Why Broadband?

By Dr Sebastian Georgi

Dr Sebastian Georgi is one of the system engineers for the WMAS system that is currently being developed by Sennheiser. For more than 10 years, he has been conducting research into wireless broadband techniques and how to specifically tailor them to professional audio applications. Georgi did his PhD thesis at Hamburg University of Technology in the field of OFDM. Georgi has a strong affiliation to music and plays the bassoon in a semi-professional orchestra in Hannover.

Introduction

Many modern wireless systems use broadband technology. This paper explains why. Professional wireless microphone systems are used as example, because with the introduction of the new Wireless Multichannel Audio Systems (WMAS) chapter in the ETSI standard EN 300 422-1, manufacturers of such systems can now offer the advantages of broadband technology. Today's wireless microphones are operated in the TV-UHF frequency range and typically use $B = 200\ \mathrm{kHz}$ of modulated bandwidth. Most of the applications demand a range of not more than 100 m.

Range

Is range the correct term in this application? Let's calculate the free space propagation range of a typical wireless microphone: The receiver shall have a noise figure $\mathrm{NF} = 10\ \mathrm{dB}$ and the transmission scheme demands a signal-to-noise ratio of $\mathrm{SNR} = 10\ \mathrm{dB}$. This results in a receiver sensitivity of

$$P_{\mathrm{sens}} = -174\,\frac{\mathrm{dBm}}{\mathrm{Hz}} + 10{\cdot}\mathrm{log10}(B) + \mathrm{NF} + \mathrm{SNR} = -101\ \mathrm{dBm}.$$

With a typical transmit power of $P_{\mathrm{tx}} = 10\ \mathrm{dBm}$, an overall link budget of $P_{\mathrm{tx}} - P_{\mathrm{sens}} = 111\ \mathrm{dB}$ is available. Free space path loss is calculated as follows:

$$\mathrm{FSPL[dB]}\ =\ 20{\cdot}\mathrm{log10}(d)\ +\ 20{\cdot}\mathrm{log10}(f_c)\ -\ 147.55.$$

At a carrier frequency of $f_{\mathrm{c}} = 500\mathrm{MHz}$ the range *d* is therefore:

$$d\ =\ 10^{\frac{111\ \mathrm{dB}\ -\ 20\cdot\mathrm{log10}(500\mathrm{e}6)\ +\ 147.55}{20}}\ =\ 16925\ \mathrm{m}$$

The range *d* equals almost 17 km in this example, even without any antenna directivity. This does not match the daily experience of wireless microphone operators. One must conclude here that free space range is not the limiting factor. So, what is the limiting factor then?

RF channel model

Only a few wireless systems (satellite communication, radio relay systems) experience wireless RF channel behaviour of pure line of sight. Most systems suffer from multipath propagation caused by reflections. At the receiver, radio waves emitted by the same source arrive from different directions, and therefore interfere with each other. Sometimes arriving waves have the same phase, which leads to constructive interference, sometimes arriving waves have opposite phase due to different path lengths and the interference is therefore destructive. Even in outdoor scenarios at least two radio propagation paths exist, the direct line of sight and the reflection over ground. In most outdoor environments further obstacles add to the number of propagation paths. Operators of wireless microphone systems doing walk tests experience dropouts caused by fading, which recover with more distance to the stationary antenna.

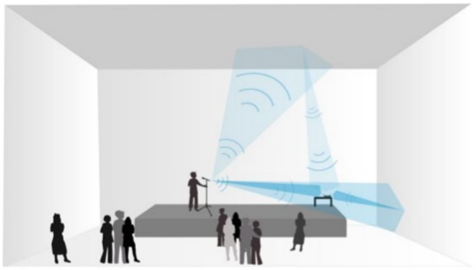

Fig. 1: Multipath propagation

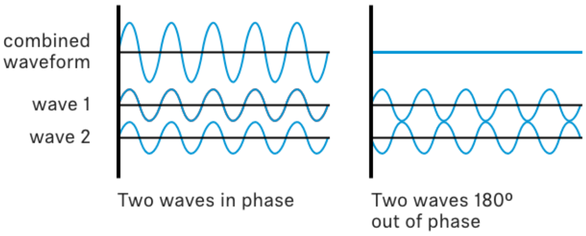

Fig. 2: Constructive (left) and destructive interference

In indoor scenarios the number of reflections is larger, making the RF channel behaviour more complex. Fading dropouts are regularly experienced, even close to stationary antennas. It can therefore be concluded that wireless microphone systems do not have an issue with range but with fast fading caused by multipath propagation. Is there a countermeasure available? Yes, there is. One solution is to use diversity reception: Operators of today's wireless microphones put their faith in the probabilistic hope that when one receiver antenna is facing destructive interference, the other receiver antenna provides sufficient signal-to-noise ratio (SNR). However, practical experience shows that this is not always the case.

