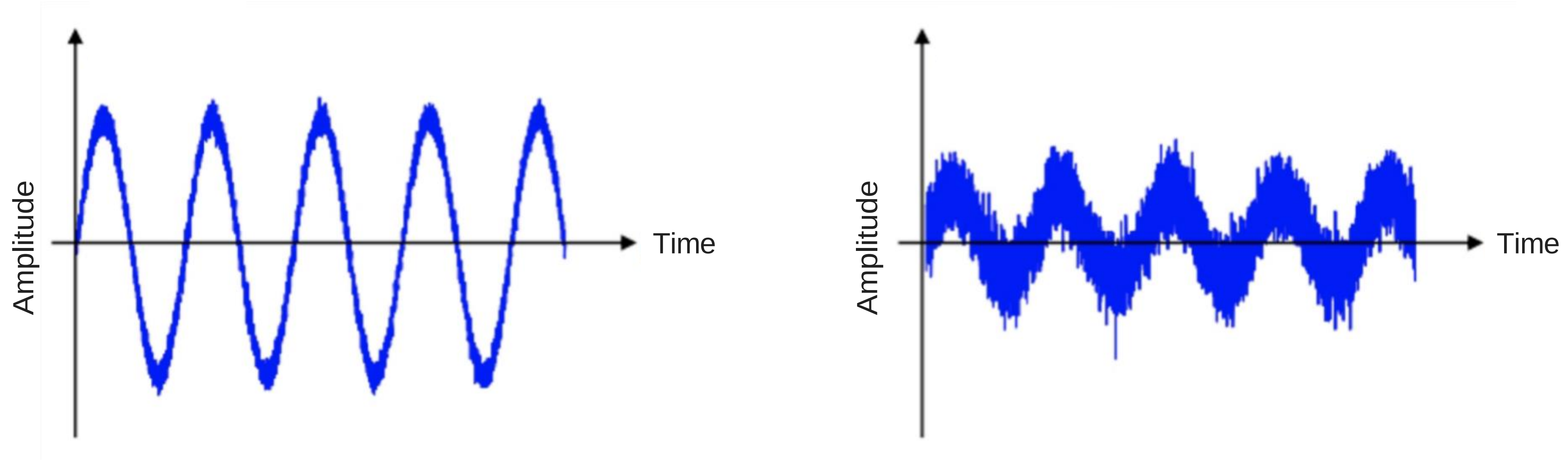



Fig. 8: Noisy frequency modulated signals: moderate (left) and high (right) noise level

## 2) Digital Modulation

In digital modulation, the audio signal is no longer represented as a continuous analog signal but by discrete “ones” and “zeros”, known as digital bits. Like the analog audio signal, these bits can also be used to modulate the RF carrier. To get an idea of how digital modulation works, a simple example is given in Fig. 9: Just change the amplitude of the RF carrier according to the bits that shall be transmitted. For example, to send a “zero”, the amplitude of the carrier would be set low, and for a “one”, the amplitude would be set high.

This example shows a significant advantage of digital modulation: the so-called threshold effect: Since the bits are represented by discrete signal levels (also known as symbols) on the modulated RF carrier, any disturbance on that carrier has no effect at all as long as the receiver can discern these discrete levels. The receiver compares the received signal with its known set of symbols and chooses the symbol with the closest resemblance. With digital modulation, error-free radio transmission becomes possible.

The obvious disadvantage of this simple example scheme is that only a single bit is transmitted each time the RF signal is changed. Therefore the data rate that can be transmitted via the given 200 kHz RF bandwidth is quite limited in this first example. A higher data rate would be beneficial to improve the quality of the transmitted audio data.

