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Compensation of a Non-ideal UWB Antenna Performance

Jens Timmermann, Philipp Walk, Alireza Rashidi, Werner Wiesbeck, and Thomas Zwick

Abstract – Non-ideal hardware degrades the performance in UWB systems. Especially the non-isotropic transmit antenna is critical: To meet the regulation, the maximal antenna gain must be substracted from the regulation which leads to reduced transmit power, and hence decreased signal-to-noise-ratio. This contribution briefly describes the modeling of a complete, non-ideal impulse radio system and, based on this, shows strategies to improve the performance. This includes optimal pulse design with joint compensation of the frequency response of the non-isotropic transmit antenna. For this two different compensation methods are presented. An UWB communication system simulation delivers the achievable bit error rates and clearly shows the improvement by the compensation measures.

Index Terms – UWB, antenna compensation, non-ideal hardware, optimal pulse design, bit error rate, system simulation

1 Introduction

The FCC regulation defines an EIRP (Effective Isotropic Radiated Power) value of only -41.3 dBm/MHz between 3.1 and 10.6 GHz for UWB transmission. To fully exploit the regulation, the pulse shape must be optimized with respect to the given spectral mask. During optimization of the radiated signal, the non-ideal characteristics of the transmit antenna must be taken into account. [1] shows a method to compensate for the frequency dependent transfer function of the transmit antenna at a certain direction. However, the transfer function is also dependent on the angle. The current contribution shows optimal pulse shaping that compensates for the frequency and angle dependent characteristics of the transmit antenna. System simulations based on a detailed system model show the improvement by the compensation.

2 UWB, non-ideal communication system model

Fig. 1a shows the system model for impulse radio transmission with PPM modulation, including a correlation receiver. The reference signal has the same pulse shape like the transmit signal. The system model includes a series of non-ideal components, like the pulse generator with jitter, transmit and receive antennas, the UWB multipath indoor channel as well as the LNA. These components are described by behavioral models in the Advanced Design System (ADS), based on simulations and/or measured data of physical hardware. A detailed description can be found in [2].

In contrast to [2], the transmit filter (as well as the receive filter) is supposed to be ideal since this contribution concentrates on the compensation of the non-ideal transmit antenna at the transmitter side. However, the compensation methods presented here can also be used to compensate the joint transfer function of a transmit filter and a transmit antenna. In this contribution, a Monocone antenna is used both, at the transmitter (Tx) and at the receiver (Rx). The Monocone antenna has an omnidirectional azimuth pattern, while the gain $G(f,\theta)$ and the elevation characteristic depend on the frequency f. Fig. 1b shows the Monocone antenna together with the definition of the elevation angle θ.

Fig. 2a shows the gain at an elevation angle of 90° while the azimuth angle can be arbitrary due to the symmetry of the antenna. Since the transmitter and the simulated receiver positions are at the same height, this is the direction of the Line Of Sight (LOS) path. The antenna gain differs between -1.5 and -8 dBi. The complete 3D measurement data of the antenna is implemented in the system model. Data is available between 2.5 and 12.5 GHz with frequency steps of 6.25 MHz. At each frequency, the maximum antenna gain $G_m(f)$=max $G(f,\theta)$ is determined over all directions, which is called the 'max. gain per frequency' function, see Fig. 2b. The maximum of this function is G_{max}=6.4 dBi. It occurs at the combination: θ_{max}=52° and f_{max}=10.2 GHz. At θ_{max}=52°, the frequency dependent antenna gain $G(f,\theta_{max})$ is called 'gain at max. gain direction', see Fig. 2b.

3 Pulse design

The FCC regulation, which limits the effective radiated spectral power density to *EIRP*= -41.3 dBm/MHz, requires that the pulse shape must be optimized to utilize this optimally, taking into account the frequency dependent gain.

