At the limits of physical feasibility

An interview with Gerrit Buhe from Sennheiser

Gerrit Buhe, Development Electronics & Signal Processing

Mr Buhe, around ten years of research and development went into the Digital 9000 system. Looking back, what was the greatest challenge?

The greatest challenge was at the same time an ever-present one: developing a wireless microphone system with digital transmission and really outstanding audio characteristics meant going close to the limits of physical feasibility. And once we are at these physical limits, technical complexity positively explodes. We went into a huge amount of detail in many places and developed a lot of small solutions that enabled us to achieve higher data transfer rates for the audio data than is usually the case.

Our analogue wireless systems are used for events and shows that usually involve a large number of channels – and our digital wireless system had to be every bit as good as them – at least! That is why we have to operate in the UHF range, as this is the only frequency range where large multichannel installations are possible today. However, before a wireless system can be approved for UHF use in the first place, the wireless link must not exceed a certain channel bandwidth. That limits the transmittable data transfer rate. What is more, a good signal-to-noise ratio is absolutely essential for transmitting a high data transfer rate. This is physics, and you can't get around it. Our focus was therefore on ensuring the best possible data transfer rate that can reliably be transmitted in the UHF band, and, as a result, optimum audio quality and high dynamics. We achieved this firstly by adapting the most modern and frequency-efficient modulation methods to our requirements. Secondly, we developed a large number of sophisticated extras to minimise the proportion of non-audio data.

Do you think that you and your team have now developed the ideal digital wireless microphone?

The absolutely ideal digital wireless microphone doesn't exist – but I think we are very close to it! But seriously, there is no such thing as the ideal microphone for all applications because, due to the physical limitations that I mentioned before, a digital microphone must always make a sensible compromise, for example as regards the operating time, size and weight, or range. However, our system offers the customer two modes and therefore covers a large bandwidth of applications and scenarios. Never before has such high audio quality been transmitted wirelessly in the UHF band as with Digital 9000.

What are the two modes that the system offers?

The High-Definition mode and the Long-Range mode. The High-Definition mode offers uncompromising audio quality without compression of the audio signal – just as if a wired microphone is being used. This even opens up new areas of application for the wireless microphone. For example, only wired microphones were used for demanding jazz concerts because the noise-suppressing compander of an analogue wireless system was unacceptable for the sound of this type of music. Digital 9000 not only eliminates the need for a compander, it also transmits the audio signal without compression, in other words with the full amount of data. No other manufacturer has so far attempted to offer such a high-definition mode, we are truly unique.

The Long-Range mode is our 'workhorse' for all critical situations. It offers a high level of robustness for tough RF scenarios with many sources of interference. This mode uses our own Sennheiser Digital Audio Codec, which we are justifiably proud of, because it is also responsible for outstanding audio quality.

What is so special about this codec?

With this codec, the Long-Range mode is just as robust as conventional analogue FM transmission but offers better audio quality. Like many components of the Digital 9000 system, this codec also has its own history, which began in a completely normal way when we started looking at all of the codecs available on the market. We found that none of them fulfilled our high requirements with regard to latency, dynamics, the absence of artefacts, etc. This was followed by a long period of intensive cooperation with universities and experts in the field such as Prof. Zölzer of Hamburg's Helmut Schmidt University.

Unfortunately, we didn't succeed in making the decisive breakthrough at this point, but we had found important solutions to various aspects and had gained so much experience in audio data compression that we decided to continue working on a codec of our own. And our perseverance paid off: the audio quality of the SeDAC is very, very high, and it also ensures stable operation even under the influence of errors, which is extremely important for digital transmission as it is not as 'forgiving' as an analogue system. In order to also provide our digital system with a certain 'forgiveness', we fitted the codec with a special error concealment feature which combines a process of our own with a process developed by Prof. Zölzer. The error concealment feature ensures that the audio signal is reliably picked up even at the limits of the coverage area, enabling Digital 9000 to work better for a longer time than other systems.

In what way is an analogue system 'forgiving' and how does the error concealment feature work?

One example of the forgiving nature of analogue systems is how they behave when they encounter gaps in the field strength. Such a rapid drop in the receiving signal is caused by multi-path propagation, which is almost always present. With an analogue system, these gaps will result in a proportional decrease in the signal-to-noise ratio, which, for psychoacoustic reasons, usually will not have serious consequences. In a digital system, however, you will need to put much effort into intelligent diversity and error correction processes to avoid dropouts in the data stream or, even worse, in the audio signal.

For the error concealment feature, you could say that we have put human behaviour into algorithms. In the system, several fixed and one adaptive predictor operate at the same time and they each predict what the next sample will probably look like. The predictors are given points for each correct answer, so if audio data is missing due to interference of the signal, the predictor that was most successful in making predictions so far is allowed to repair the audio signal. These errors are much shorter than a millisecond. For longer errors in the audio signal, a further process examines whether a repair is worthwhile or whether the system shall gently mute. All these processes must happen without additional delay, which was one of the special challenges we had to meet.

The Digital 9000 system no longer requires intermodulation calculation. Why is that?

