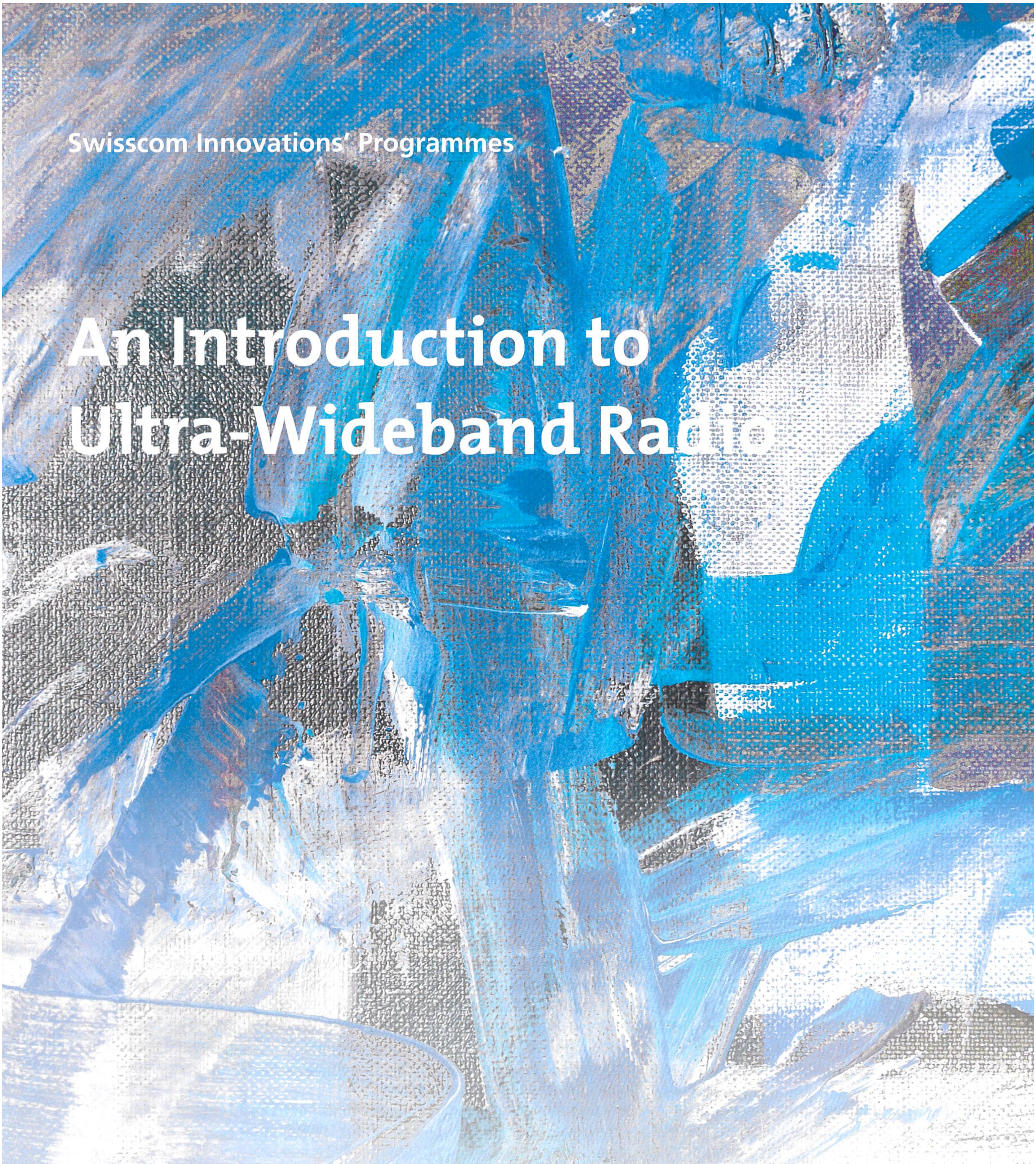
An introduction to ultra-wideband radio



Swisscom Innovations' Programmes

An Introduction to Ultra-Wideband Radio

Ultra-Wideband Radio (UWB) is a new approach to short-range data communications that uses a much larger bandwidth than conventional systems while using transmission powers that are as low as the spurious emissions from electrical appliances. Due to its large bandwidth, the expected data rates are much higher than any short-range communications solution available today. This article provides a short introduction to the basic principles of UWB and shows why UWB might well be a key networking technology of the future.

