Influence of UWB Pulses on a Wireless Local Area Network in the 2.4 GHz ISM Band

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Abstract—**This paper describes the effects on the data communication of wireless local area network inside the 2.4 GHz ISM band by applying UWB pulses with different pulse repetition rates in a GTEM cell. The effect on the transmission rate has been covered by two different measurement setups. First the general influence on a wireless communication has been investigated. Second the influence on the receiver and transmitter has been analyzed. It is shown that UWB pulses with high pulse repetition rates influence WLAN communication inside the 2.4 GHz ISM band.**

Key words: UWB pulse, wireless communication, 2.4 GHz ISM band, Wireless LAN

I. Introduction

Wireless communication systems earn more and more popularity every day and become even more a part of our daily environment. Mobile communication, wireless internet and network access or cable replacement are the common used fields of application for digital wireless communication systems.

Especially network and cable replacement systems using the 2.4 GHz ISM (*Industrial, Scientific and Medical*) band are of special interest in modern industrial environments [1] as this frequency band is under special conditions nearly worldwide license free. The most used commercial digital wireless communication systems inside the 2.4 GHz ISM band are Bluetooth, Wireless LAN (WLAN) and ZigBee.

The exposition of wireless communication systems by *High Intensity Radiated Fields* (HIRF), e.g. radar, or by *High-Power Electromagnetic* (HPEM [2]) sources, like *Ultra Wideband Pulses* (UWB) or *High Power Microwave* (HPM) is an EMC research topic of special interest. Effects caused by these sources in the direct vicinity of the used electronic devices can be tremendously as the power of HIRF or HPEM sources is very high. Also high pulse repetition frequencies can have influences on the communication link. Possible electromagnetic effects can be characterized in a variety of ways as described in [3].

In general the electromagnetic effects are described by different types of coupling. Coupling of HPEM sources into electronic systems, especially communication systems, is described by frontdoor and backdoor coupling. Reference [4] subdivides these coupling methods in frontdoor and backdoor coupling as follows:

- noise (frontdoor),
- false information (frontdoor),
- transient upset (backdoor) and
- permanent damage (backdoor).

Measurements of backdoor and frontdoor coupling into different wireless communication devices and different general PCB antennas have been performed in [5, 6]. It has been shown that the coupled voltage peak levels of frontdoor and backdoor coupling can reach levels that possibly can interfere wireless communication system. This paper will show the influence of UWB pulses on the performance of a WLAN system in the 2.4 GHz ISM band.

This paper is organized as follows. Section II covers a general summarization of wireless communication systems using the 2.4 GHz ISM band. Section III introduces a description of UWB pulses. The used measurement setup will be presented in Section IV. The results of the measurements are summarized in section V. Finally section VI will draw a conclusion.

II. Wireless Communication inside 2.4 GHz ISM band

Today's digital wireless communication systems inside the 2.4 GHZ ISM band are using frequencies from 2400 MHz to 2484 MHz. The most common used standards are Bluetooth [7], ZigBee [8] and Wireless LAN, which is described below in more detail. As mentioned above these communication systems are licensed worldwide if special regulations are followed.

IEEE 802.11 denotes many wireless local area network (WLAN) standards and is totally described in [9]. Nowadays the most used systems in industry and home are 802.11b with a maximum transmission rate of 11 Mbit/s and 802.11g with a maximum transmission rate of 54 Mbit/s, respectively. While 802.11b uses *Direct Sequence Spread Spectrum* (DSSS) 802.11g uses *Orthogonal Frequency Division Multiplex* (OFDM) technique. A draft of a new standard (802.11n) has been released in 2007 with a maximum transmission rate of up to 540 Mbit/s by using *Multiple-Input Multiple-Output*

(MIMO) technology. WLAN uses a frequency bandwidth of 20 MHz and subdivides the ISM band into 11 overlapping channels. The output power is limited to 20 dBm (EIRP).

III. Ultra Wideband Pulses

The investigations in this paper are performed with the use of an unipolar ultra wideband pulse. The unipolar UWB pulse $u_{UWB}(t)$ can be approximated in time domain with the use of a double exponential function [10]

$$u_{UWB}(t) = V_p \cdot k \cdot \left(\exp\left(-\frac{t}{\beta} \right) - \exp\left(-\frac{t}{\alpha} \right) \right), \qquad (1)$$

where V_p denotes the maximum voltage of the pulse, α and β are time constants and k is a normalization factor, which is calculated by

$$k = \frac{1}{\exp\left(\frac{\alpha \cdot \ln(\alpha / \beta)}{\alpha - \beta} \right) - \exp\left(\frac{\beta \cdot \ln(\alpha / \beta)}{\alpha - \beta} \right)}. \qquad (2)$$

The amplitude spectrum $U_{UWB}(f)$ of an ultra wideband pulse can by calculated by using the Fourier transformation of (1):

$$U_{UWB}(f) = V_p \cdot k \cdot \left(\frac{1}{1/\beta + j2\pi f} - \frac{1}{1/\alpha + j2\pi f} \right). \qquad (3)$$

By transmitting a unipolar UWB pulse via air the unipolar UWB pulse becomes bipolar as no constant component can be transmitted. For tests with radiated UWB pulses *Impulse Radiating Antennas* (IRA) [11] or the Gigahertz Transversal Electromagnetic (GTEM) cell [12] can be used.

