Comparing Non-ideal Ultra-wideband Transmission for European and FCC Regulation

Jens Timmermann, L. Zwirello, E. Pancera, M. Janson, and T. Zwick

Institut für Höchstfrequenztechnik und Elektronik, Universität Karlsruhe (TH)
Kaiserstr. 12, 76131 Karlsruhe, Germany
Tel.: +49 721 608 6255; Fax: +49 721 69 18 65
jens.timmermann@ihe.uka.de

***Abstract* — The performance of UWB transmission can be degraded by non-ideal frontend components. In literature, there exist only few contributions about non-ideal impulse radio transmission, and they are based on the FCC regulation. Non-ideal system considerations for the European regulation are however missing. This paper uses a detailed system model based on measurement data and compares the achievable performance when analogue filters for the European and the FCC regulation are included. The results show that a loss of signal-to-noise ratio due non-ideal filters and bandwidth limitations is very critical at small distances. Filter optimization is hence necessary to improve the system performance.**

***Keywords* — UWB, analogue filter, system modelling, group delay variation, bit error rate**

I. Introduction

In 2002, the FCC decided a regulation for the use of ultra-wideband techniques inside a frequency range between 3.1 and 10.6 GHz. Up to now, a variety of scientific investigations has been published mostly with respect to the FCC mask. However for Europe, another regulation is valid that allocates two smaller frequency ranges. In this paper only the upper range is considered. It has a bandwidth of 2.5 GHz and covers frequencies from 6 to 8.5 GHz. The research based on the European ultra-wideband regulation is very limited. To our knowledge, system aspects including Dirty RF behavior for the European regulation is completely missing in literature. The aim of this contribution is to study the impact of a non-ideal analogue transmit and receive filters on the system performance for both the European and the FCC regulation. The system model used for the simulation includes a variety of non-ideal components such as antennas, channel, low noise amplifier, noise and interference. They are mainly based on measurement data.

II. System Modeling

The system model for non-ideal impulse radio transmission is shown in Fig. 1. In general, it includes an analogue transmit filter, an UWB transmit antenna, an indoor channel influenced by Additive White Gaussian Noise (AWGN) and AWGN interference, a low noise amplifier and an analogue receive filter. The detection is done by a correlation receiver. A detailed description of the system model can be found in [1]. The pulse shape used for simulation is a conventional pulse that can be generated by low-cost devices. For the European regulation, it is a Gaussian Monocycle with center frequency of (6+8.5)/2 GHz=7.25 GHz. The efficiency of the pulse is calculated by integrating the power spectral density between 6 and 8.5 GHz and dividing the result by the integrated limit value of the regulation. The efficiency inside the relevant range is 96.13%. Since a transmit antenna with maximal gain of 6.4 dB is used, the amplitude of the pulse is reduced by this value to meet the regulation. For this reason, the power efficiency reduces to only 21.96 %. Since the pulse would violate the regulation outside the relevant range, a transmit filter designed for the European mask must be used.

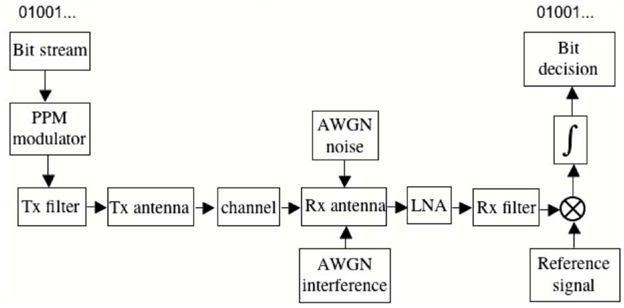

Fig. 1 Non-ideal system model with correlation receiver

For the FCC regulation, also a Monocycle is used but with a slightly modified center frequency of (3.1+10.6)/2 GHz=6.85 GHz. The efficiency between 3.1 and 10.6 GHz is 78.89 %. This is less compared to the Monocycle for the European regulation since the decaying spectrum of the Mopocycle is integrated over a larger relevant frequency range. Substracting the maximal antenna gain delivers an efficiency of only 18.01 %. An analogue transmit filter designed for the FCC mask must be placed to meet the FCC regulation. The following subsections consider the design and modelling of both hardware components and the channel in the system model.