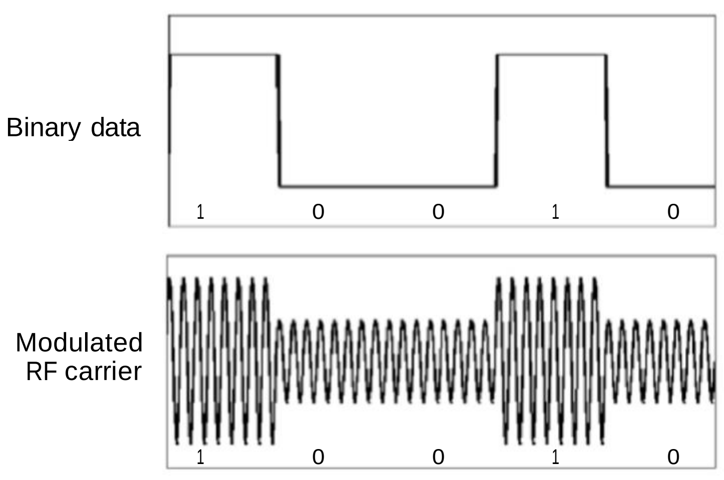



Fig. 9: Operating principle of digital modulation

One way to increase the transmitted data rate is to map multiple bits onto a single symbol as depicted in Fig. 10. Here, each symbol is defined by a specific amplitude and phase value (red dot, left picture). Four symbols (blue dots) are defined in the example, so it is possible to transmit two bits per symbol. In the Evolution Wireless Digital platform, the same principle of modulation — called QPSK — with four different symbols is applied. The acronym QPSK stands for Quarternary Phase Shift Keying, meaning that only the carrier phase is changed for every symbol. Fig. 10 shows this principle, where each blue point has the same amplitude, and the phase is rotated in 90-degree steps. The term quarternary means that four different symbols exist.

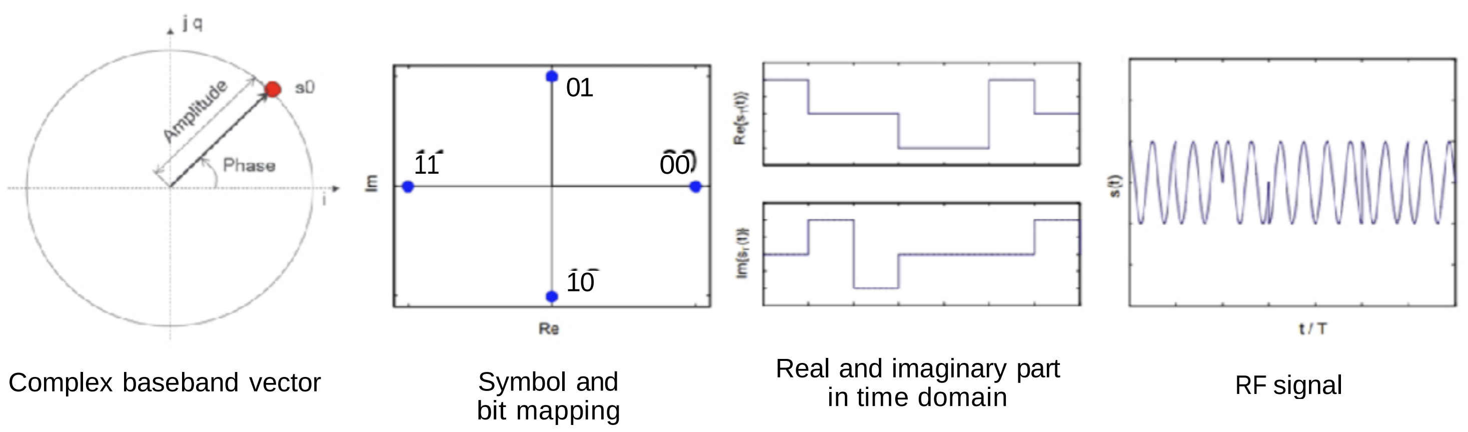



Fig. 10: Example of digital modulation with 4 symbols: QPSK

In principle, increasing the number of bits per symbol is possible and thus increasing the data rate. This can be done by defining more symbols: e.g. 16 symbols = 4 bits per symbol. In such a way, many more bits are transmitted with every symbol. However, the receiver must discern more different symbols to get the correct bits, which would compromise robustness. This principle can be seen in the example in Fig. 11, where two modulation schemes are shown. The left one uses four symbols like QPSK, and the right one uses 16 symbols (aka. 16-QAM). Both signals are transmitted using the same average power, and both are disturbed by roughly the same amount of noise at the receiver. So, the clear red dots are sent, and the receiver will observe the cloudy blue dots. It becomes evident from the two pictures in Fig. 11 that the receiver will make fewer mistakes in deciding what symbols were actually sent in the case of the QPSK signal. Therefore, a QPSK scheme was chosen deliberately for the Evolution Wireless Digital family to provide the customer with the highest possible link robustness.