The programme "EMC and Environmental Business Impact" investigates the electromagnetic compatibility (EMC) aspects of emerging telecommunication technologies and the biological effects of electromagnetic radiation. Necessary actions and guidelines are elaborated allowing Swisscom to improve the quality of service and the acceptance of wireless telecommunications on a long-term basis and to minimise installation and troubleshooting costs.
With its Innovation Programmes, Swisscom Innovations follows the objective of recognising early on the impact of technological developments, finding new business opportunities, promoting technical synergies, and developing concrete innovation proposals. Further, the expertise built up enables active engineering support of business innovation projects.

Ultra-Wideband (UWB) Radio can loosely be defined as a wireless transmission scheme that uses a very large transmission bandwidth at very low power levels. This is achieved by transmitting very short, impulse-like low power

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pulses. Just over one hundred years ago, Marconi achieved the first over-the-horizon radio transmission by using a spark gap transmitter. In the years that followed, wireless communications developed towards analogue, narrowband systems and relatively recently towards digital systems. With the advent of UWB, we seem to have come full circle.
UWB is considered a high-potential new radio interface for very high-rate, short-range communications with potential applications in short-range networking such as ad hoc, home and office networking and WLAN/WPAN communications. Equally, it is envisaged to play a role in lower rate communications for applications such as sensor networks and control applications.

UWB devices will transmit with a power spectral density so small that the signal essentially disappears in the background noise. Due to its enormous bandwidth, it is expected that data rates of 200 Mbit/s are possible at a distance of 10m.

In this article, we will present a short introduction to UWB technology, emphasising how this technology is different from other short-range communication schemes. We begin with a definition of what UWB is and how it is different from other wideband and narrowband technologies, emphasising its low power operation. This is followed by a short description of the modulation and transceiver design of UWB devices to demonstrate the implementation advantages possible, in particular for handheld and mobile applications. The article concludes with a look at expected performances and a few potential applications.

A Definition of UWB

While the term Ultra-Wideband may not itself be very descriptive, it helps to separate UWB technology from the more traditional "narrowband" systems, as well as the more recent "wideband" technologies that are typically referred to when describing 3G cellular technology.
Narrowband signals are defined as signals whose bandwidth is much smaller than their carrier frequency. Wideband signals, such as in UMTS, are still narrowband by this definition but due to their bandwidth being a multiple of the information rate, they are termed "wideband". In the case of UWB, the bandwidth is of the same order of magnitude as the centre frequency and therefore wideband. Currently, a signal is considered UWB if it has a bandwidth of greater than 500 MHz or 25% of the centre frequency, based on the description by the Federal Communications Commission (FCC) of the United States [1, 2].
As mentioned above, the transmitted UWB signal is a stream of impulse-like pulses. Typically, the pulses are of sub-nanosecond duration, resulting in a bandwidth of up to several GHz. If compared, for example, to UMTS, which has a bandwidth of 5 MHz, it is obvious that UWB cannot be allocated a dedicated frequency band but instead needs to coexist with current systems, licensed and unlicensed. As the bandwidth of the signal is very large, the signal energy is spread over a large frequency range, making the signal noise-like. The idea is that UWB devices will transmit with a power spectral density so small that the signal will essentially vanish in the already present noise. Given the bandwidth requirements and the type of foreseen applications, UWB is clearly aimed at the unlicensed market.

Bandwidth, Transmission Power and Regulations

Currently, the only country with the regulatory framework in place to permit UWB operations is the USA [1,2]. While the regulatory process in Europe has started at ETSI and CEPT, it is generally expected that no European regulations will be in place before 2004. In order to put some numbers on bandwidth and transmission powers, we will therefore refer to the limits as imposed by the FCC. It may be worth mentioning that current trends for European regulations broadly follow the example set by the FCC and most likely the regulations will be very similar.
Returning to the issue at hand, namely the UWB transmission power spectral density, we find that the maximum is fixed at -41 dBm/MHz, corresponding to approximately 75 nW/MHz. This is similar to the emissions of current generation CPUs in Personal Computers, with the difference that the UWB emissions are actually desired and more wideband. While emissions at or near the level of UWB were previously allowed in the form of unintentional spurious emissions from electronic equipment, new rules were needed to govern intentional transmitters.
The main band for UWB transmissions is between 3.1 GHz and 10.6 GHz, a total of 7.5 GHz or 1500 times the bandwidth of a UMTS signal. Given the stringent power limits, the total power only adds up to around 550 μW if a UWB transmission were to use the entire band.