A. Design of Analog Filters for ECC and FCC Mask

Coupled line theory states that an electromagnetic interaction happens between two transmission lines if they are close to each other. This causes power coupling between the lines. Designing a bandpass filter can be done by cascading a number of coupled lines. This method is used to develop a Chebyshev filter for the European mask with a passband from 6 GHz to 8.5 GHz. Details about RF analogue filter design can be found in [2]. For the fabrication, the chosen substrate is

Rogers 4003 with a permittivity of 3.38. The height of the substrate is 0.813 mm and the thickness of the copper conductor is 0.017mm. Fig. 2 shows the fabricated bandpass filter for the European regulation. Fig. 3 presents the measured transmission S_{21} and input reflexion S_{11} together with the European regulation. The filter shows an insertion loss of about 3 dB and a nearly flat transmission behavior between 6.5 and 7.8 GHz with ripples of about +/- 0.5 dB. The regulation is never hurt. Reflexions are smaller than 10 dB inside the relevant range. The group delay is shown in Fig. 4. The maximal group delay variation inside the frequency interval [6 8.5 GHz] is 1.75 ns which is strongly non-ideal. However, the aim of this work is to study the influence of non-ideal filters and not to optimze them. The complete measurement data of the filter is included into the system model.

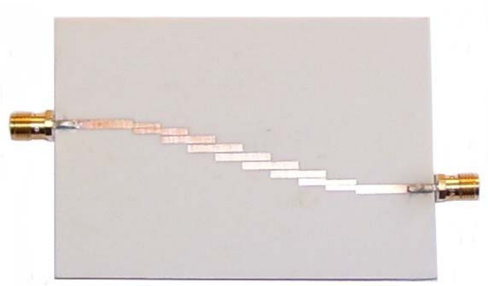

Fig. 2 Fabricated filter for the European regulation

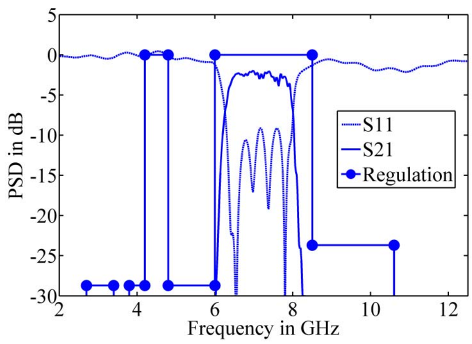

Fig. 3 Measured S Parameters of filter for the European regulation

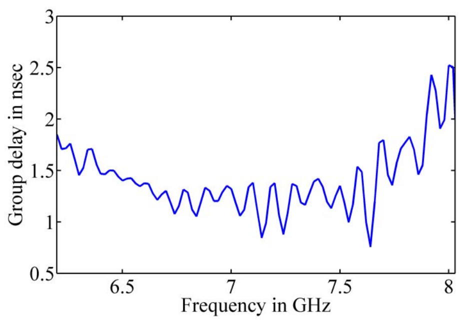

Fig. 4 Measured group delay filter for the European regulation

In a second step, an analogue microstrip filter for the FCC regulation is designed. The applied filter design method is called “optimum distributed highpass filter” [2]. Basically, a cascade of shunt short-circuited stubs is used with an electrical length Θ_c. The index c denotes the cut off frequency (here: 10.6 GHz). The stubs are connected by lines of the electrical length $2\Theta_c$. Fig. 5 shows the fabricated filter for the FCC regulation. The substrate and conductor properties are the same as in Fig. 2.

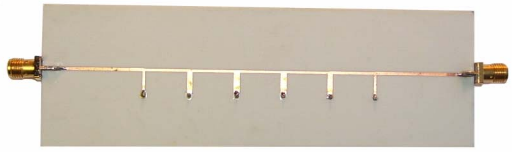

Fig. 5 Fabricated filter for the FCC regulation

Fig. 6 presents the measured transmission S_{21} and the input reflexion S_{11} together with the FCC regulation. The filter shows again an insertion loss of about 3 dB. Reflexions are smaller than -5 dB inside 3.1 and 10.6 GHz and mostly about -10 dB. The group delay is shown in Fig. 7. The maximal group delay variation inside [3.1 10.6] GHz is 1.1 ns. Again, the measurement data of the filter is included into the system model.