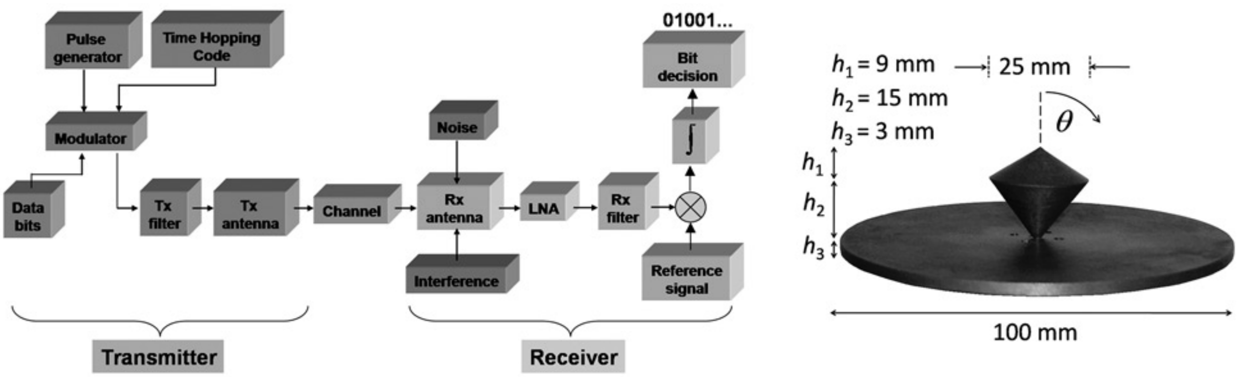

Fig. 1: a) System model with non ideal components; b) Monocone antenna

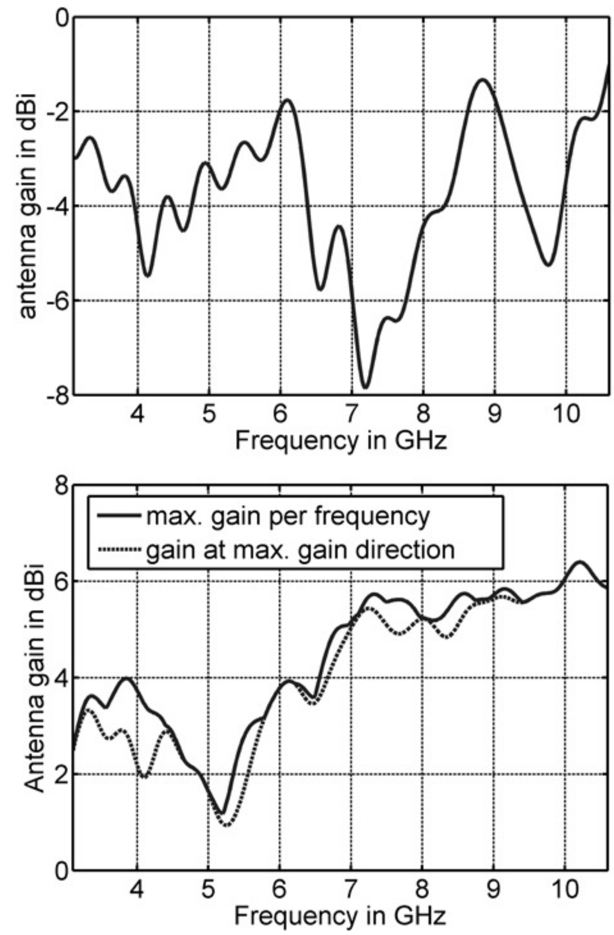

Fig. 2: a) Antenna gain in line of sight direction; b) Maximal gain considerations

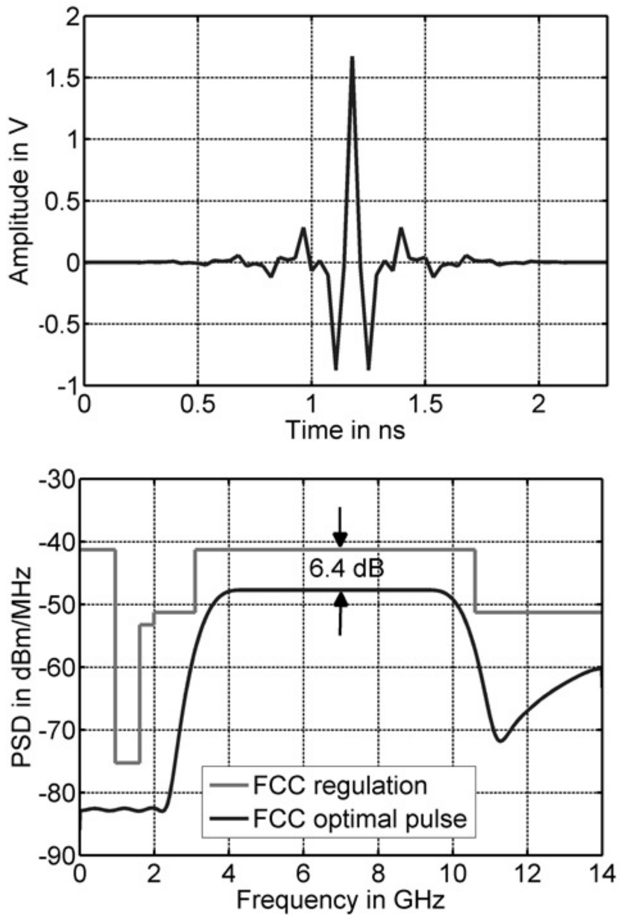

Fig. 3: a) Optimized pulse without compensation in the time domain; b) power spectral density of the pulse (6.4 dB below the mask)