For description of the repetition rate of UWB pulses the *Pulse Repetition Frequency* (PRF) has been used.

IV. Measurement Setup

The used WLAN system was built by using two personal computers with a PCI WLAN adapter (TRENDnet [13] TEW-503PI 802.11a/b/g Wireless PCI Adapter). The two wireless adapters have been used in ad-hoc mode using 802.11b- and g-mode. All measurements have been performed by using WLAN channel 6 of the ISM band (2437 MHz) without any encryption of the WLAN system.

For coupling of the UWB pulses into the wireless communication system a GTEM cell (GTEM 5317) has been used. The transmitting antennas of the WLAN system have been placed on the ground of the GTEM cell on a lead-through and have been connected via SMA cables to the WLAN cards. Normal COTS bar antennas have been used.

The UWB pulses have been generated by using the PGB3 from Kentech Instruments Ltd [14] directly connected to the input of the GTEM cell. The used pulse generator has a specific output peak voltage at 50 Ω that is higher than 12 kV. The specific rise time is less than 100 ps and the specific pulse duration (FWHM) is less than 3 ns. The UWB pulse generator can achieve a PRF of 1 kHz. The generated pulse shape is depicted in figure 1 with a measured and an analytical (using eq. (1) with $V_p = 13.5 kV$) plot.

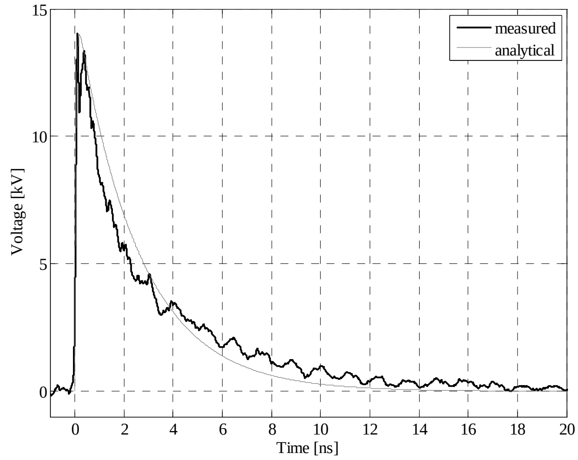


Fig. 1: Pulse shape of applied unipolar UWB pulse from PGB3 pulse generator.

The measurement has been divided into two different measurement scenarios. In the following measurements only frontdoor coupling has been covered as backdoor is depending on the whole computer system which has been used and is depending on many other effects caused by UWB pulses onto the computer itself. The measurement scenarios are described below.

A. Scenario I (Influence on Communication Link Mode)

Scenario I has been performed in order to determine the influence of applied UWB pulses on the data transmission of the WLAN in different modes of operation (b/g-mode). The general measurement setup is depicted in figure 2. The antennas have been placed inside the GTEM cell at the same distance to the feeding point at a septum's height of h = 0.8 m. The distance between the antennas is d = 0.5 m.

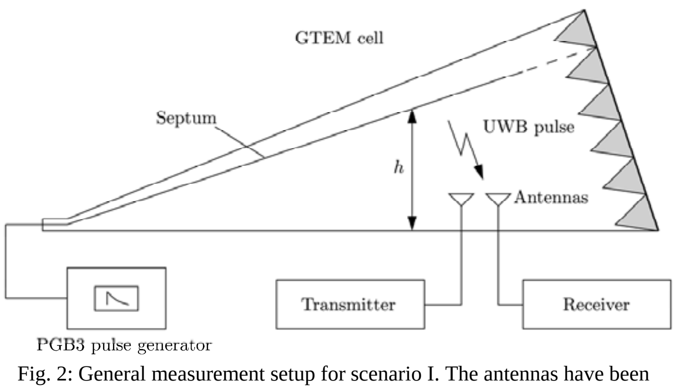


Fig. 2: General measurement setup for scenario I. The antennas have been placed both at the same distance to the feeding point (z = 2.5 m) of the GTEM cell at a septum's height of h = 0.8 m.