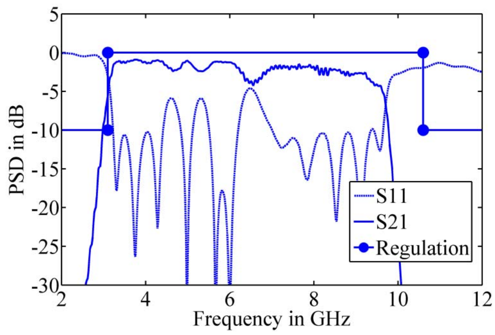

Fig. 6 Measured S Parameters of filter for FCC regulation

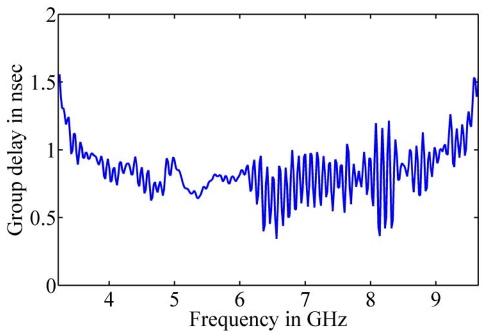

Fig. 7 Measured group delay of FCC filter

B. MODELING OF CHANNEL AND ANTENNAS

As already mentioned, a transmit antenna with maximal gain of 6.4 dB is used. Both the transmit and the receive antenna is a Monocone antenna, see Fig. 8 (left). Its 3D pattern is measured from 2.5 to 12.5 GHz with a frequency step of 6.25 MHz. The measurement data is used in the system model.

The channel is simulated by Ray Tracing techniques [3], whereas the transmission paths are weighted by the measured antenna patterns. Again, the data is obtained from 2.5 to 12.5

GHz with a step of 6.25 MHz. Consequently, the impulse response can be resolved up to t_{max}=1/6.25 MHz=160 ns. Multiplication by speed of light delivers a maximal path length of 48 m which is sufficient for indoor applications. The advantage of simulation based channel modelling is the possibility to study arbitrary transmitter and receiver configurations in short time. Fig. 8 (right) shows the 3D scenario of the investigated lab environment together with a transmitter position (Tx) and some receiver positions (Rx). Both Tx and Rx are situated at the same height of 2m.

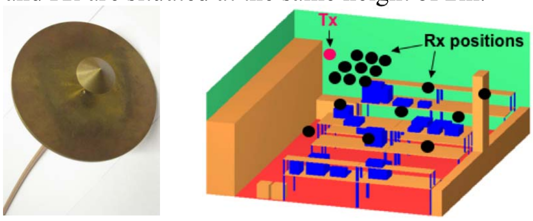

Fig. 8 Monocone antenna and lab scenario

A verification of the channel model in the UWB case has been performed in [4] by comparing simulation and measurement data. Another investigation can be done by comparing the simulated UWB pathloss from Ray Tracing to existing UWB pathloss models.

First, the UWB pathloss for Ray Tracing is determined. Let $H(f,d)$ be the simulated ratio between complex receive and transmit voltage at a given frequency f and distance d. The UWB pathloss $L_{\text{Ray Tracing}}$ (ratio between received and transmitted power) inside the frequency range [3.1 10.6] GHz is then given by Equ. (1).

$$L_{Ray\,Tracing} = \frac{P_{rx}}{P_{tx}} = \int_{3.1GHz}^{10.6GHz} \left|H(f,d)\right|^2 df \qquad (1)$$

Since the simulation is only done at discrete frequencies, the integral reduces to a sum.

Second, an UWB pathloss model for freespace propagation is considered: For an ultra-wideband signal with minimal frequency $f_{\min}$ and maximal frequency $f_{\max}$, an extended Friis equation (Equ. (2)) describes the UWB power pathloss) [5].

$$L_{\text{Freespace}} = \frac{c^2}{(4\pi d)^2 f_{\min} f_{\max}} \qquad (2)$$

For the FCC regulation, $f_{\min}$=3.1 GHz and $f_{\max}$=10.6 GHz is used (European regulation: $f_{\min}$=6 GHz and $f_{\max}$=8.5 GHz).