Fig. 3 shows the FCC power optimized pulse for the radiation via the Monocone antenna in both, time and frequency domain together with the FCC mask $S_{FCC}(f)$. The pulse amplitude is designed for a pulse repetition time of 28.57 ns. The target mask is the FCC mask reduced by G_{max}=6.4 dBi to avoid a violation of the FCC mask. The pulse is the solution of a FIR filter optimization problem with a filter order N=66 [3], where the method 'direct maximization of the normalized effective signal power' [4] has been applied. The problem is that this pulse does not optimally exploit the EIRP=-41.3 dBm/MHz of the regulation since the frequency dependent antenna gain is not compensated. It only exploits the flat mask. This pulse design method is called 'without compensation'. In this contribution, the input of the FIR filter is assumed to be a Dirac. The optimization problem can also be expressed for an arbitrary input basis pulse [5]. This would lead to different FIR coefficients but to the same output pulse for transmission.

4 Compensation for the transmit antenna characteristics and performance analysis

An improved performance is expected if the antenna gain variations versus frequency are taken into accout for the pulse design, to fully exploit the regulation and compensate for the antenna chacteristics. It is assumed that the antenna gain characteristics are known by a measurement and that there are no distortions of the pattern by objects in the nearfield. The question is however which of the two antenna gain functions in Fig. 2b must be compensated. Both functions are very similar. A correct compensation without violation of the FCC mask should use the 'max. gain per frequency' function. The other function describes, as already mentioned, the frequency dependent gain in the direction of the maximum gain. This function is slightly below the 'max. gain per frequency' function. It underestimates the maximal gain at a given frequency. A compensation in the direction of the maximal gain hence leads to violations of the regulation in other directions and cannot be used. As a consequence, the behavior to be compensated is the 'max. gain per frequency' function. This contribution proposes two methods: First, this function is substracted from the desired mask, so that a modified power spectral density (PSD) is created. For a fixed filter order of N=66, the corresponding FIR filter, and hence the 'adapted optimal pulse shape' is determined. The pulse shape and its power spectral density are shown in Fig. 4, together with the modified target mask. Since the filter order N determines the complexity and cost of the pulse shaper, a practical implementation should be based on a cost-benefit analysis.

It can be seen that the pulse PSD at the antenna input is still suboptimal, which results from the fact that the target mask is a difficult function. Fig. 5a visualizes the influence of the transmit antenna in frequency domain.

Since the Tx and Rx antennas are at the same height, the main part of the signal is received from the LOS direction. The signal radiated into the LOS direction is called 'at Tx antenna output ($\theta = 90^\circ$)'. It is obtained by adding the corresponding gain value from Fig. 2a to the signal 'at Tx antenna input'. The function 'max. at Tx antenna output' is obtained by adding the 'max. gain per frequency' function to the signal at the Tx antenna input. Its peak value is the limit of the FCC mask. For comparison, Fig. 5b shows the corresponding curves without compensation. It can be seen that the signal at the Tx antenna output without compensation has lower power spectral