The better solution is the use of broadband signals. Interference strongly depends on the frequency of the carrier wave used. Destructive interference happens when phases of arriving radio waves have opposite signs. When the radio signal consists of a sufficiently wide frequency range, constructive and destructive interference is spread over the bandwidth and the strength of the receive signal is never fully faded.

Narrowband vs. broadband

Is a bandwidth of $B = 200\ \mathrm{kHz}$ narrowband or broadband?

To distinguish these two types of wireless RF channel behaviour, signal bandwidth is only one parameter. The second parameter is the coherence bandwidth B_c of the wireless channel. It roughly describes in which bandwidth the RF channel's transfer function can be considered equal. Both parameters have a counterpart in the time domain: the modulated bandwidth is roughly reciprocal to the length of each modulated symbol T_s. That means basically, the faster information symbols are transmitted, the more bandwidth the signal occupies. The coherence bandwidth is reciprocal to the maximum delay spread τ_max of all paths the radio wave travels upon. That means the more the propagation paths differ in delay, the faster the channel's transfer function varies over frequency. In audio terms, τ_max is called reverberation time.

A narrowband RF channel is present when the modulated bandwidth is significantly smaller than the coherence bandwidth $B \ll B_\mathrm{c}$ or the symbol duration is significantly larger than the maximum delay spread $T_\mathrm{s} \gg \tau_\mathrm{max}$. In this case the RF channel can be characterized by one multiplicative factor only, which makes equalization quite simple on the receiver side. On the other hand, the entire signal suffers from fading and the previously mentioned dropouts occur.

A broadband RF channel is present when the modulated bandwidth is significantly larger than the coherence bandwidth $B \gg B_\mathrm{c}$ or the symbol duration is significantly smaller than the maximum delay spread $T_\mathrm{s} \ll \tau_\mathrm{max}$. In this case constructive and destructive interference happen simultaneously to the receive signal at different portions of the modulated spectrum – fading becomes frequency selective. This reduces the risk of dropouts dramatically. On the downside, more complex equalization and channel coding techniques need to be applied which increases system implementation complexity.

Orthogonal Frequency Division Multiplexing (OFDM) allows simple equalization even in broadband channels by using multiple carriers:

	Narrowband RF Channel	Broadband RF Channel	
		Single Carrier	Multi Carrier (OFDM)
Frequency domain	$B \ll B_\mathrm{c}$	$B \gg B_\mathrm{c}$	$B \gg B_\mathrm{c}$
Time domain	$T_\mathrm{s} \gg \tau_\mathrm{max}$	$T_\mathrm{s} \ll \tau_\mathrm{max}$	$T_\mathrm{s} \gg \tau_\mathrm{max}$
Equalizer	simple	complex	subcarrier-wise
Fading	entire signal	frequency selective	some subcarriers

To finally answer the question if a bandwidth of $B = 200\ \mathrm{kHz}$ is narrowband or broadband, the RF channel environment needs to be considered. Second-generation cellular communication system GSM uses $B = 200\ \mathrm{kHz}$ as well, but inside a cell radius of up to several kilometres. Here, the wireless RF channel can be considered broadband. In the case of GSM, 26 out of 142 bits inside one frame are already used as training sequences to estimate and equalize the wireless RF channel.

In the case of wireless microphones operating in $B = 200\ kHz$ with a typical distance of 100 m, the RF channel behaves mostly narrowband, especially in outdoor scenarios.

Measurements

The following pictures show real-time measurement data from an outdoor walk-test scenario. In each picture, the upper plot shows the RF receive power in colour representation (i.e., red is 50 dB attenuation) over time (x-axis) and frequency (y-axis). The lower plot shows the RF receive power over time (x-axis) for systems with different bandwidths from $B = 200\,\mathrm{kHz}$ to $B = 6\,\mathrm{MHz}$, which are normalized to have identical transmit power. The effect of frequency-selective fading can be clearly seen. Systems using $B = 200\,\mathrm{kHz}$ suffer from deep fading notches while $B = 6\,\mathrm{MHz}$ system's receive power is nearly steady.