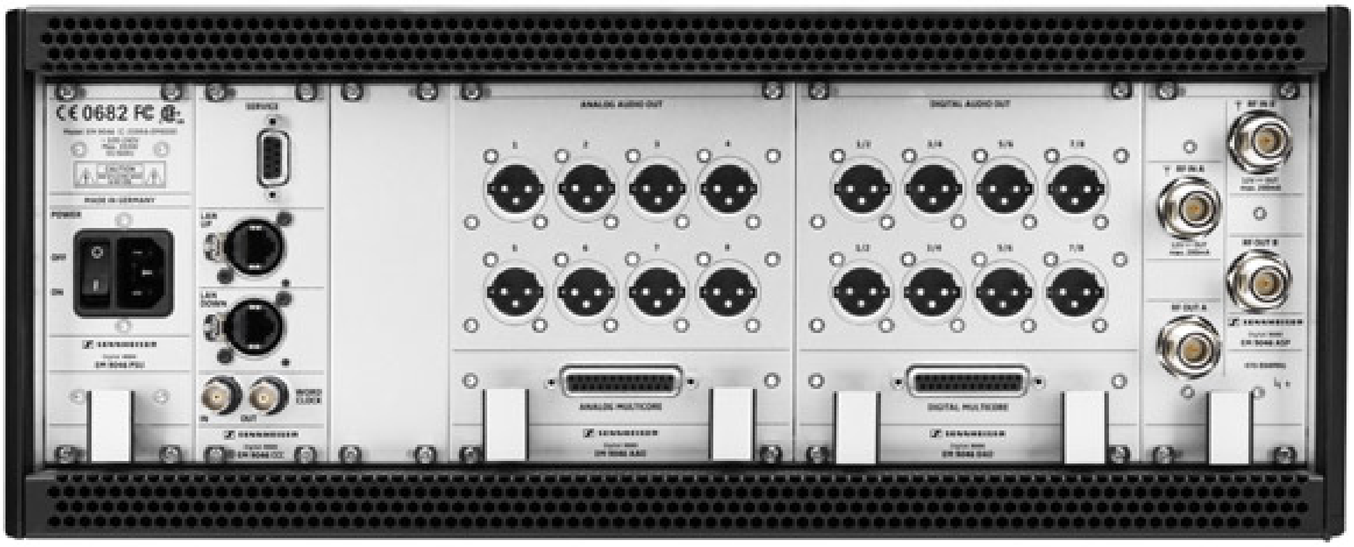
Digital 9000 is not only a digital milestone; it has also improved wireless transmission a lot. The system is so carefully designed with maximum linearity in all stages that, for example, the strong intermodulation interference that usually occurs between two close-by radio microphones is a thing of the past. Due to the digital modulation that Digital 9000 uses, the transmitter output stages especially need to work linearly as otherwise the system would not be able to differentiate between the many amplitude and phase statuses which transport the bits. This linearity reduces the efficiency and thus the operating time of the transmitter but has – besides the extremely low modulation distortion – the additional advantage of suppressing intermodulation. Moreover, the transmitters are fitted with isolators that allow the RF signal to pass only in the transmitting direction, whereas incoming RF signals are rendered 'harmless' via a sink.

Does digital make everything easier?

I would rather say that digital is one of those modern magic words that make things appear simple, which are in reality based on or require highly complex internal processes. One challenge, for example, is robust transmission. Most of the usual methods to achieve robust data transmission cannot be used for microphones, as they would further increase the latency of the system. Artists, who also hear themselves on the monitors as they perform, would not yet hear an echo effect but would have to deal with unacceptable sound colourations that occur with delays from ten milliseconds. These colourations are caused by phase cancellations at certain audio frequencies (comb filter effect) and are extremely disturbing.

How does the system ensure robust transmission and error protection if most of the usual methods cannot be used?

One of our patented solutions is what we call relevance-adapted RF channel coding. As we want to achieve optimum error protection but want to employ the smallest possible data transfer rate to do so – otherwise it would take up space that we would rather use for the audio data – the transferred bits are evaluated and divided into groups. Among them are so-called 'least significant bits', where an error will scarcely have any consequences. For these, low-level error protection is entirely sufficient. For the more highly rated, more significant bits, error protection increases linearly. The more interference energy a potential error can generate, the higher the error protection will be.



Does a digital transmission link behave differently than an analogue one?

The physics of RF propagation are of course identical but while we have decades of practical experience with analogue FM links there was no theoretical data for modelling the propagation paths that are relevant to us. For mobile communications, such data has existed for a long time. For example, I can access data for signal transmission on hilly terrain at a speed of 50 km, and many more profiles. For our applications, however, we first had to collect this data. So we looked at halls and venues throughout the world, took measurements, for example to see what kind of distortion was occurring, and considered how we might remedy the problems, and so on. We then modelled these 'propagation channels' in order to optimise the algorithms of our transmission processes. Algorithms which, for example, serve to equalise an audio signal or are used for the diversity technique.

Talking about diversity: the system's receiver operates with True-Bit Diversity. How does it differ from True Diversity?

In wireless transmission, particularly deep cancellations can occur as a result of multi-path propagation, in other words due to reflection from walls, structures or objects. For that reason, we use two antennas and two entire reception paths and completely demodulate both paths down to the bit level. Additionally, the receiver evaluates the reliability of each demodulated bit per path. Whereas a conventional True Diversity system only examines the strength of the received signal, Digital 9000 checks the quality of each individual bit and combines the bits of both reception paths and their probability evaluation. Error recognition and correction benefit from this, and more errors can be corrected. A lot of extra effort has been put into this diversity method. This attention to detail for every aspect of the transmission has created a system that truly advances digital wireless transmission.

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