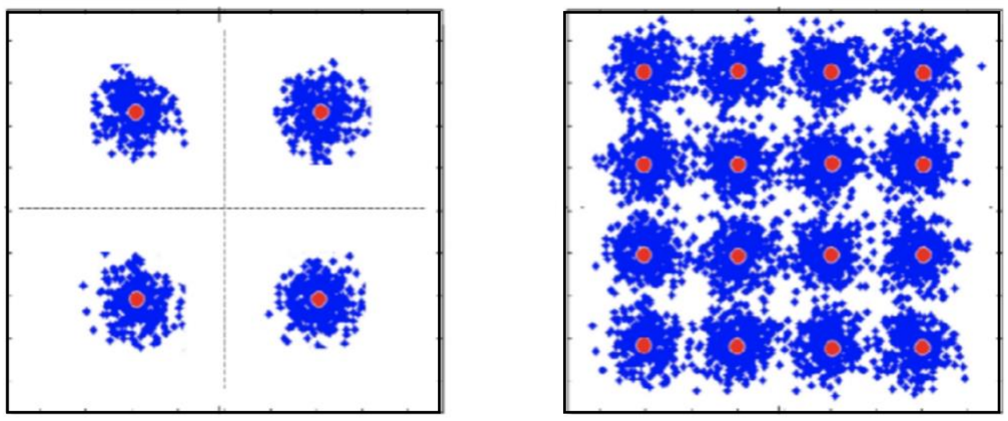


Fig. 11: Noise influence on QPSK and 16-QAM

## Mitigation Through Holistic Hardware Design

As was already covered in the previous sections, standards of unlicensed frequency bands do not guarantee high performance or quality service for users of proprietary systems that operate within one of those bands. This fact implies of course a lack of strict target values that must be achieved for user satisfaction. The multitude of potential services, use cases, and the resulting unlimited interaction of potential disturbances thereof in conjunction with other “out-of-band” systems rather requires a high robustness against a wide range of interferers. It is up to the manufacturers to take care of the requirements and use cases of their customers.

The big challenge in designing transmitter and receiver hardware of wireless microphones is to minimize the generation of and susceptibility to noise and distortion effects as well as interferers. Furthermore, ease of use is expected, most user expectations have changed where systems should be more turnkey without requiring specialized RF expertise as in the past. The magic ingredient in designing a robust and reliable wireless microphone system is thoroughly balanced RF link budgeting with regard to the use cases and environment the systems are operated in, which requires minimum or ideally no intervention by the user.

This was the guiding principle for technical decisions in designing the Evolution Wireless Digital system platform. The platform concept for the hardware architectures achieves high robustness by means of optimized individual building blocks as well as enough flexibility to cover several different products of a large portfolio with several family members. Furthermore, power consumption and price sensitivity have been an overarching requirement. Whereas the power aspect was more important for the portable, battery-operated devices, the price was important for all devices. Here, we were aiming for a product family that is accessible to a larger user group looking for professional-grade wireless equipment. With this in mind, the technical design decisions taken for the hardware of the Evolution Wireless Digital transmitter and receiver are explained in the following sections.

## Transmitter (TX)

The basic job of a wireless transmitter is to adopt a source signal, which carries dedicated information, to the characteristics, limitations and impairments of the wireless communication channel, within the so-called digital baseband. Independent of being analog or digital in nature, the transmitter applies a modulation that changes the characteristic (e.g. amplitude, phase, frequency or even more complex combinations of these) of the carrier. Additionally, the modulated signal is translated by frequency conversion from baseband (BB) to the RF channel frequency. Finally, the required output power level needs to be provided by amplification of the signal, to be able to transmit the signal over the targeted distance.

The available transmit power and the spectral purity with regard to unwanted emissions are important transmitter performance parameters of wireless microphone systems operating in crowded and bandwidth-limited unlicensed UHF spectrum, competing especially with TV broadcasting. Additionally, as the microphones are mobile by nature, efficient powering solutions are mandatory for reasonable runtime of the battery-operated devices.

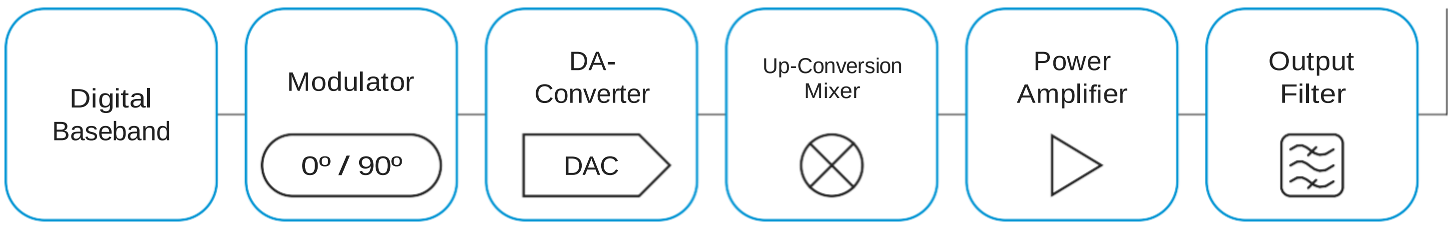



Fig. 12: Generic block diagram of a transmitter (TX)