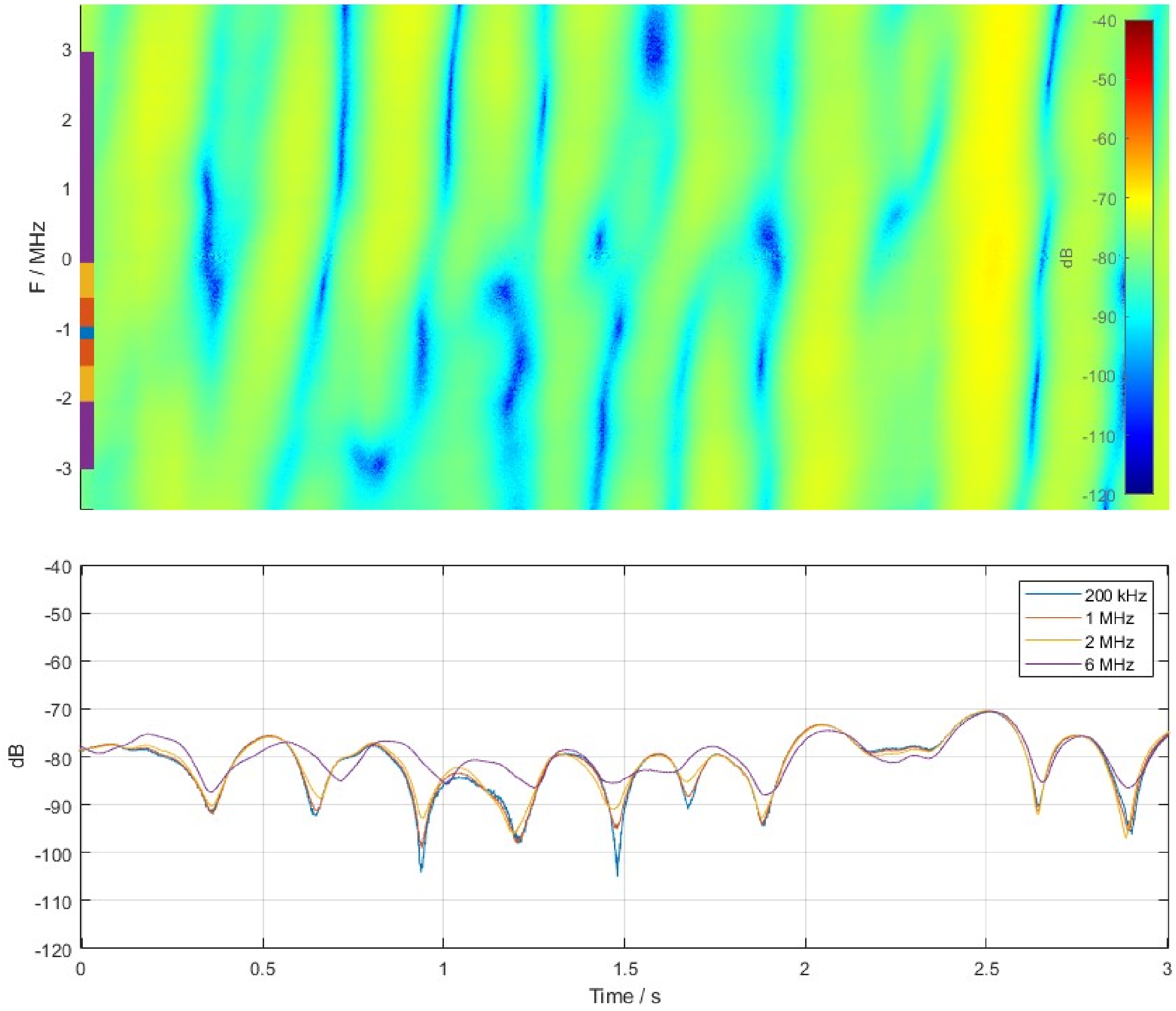

Fig. 3: Outdoor walk test at 482 MHz centre frequency

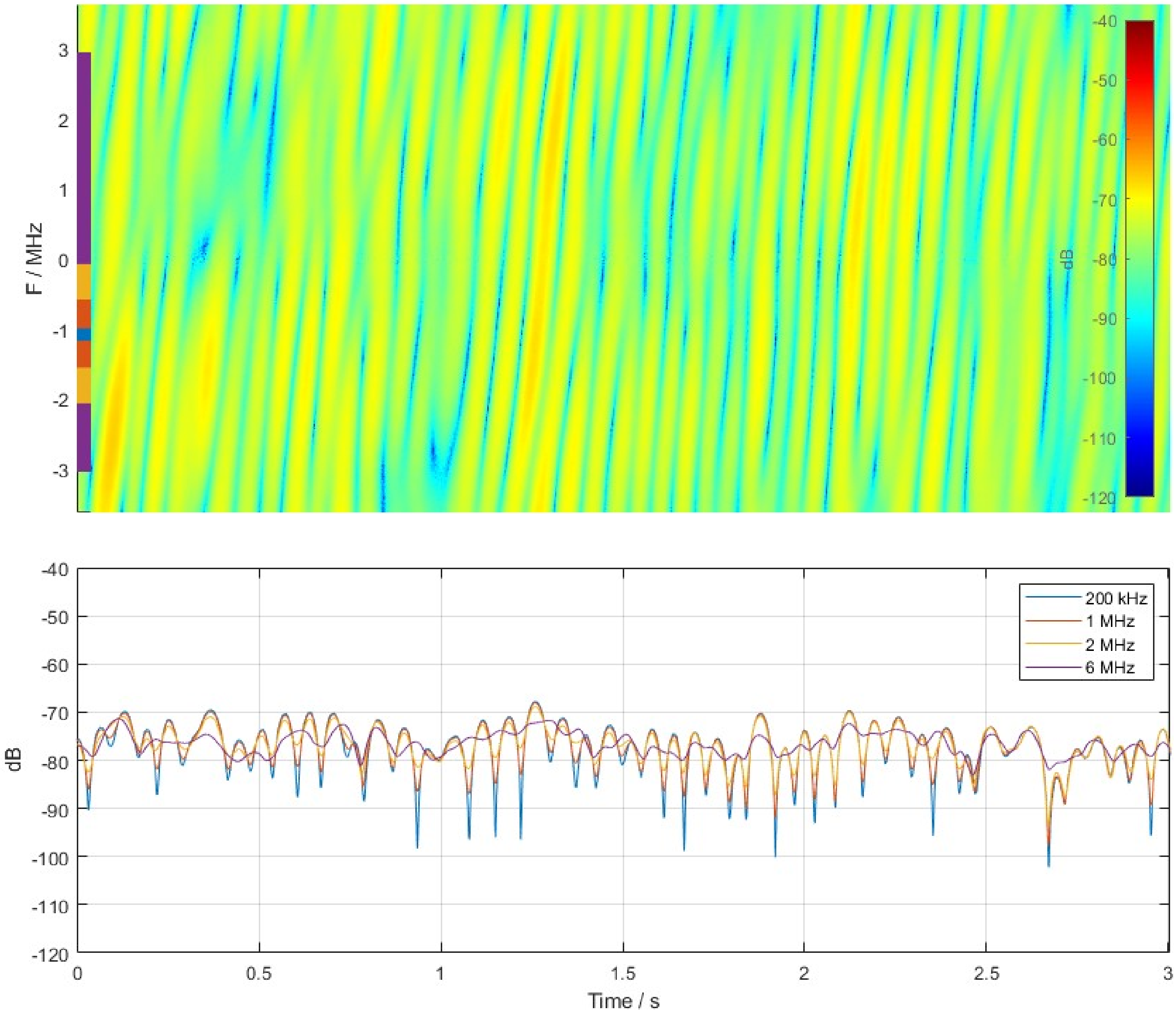

Fig. 4: Outdoor walk test at 1375 MHz centre frequency

Figure 3 shows measurement data at $f_c = 482\ \mathrm{MHz}$ centre frequency and Figure 4 shows a similar walk test but at $f_c = 1375\ \mathrm{MHz}$ centre frequency. The fading effect is comparable, only the time variance is increased due to roughly tripled doppler frequency caused by the same movement speeds.

Conclusion

Today, wireless microphone systems operate with a bandwidth of $B = 200\ \mathrm{kHz}$ employing RF channels, which need to be considered narrowband. It has been shown that narrowband systems do not have an issue with range but with fast fading caused by multipath propagation on most applications. Therefore, a large fading margin is applied to the link budget and receive diversity is used to reduce the probability of dropouts caused by fading. Implementation is based on single-carrier digital modulation schemes, keeping system complexity low.

RF channels such as entire TV channels of bandwidth $B = 6\ \mathrm{MHz}$ offer broadband properties in most scenarios. Dropouts can be avoided here by applying broadband transmission schemes such as OFDM. This eliminates the root cause for dropouts caused by fading. Although the free space distance of broadband channels is reduced due to higher thermal noise penalty, it is more than compensated for in real environments due to a much lower demand for fading margin.