Modulation and Transceivers for UWB Signals

UWB is relatively new. There exist no functional, agreed-upon industrial standards yet. It appears that the IEEE 802.15.3a working group is at the moment the only UWB industrial standardisation effort [3]. As a consequence, any technological solution that fits into the framework given above is considered UWB. Hence, the transmitted pulses can be modulated and coded in many different ways. The information can be encoded in the pulse amplitude, phase, position or any combination of these [4, 5].

Normally, the signal has a very low duty cycle, i. e. the ratio of the duration of the pulse and the time between pulses is small. Typically, a single information bearing data symbol is encoded using a group of pulses, introducing a form of repetition coding. The group of pulses is normally created using some pseudo-random spacing between the pulses in the group. The purpose of this pseudo-random spacing is to avoid the spectral spikes that appear in the spectrum of constant rate (periodic) signals and to make the signal more noise-like. In this way, the adverse effects on other systems residing in the same spectrum are minimised.

A second distinguishing feature of UWB systems is their carrier-less operation. While conventional systems use a carrier to achieve baseband translation to the carrier frequency, UWB systems are baseband only. Indeed, the baseband signal is directly feeding the transmitter antenna. Since the required power is very small, it is not necessary to use a transmitter stage amplifier, as the signal from the pulse-form generator can produce sufficient output power. This architecture allows very cost and power-efficient, miniaturised implementations of the transmitter, avoiding the need for an amplifier. On the other hand, in order to use for example pulse position modulation or precise distance measurements for positioning, a very precise timer needs to be implemented, a key component of any UWB system [6, 7].

The UWB receiver is a normal matched-filter (Correlator, Integrator, Sample and Hold). This is, however, not necessarily trivial in practice as the received signal is very low power and the receiver needs to acquire an exact time base in order to decode the received signal. Since the noise may be of the same order of magnitude as the UWB signal, the latter risks being swamped by the noise, making synchronisation a challenge.

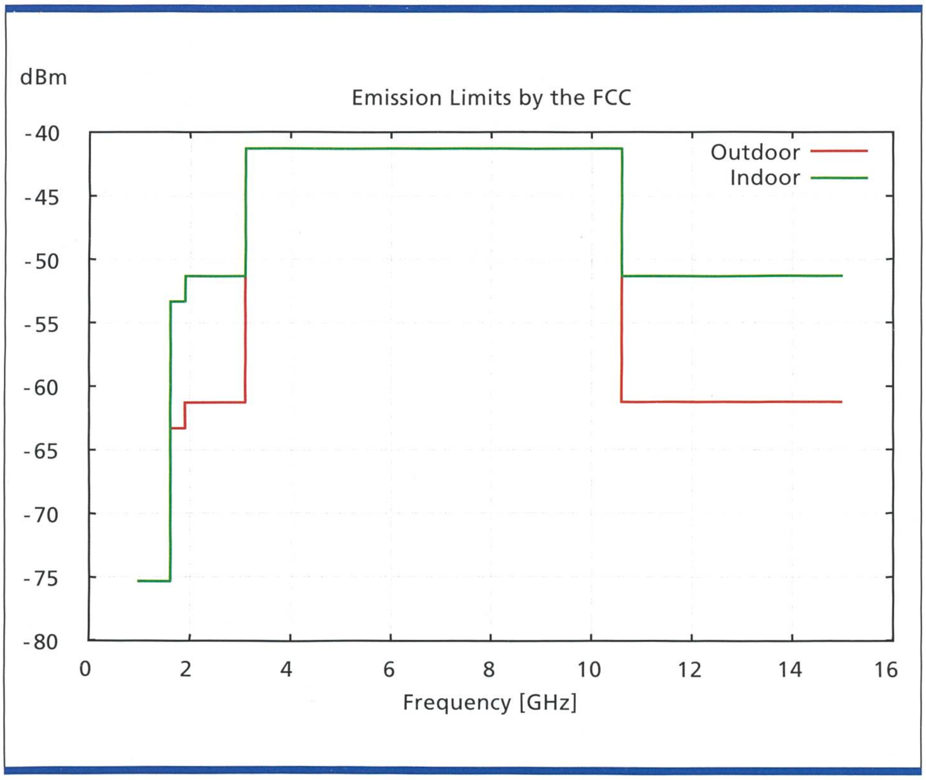

Fig. 1. Graphical representation of the emission limits for UWB communication applications. Note that the outdoor limits are lower than the indoor limits in order to protect incumbent radio services [2].