In the design of Evolution Wireless Digital systems, the transmission power was intentionally limited to 10 dBm. The goal was to reduce the overall power consumption and to operate amplifier stages in the linear region backed-off from compression for minimal distortion. This is not only the first step to fulfill spectral mask and emission requirements from the regulatory standards, but also reduces interference in adjacent channels so as to allow more channels to be spaced across the band. More importantly, the above-mentioned transmitter intermodulation is significantly reduced when reducing the transmit power of involved transmitters. Furthermore, 10 dBm of transmit power is high enough to set up a reliable wireless link over 100 m when simultaneously applying proper design and optimization of the corresponding receiver sub-system.

Receiver (RX)

Regarding the basic functionality in general, the wireless receiver is the counterpart of the transmitter within the wireless system and has to fulfill the task of detecting weak wanted signals at the antenna in presence of noise and unwanted interfering signals. The downstream signal chain operates inverse to the transmitter: The detected signal is immediately filtered and amplified by the low-noise amplifier (LNA). The major focus here is to avoid adding noise or attenuating the wanted signal to not degrade the SNR. Furthermore, the signal is down-converted to intermediate frequency or baseband by a mixer, maybe additionally filtered and amplified and finally demodulated, Digital-to-Analog converted and processed by the baseband to get the original physical representation. As for the transmitters, the antenna is an integral part of the RX sub-system as well and can boost or significantly degrade the overall performance.

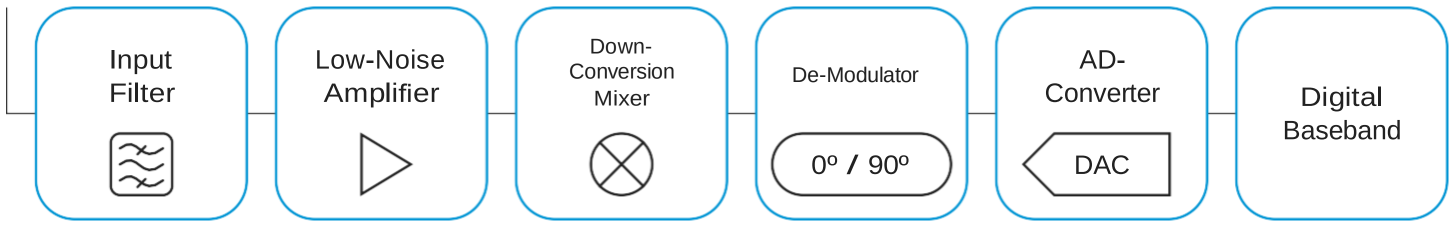



Fig. 13: Generic block diagram of a receiver (RX)

In general, as a receiver has neither direct control of its receiving signal quality at the antenna nor the noise level or frequency and power level of interferers, it must be designed for a variety of different challenging user scenarios. One of the main enemies we must tackle is the channel fading due to frequency selective small-scale effects outlined in the previous chapter. In worst-case a signal drop of about 40-50 dB should be expected and needs to be handled by the system. This requires enough of so-called fading margin, while handling all other degradation mechanisms in parallel. The fading margin can be considered as some kind of guard band between the transmit power at the receive antenna, only attenuated by free-space path-loss, and the thermal noise within the channel bandwidth that “protects” the wireless link from dropping out. Of course, systematic receiver parameters in terms of noise-figure (NF) and required minimum SNR for targeted bit-error-rate (BER) must be included. The degradation due to interferers like the image-frequency, intermodulation distortion, reciprocal mixing of LO phase noise, blocking or so-called spurious response of the mixer are desensitization effects. Whereas fading is significantly reducing the transmit power of the signal, desensitization is degrading the sensitivity of the receiver and tackling the other end of the transmission link. This again visualizes the importance of overall system design and optimization, as it is not a single parameter that is the key for the targeted performance.