At the point of installation the peak electric field strength caused by the UWB pulse is 16.8 kV/m. The coupling response at the antenna foot of the applied UWB pulse is shown in figure 3 with a peak voltage of approx. 312 V.

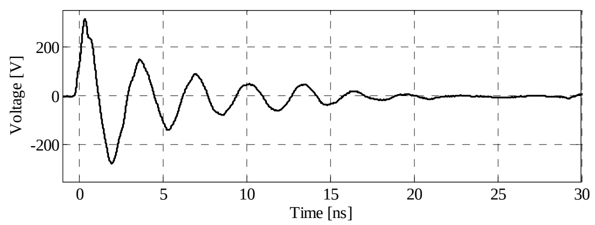
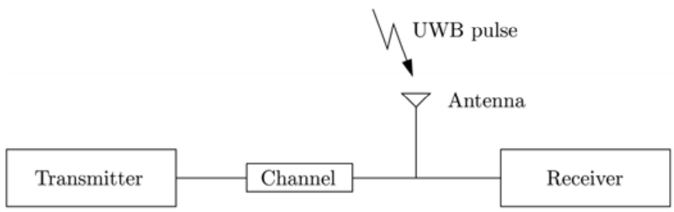


Fig. 3: Coupling response of an applied UWB pulse into the antenna.

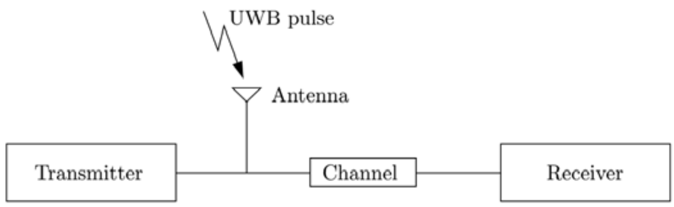
B. *Scenario II (Influence on Transmitter / Receiver)*

Scenario II has been used to determine the direct influence on the receiver and the transmitter of a WLAN communication link operation in g-mode (54 Mbit/s). The general measurement setup is depicted in figure 4 (a) and (b). In comparison to the previous measurement scenario only one antenna has been placed inside the GTEM cell for coupling of the UWB pulses. The bar antenna has been placed at the same distance to the feeding point of the GTEM cell as in previous scenario. The communication channel has been replaced by an attenuator of 50 dB in order to simulate the channel. While figure 4 (a) shows the setup for the coupling effects into the receiver (receiving PCI card), figure 4 (b) depicts the setup for coupling effects into the transmitter (transmitting PCI card), respectively.

With this measurement setup it is possible to gain information which side of the communication link is more interfered by applied UWB pulses with different PRF's and peak voltages.



(a) Measurement setup for coupling into the receiver



(b) Measurement setup for coupling into the transmitter

Fig. 4: General measurement setup with transmitter, channel and receiver of a wireless communication system.

V. Measurement Results

The results of the in section IV described measurement setups are covered in this section. All results are measured by using the network testing tool *Iperf* [15] in TCP mode. All following plots show the reduction of the data rate by applying UWB pulses with different PRF's and peak voltages.

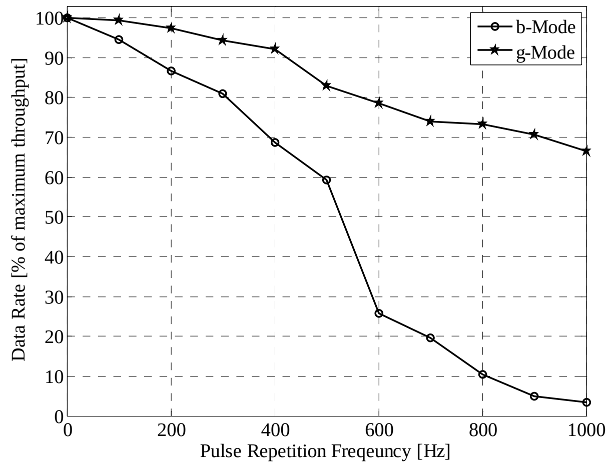


Fig. 5: Measurement results for scenario I. Influence on data transmission in IEEE 802.11b- and g-mode are shown. (100 % corresponds to a data rate in g-mode of ~28.0 Mbit/s and in b-mode of ~6.6 Mbit/s).

A. *Results of Scenario I*

Figure 5 shows the influence of UWB pulses with different PRF's on the WLAN data transmission in b- and g-mode.