UWB Propagation and Multipath Fading Resistance

Given the UWB operating frequencies in the GHz range and the low power, UWB is most suited for short-distance communications. Although it is possible to trade effective throughput for greater transmission distance, the current regulations by the FCC are primarily aimed at indoor use and restrict outdoor use to peer-to-peer type applications that do not require any fixed infrastructure. The main aim of this measure is to protect current users of the spectrum and in particular services that are especially susceptible to interference, such as GPS.

UWB is very robust against multipath fading effects [8]. Multipath interference occurs when a strong reflected wave, for example off a wall, ceiling, vehicle etc., arrives partially or totally out of phase with the direct signal path. In the case where the direct path and the multipath component overlap, the resulting signal will be distorted or weakened. In UWB, the duty cycle is very low and the pulses are so short that the direct signal has finished before the reflected multipath copy arrives. A separation in the path length of some tens of centimetres suffices to avoid any overlap. Therefore, UWB systems are particularly suited to highly mobile, high-speed applications but also for applications in highly cluttered environments such as found in offices and homes.

Applications and Data Rates

The strong interest in UWB is mainly due to its potential data rates at short distances, which are a consequence of the extremely large bandwidth. It is expected that coming chip-sets will support data rates of up to 500 Mbit/s at very short range and more than 200 Mbit/s at around 10 m [9]. For the time being, all the major companies in the field use proprietary technical solutions and most likely an industrial standard will be needed before we will see widespread application of UWB devices. A further factor of success will certainly be price: Current goals are to be able to eventually produce UWB solutions for the price of a Bluetooth chip set or less, which, based on the reduced implementation complexity, may well be possible.

Potential applications are many and varied. For example, inhouse transmission of video and audio, from PC to printers or multimedia projectors, from a notebook computer to an Access Point, Sensor networks and Radio Tags. But also ad hoc networking may benefit from UWB by using its inherent positioning information for e.g. routing.

Conclusions

We have presented a brief introduction to the basic principles of UWB radio. Due to the enormous bandwidth used, the data rates that can be achieved are impressive. Since the signal power is very low, UWB systems should be able to coexist with existing communication systems in the same band. Due to the sub-nanosecond duration of UWB pulses and the low duty cycle, UWB signals are particularly resistant against multipath fading and therefore very suitable to high speed mobile applications or applications in dense cluttering environments. Hence, UWB is thought to be a key technology for future short-range networking applications.

Zusammenfassung

Ultra-Wideband (UWB) Radio ist eine neuartige Funktechnik, die sehr hohe Datenraten ermöglicht, indem impuls-ähnliche Signale mit einer sehr grossen Bandbreite verwendet werden. Dabei bleibt aber die Leistung gering, etwa in der Grössenordnung des Umgebungsrauschens. Dadurch kann UWB mit bereits existierenden Funktechnologien im selben Frequenzband koexistieren. UWB ist besonders robust gegen Mehrwegausbreitung und deshalb geeignet für mobile Anwendungen. Mit erwarteten Datenraten von 200 Mbit/s bei einer Distanz von 10 m ist UWB eine Schlüsseltechnologie für zukünftige Kleinnetzwerke.

Abbreviations

3GT	Third Generation Mobile Cellular Systems (such as UMTS)
CEPT	European Conference of Postal and Telecommunications Administrations
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission (USA)
IEEE	Institute of Electrical and Electronics Engineers
UMTS	Universal Mobile Telecommunication System
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area Network

References

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Outlook

In theory, UWB should be able to coexist with the many different radio technologies that are in use today. However, there is some concern as to whether this is really the case, in particular among users of licensed spectrum. There are many factors that affect the level of interference to be expected from UWB, such as distance to the victim receiver, the transmission channel, the type of modulation technique, the pulse shape etc. In this context, Swisscom Innovations has started to investigate the potential effects that UWB may have on existing wireless systems and services that Swisscom operates. We will furthermore investigate some of the technical challenges and performance limits of UWB in order to evaluate the business potential of the new technology. 10

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