For Evolution Wireless Digital a classical heterodyne architecture has been chosen to get the flexibility in handling fading notches and interferers properly and balancing the different performance parameters to achieve excellent selectivity and robustness of the RX sub-system. To further improve robustness against fading notches, intelligent switching diversity is applied as outlined in the previous section.

## RF Frontend

The RF Frontend is a classical and straightforward approach comprised of bandpass filter and LNA followed by another bandpass filter, here called interstage filter. The overall bandpass functionality is split over the two filters to achieve required image rejection and blocking performance. The selected low-power LNA provides gain and suitable low noise to minimize its impact on subsequent stages.

## Down-Conversion Mixer

For down-conversion an active mixer offering configurable gain has been chosen. Together with a preceding switchable attenuator and the subsequent variable gain amplifiers (VGA) of the demodulator module, it teams up as part of the automatic gain control loop (AGC) for efficient signal-power handling, steered by the signal processing algorithms inside an FPGA.

## Voltage-Controlled Oscillator (VCO)

Although being not the first block in the receive chain, an integral part in both RX and TX is the VCO or LO. To limit implementation complexity in terms of circuit design and more easily enable product variants, a shared low-power VCO is used. This VCO, applicable from 470 MHz up to 1.8 GHz, provides the critical switching bandwidth and phase-noise performance needed.

In TX, all the signals as well as the boundary conditions the VCO interacts with and within should be well known. Focusing exclusively on phase noise, the VCO contributes significantly to spurious emission (out-of-band and far-off noise) and spectral regrowth. Both are important to meet the requirements according to regulatory standards. Beside fulfilling the spectral mask requirement, the latter is also important in terms of power being spread into the neighboring channel, so-called adjacent-channel power. It is interpreted as noise or interference by a receiver operating in a neighboring channel and hence degrading the system performance of the corresponding link.

In RX, phase noise is even more critical, as the input of the receiver is theoretically open for every signal (frequency). So special care should be taken, as the phase noise, LO harmonics as well as other spurs directly contribute to system desensitization. Important mechanisms to mention are, for example, reciprocal mixing, adjacent-channel selectivity (ACS), blocking and spurious response, occurring when interacting with the mixer. Today, VCO modules are often used that already include complete phase-locked loops (PLL), reducing the implementation effort and offering a good phase-noise performance.

## Intermediate Frequency (IF) Stage

The IF stage is comprised of a highly selective surface-acoustic-wave (SAW) filter for channel selection followed by a fully integrated in-phase-quadrature (IQ) demodulator module. A precise calibration routine from the field programmable gate array (FPGA) during production test aligns the IF parameters such that the frequency is well centered and impairments in the transfer function, like linear distortion, are properly equalized.

The demodulator is a complete module with two variable-gain amplifiers (VGA) and integrated PLL as well as an active output low-pass filter to suppress aliasing for the subsequent analog-to-digital converter (ADC). Especially the flexibility in terms of amplification by the two VGAs is an important aspect for the implemented AGC algorithm.

FPGA

Beside already mentioned AGC algorithm, frequency calibration and equalization, the FPGA also provides the analog-to-digital conversion interface by means of its integrated 12-bit ADC. The limited performance compared to expensive external high-performance ADCs has been considered within the overall system design and was overcome by clever offset concepts and digital filtering techniques, leading to an overall cost and power-efficient solution.

## Conclusion

The digital transformation is well underway, affecting virtually every aspect of our lives, but its benefits are not automatic. Realizing the full potential of digital innovation for professional audio requires a thoughtful, holistic perspective that integrates decades of accumulated expertise with today's latest breakthroughs to truly deliver the future of wireless audio.

That's why, in this whitepaper, we've provided insights into the main challenges of wireless microphone system design and an overview of the mitigation measures that can be applied when designing digital wireless transmission technology.

And that's why, after more than 65 years of expertise in wireless technology, and more than a decade of expertise in delivering the world's most advanced digital wireless systems, Sennheiser has made digital wireless accessible to more artists and performers than ever with Evolution Wireless Digital microphone systems. With Evolution Wireless Digital, Sennheiser has created a wireless workhorse that allows users to set up in seconds and enjoy the highest input dynamic range of any wireless system currently on the market. Increased bandwidth and the lowest latency of any digital wireless system currently available make Evolution Wireless Digital systems a powerful tool for those who put quality and performance above all else.


Evolution Wireless Digital
Setup simplicity. Digital clarity.

Learn more at www.sennheiser.com/evolution-wireless-digital