Another UWB pathloss model is the two-path model where a ground reflection is taken into account. The UWB power pathloss $L_{\text{two-path}}$ is described by Eq. (3) [6].

$$L_{\text{Two-path}} = \frac{1}{f_{\max} - f_{\min}} \cdot \int_{f_{\min}}^{f_{\max}} \left(\frac{c_0}{4\pi d}\right)^2 \left(1 + r^2 + 2r\cos\left(\frac{2\pi f \Delta l}{c_0} + \varphi\right)\right) df \qquad (3)$$

with

$$\Delta l = \frac{2h_{\text{Tx}} h_{\text{Rx}}}{d} \qquad (4)$$

In Eq. (3) and (4), d indicates the distance between Tx and Rx; $r \cdot e^{j\varphi}$ is the complex ground reflexion coefficient and c_0 the speed of light. h_{Tx} and h_{Rx} are the heights of transmitter and receiver. All three expressions for the UWB power pathloss are compared as a function of distance, see Fig. 9. The figure shows that the simulated UWB power pathloss for Ray Tracing is in between the two existing models. This makes sense since the simulated receiver positions are at the same height and show a strong line of sight (LOS) component.

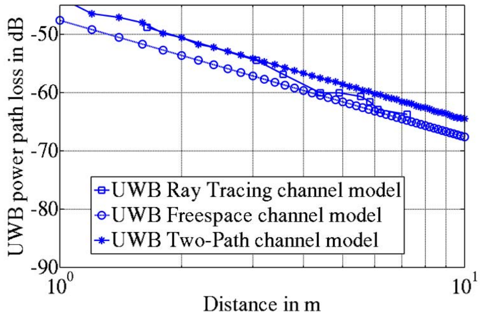

Fig. 9 UWB power pathloss in dB

C. Modeling of LNA, Noise and Interference

Modelling of the LNA is done by implementing the measured S parameters and the noise figure of 2.5 dB of a commercially available UWB LNA (Hittite HMC C022). It shows about 14 dB gain and has only a small group delay variation of 0.04 ns inside [3.1 10.6] GHz.

Noise is modelled as Additive White Gaussian Noise (AWGN) with a noise temperature of 300 K. Interference is also modelled as AWGN. The demodulation is done by a correlation receiver.

III. Performance for Both Regulations

The system simulation is performed using Ptolemy environment in Advanced Design system. The discrete sampling time step used in the simulation is T_{Step} =35.714 psec to have sufficient time resolution for the pulse shape. Using the sampling theorem, the maximal signal frequency necessary for the simulation is $f_{\max}$=1/(2*T_{Step})=14 GHz. Since antenna and channel data is only available up to 12.5 GHz, zeropadding is applied at the missing frequencies. Further settings are: pulse repetition time T_{PRF}=168*T_{Step}=6 ns, PPM shift ΔT_{PPM}=40*T_{Step}=1.4286 ns. The interference power is -70 dBm inside the frequency range [0 14] GHz. The aim of the system simulation is to analyze the achievable bit error rates for both the inclusion of filters for the European and the FCC regulation.

First, a reference behavior is derived for the case that no transmit and receive filters are applied. Without filters, the bit error rate versus distance for both the FCC and the European Gaussian Monocycles is nearly identical since the pulse shapes are almost equal (for the FCC case, a pulse with center frequency of 6.85 GHz is chosen and for the European regulation the center frequency is 7.25 GHz). This reference performance is called "without filter". It is obtained in presence of the non-ideal behavior of the antennas, the LNA the channel, the noise and an interference power of -70 dBm inside the interval [0 14 GHz].

In a second step, the analogue filters are taken into account whereas the Tx and Rx filters are equal. The system settings remain the same. Only the synchronization point is adapted since the physical length of the filters causes a delay. Fig. 10 compares the respective performance for both the inclusion of the European and the FCC filters together with the reference curve "without filter". The number of the simulated bits is 10^5.

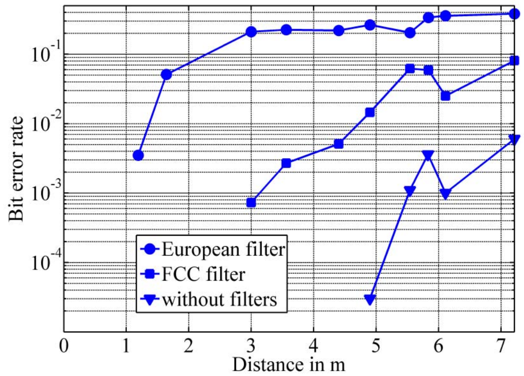

Fig. 10 Bit error rate versus distance including interference (-111 dBm/MHz)=-70 dBm

It can be seen that the inclusion of analogue filters can lead to a severe degradation of the system performance. One reason is the limitation of the bandwidth of the pulse spectrum which leads to smaller transmit power and hence to worse signal-to-noise ratio (SNR). At a distance of 6m, the degradation of the bit error rate is in the order of 1 decade for the FCC filter and 2 decades for the European filter.