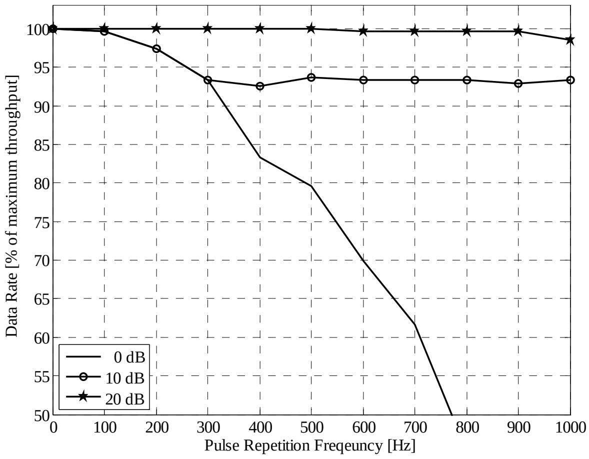
Generally one can see that the data rate decreases with an increasing pulse repetition frequency. Comparing the IEEE 802.11b-mode with the g-mode, the b-mode is much more disturbed as the g-mode. While the g-mode decreases at a PRF of 1 kHz to 68 % of the maximum data rate (28.0 Mbit/s), the data rate of the b-mode decreases to 5 % of the maximum data rate (6.6 Mbit/s).

B. *Results of Scenario II*

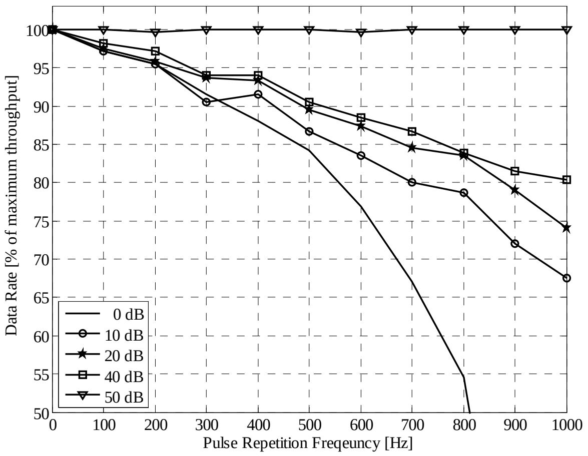
Table I summarizes the different applied UWB pulses with different peak voltages, peak electric field strengths and the coupled peak voltage into the bar antenna. The attenuation factor with respect to the maximum peak voltage of the UWB pulse is also included.

TABLE I
Parameters of applied UWB pulses for Scenario II

Peak voltage V_P of UWB Pulse	**Attenuation factor to $V_{P,\max}$**	**Peak electrical field strength E_P at point of antenna**	**Coupled peak voltage $V_{C,P}$ at antenna foot**
13.5 kV	0 dB	16.8 kV/m	312 V
4.3 kV	10 dB	5.3 kV/m	98.7 V
1.35 kV	20 dB	1.6 kV/m	31.2 V
427 V	30 dB	530 V/m	9.87 V
135 V	40 dB	160 V/m	3.12 V
43 V	50 dB	53 V/m	1 V



(a) Influence of UWB pulses with different PRF's and different UWB pulse peak voltages (table I) on the transmitter of a WLAN communication link.



(b) Influence of UWB pulses with different PRF's and different UWB pulse peak voltages (table I) on the receiver of a WLAN communication link.

Fig. 6: Measurement results for scenario II. The data rate is given in per cent of the maximal possible throughput without disturbances. (100% correspond to 28.0 Mbit/s).

With the applied UWB pulses of table I the data rate in per cent of the maximum data rate without disturbances has been plotted against the PRF of the UWB pulses for coupling into the transmitter (figure 6 (a)) and into the receiver (figure 6 (b)).

Figure 5 (a) shows that the coupled UWB pulses of figure 3 interfere the transmitter of the WLAN system. By attenuation of the UWB pulse the influence has been reduced. If the incident pulse has been attenuated by 20 dB, no more interference of the transmitter is observed up to a PRF of 1 kHz.

Comparing this to the influence on the receiver in figure 6 (b) one can see, that interferences are observable up to an attenuation of the incident UWB pulse of 40 dB. At an attenuation of 50 dB the receiver has not been interfered by UWB pulses.

VI. Conclusions

A measurement setup by using the GTEM cell has been presented in order to determine the influence of frontdoor coupled UWB pulses with different pulse repetition frequencies on WLAN systems using the 2.4 GHz ISM band.

The measurements have shown that the influence of UWB pulses on WLAN systems operating in b- and g-mode is increasing with an increasing of the PRF. In this setup the b-mode has been more interfered by UWB pulses as the g-mode.

Looking in more detail at the influence on the transmitting and on the receiving part of a WLAN system it has been recognized that the receiver of the WLAN system is more affected by UWB pulses as the transmitter. Already UWB pulses with electrical field strength of 160 V/m can interfere a WLAN communication link by reduction of the data rate.

It should be noted that the used WLAN system has not been destroyed during the measurement. After turning off the UWB pulse generator all systems worked properly.

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