Furthermore, the degradation of the system performance can be caused by non-linearity of the system components. This can also be expressed in terms of a non-constant group delay. The inclusion of the European filter leads also to worse results compared to FCC filter since its group delay variations is stronger (1.75 ns versus 1.1 ns) which leads to stronger pulse distortion. Analyzing Fig. 10 for small distances, the degradation due to the inclusion of the non-ideal analogue filters is larger compared to large distances.. This can be explained by the fact that losing SNR at high SNR (small distance) has more effect on the bit error rate (BER) than losing SNR at small SNR since the gradient of the corresponding BER-SNR curve increases with better SNR.

Finally, the system performance including the filters is also given when the interference is turned off, see Fig. 11. The other non-ideal effects are still active. Turning off the interference leads more or less to a down shift of the curves from Fig. 10 and improves the performance. The improvement using the filter for the European regulation is smaller compared to the FCC case. However for the FCC filter, the bit error rate improves by about 3 decades at a distance of 5 m.

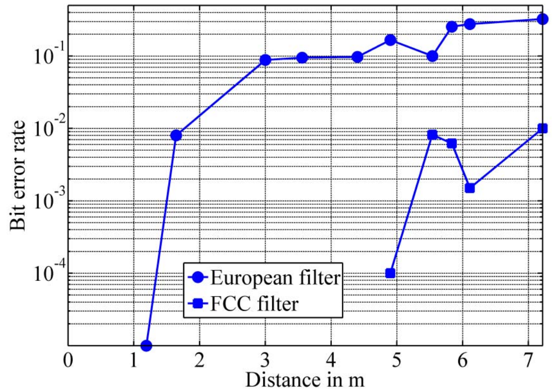

Fig. 12 Bit error rate versus distance including (only AWGN noise)

IV. Conclusions

This paper has treated non-ideal ultra-wideband transmission for both the European and the FCC regulation and compares the achievable performance in terms of bit error rate. The results present the reference behavior when filters are neglected and the degradation due to included physical filters. A Non-constant group delay and a bandwidth limitation can degrade the performance dramatically. Especially for small distances, a loss of SNR leads to a severe degradation since the corresponding BER-SNR behavior looks like a waterfall curve. Strategies to improve the transmit SNR are hence very important to achieve an efficient system. This can be achieved for example by pulse optimization and inclusion of analogue filters with a very steep slope. As a consequence the results emphasize the important role of filters in an ultra-wideband system and the necessity of filter optimization.

References

[1] J. Timmermann, E. Pancera, G. Adamiuk, W. Wiesbeck, and T. Zwick, “Estimated performance of UWB impulse radio transmission including dirty RF effects,” in International Conference on Ultrawideband, Hannover, Germany, Sept. 2008.

[2] J.-S. Hong and M. Lancaster, Microstrip Filters for RF Microwave Applications, John Wiley & Sons, Inc., 2001.

[3] J. Timmermann, M. Porebska, C. Sturm, and W. Wiesbeck, “Investigating the influence of the antennas on UWB system impulse response in indoor environments,” in 4th European Radar Conference, European Microwave Week (EuMW’07), Munich, Germany, Oct. 2007.

[4] M. Porebska, T. Kayser, and W. Wiesbeck, “Verification of a hybrid ray-tracing/FDTD model for indoor ultra-wideband channels,” in 10th European Conference on Wireless Technology, CD-ROM, Munich, Germany, Oct. 2007.

[5] S. Promwong and J. Takada, “Free space link budget estimation scheme for ultra wideband impulse radio with imperfect antennas”, IEICE Electronics Express, Vol. 1, no. 7, pp. 188-192, 2004.

[6] S. Sato and T. Kobayashi, “Path-loss exponents of ultra wideband signals in line-of-sight environments”, 2004 IEEE International Symposium on Spread Spectrum Techniques and Applications, Sydney, Australia, Sept. 2004