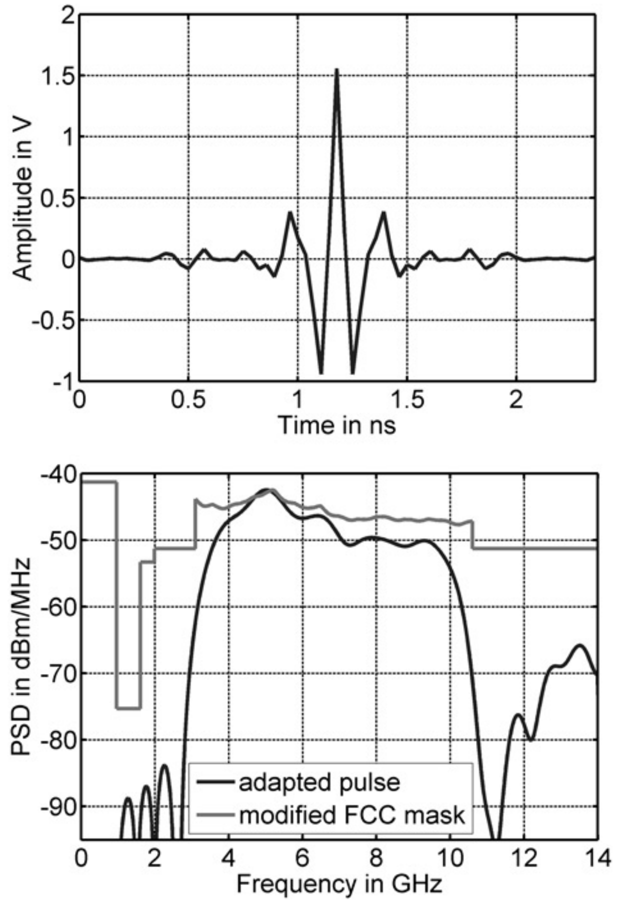

Fig. 4: a) adapted pulse shape; b) corresponding spectrum together with the modified target mask

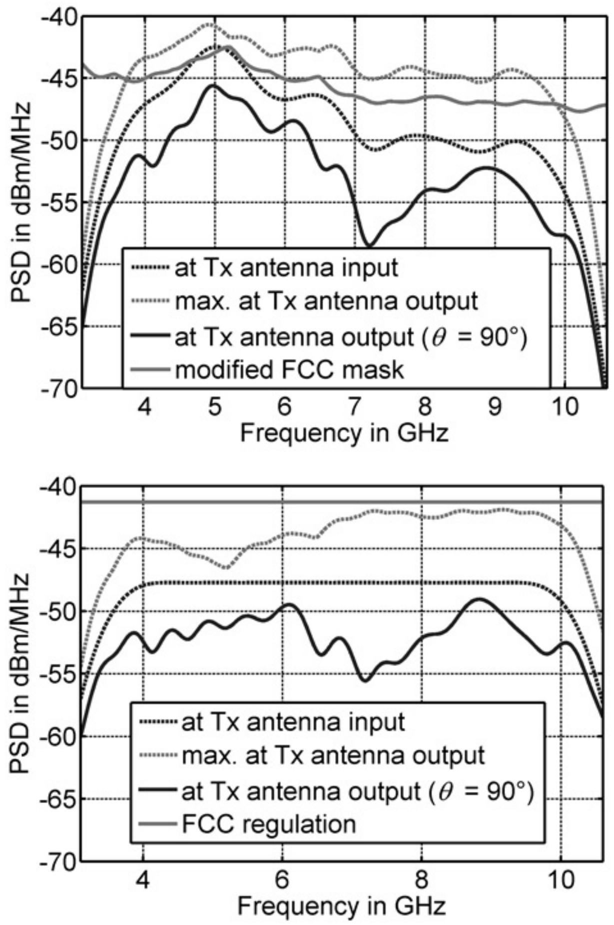

Fig. 5: a) compensation by modified target mask; b) PSD at the antenna input and output without compensation

density values. This leads to lower transmit power and hence to worse signal-to-noise ratio (SNR). The second compensation method designs an optimal pulse shape directly for the FCC mask without substracting $G_{\max}$. Then, the inverse 'max. gain per frequency' function $G_m^{-1}(f)$ is multiplied in frequency domain. The radiated signal is then exactly the FCC optimized pulse, which is shown in Fig. 6a. The values of the power spectral density are maximized and better than the corresponding values from Fig. 5. A compensation by the inverse gain function can be seen as the theoretical limit of the compensation using the 'max. gain per frequency' function.

Fig. 6b presents the performance in terms of bit error rates (BER) versus distance for the three cases: optimal pulse without compensation; compensation by 'modified target mask' (adapted pulse shape); compensation by 'inverse gain'. Aside from the fact that thermal noise at 300 K is considered, an additional interference power with a density of -87.5 dBm/MHz (additive white Gaussian noise) is supposed. This is done to achieve bit error rates worse than 10^{-5} which can be simulated in acceptable time. If the compensation is applied, the bit error rate is always improved since the SNR becomes better. The improvement using the 'inverse gain' method is better compared to the 'adapted pulse' method, because the desired mask remains a constant inside the relevant frequency range. Finally, Fig. 6b demonstrates that the improvement by compensation is highly effective for small distances. This can be explained by the fact that the gradient of the BER versus SNR curve increases with better SNR (small distance). For 1.5 m distance, the BER can be improved by two decades compared to the none compensated case.

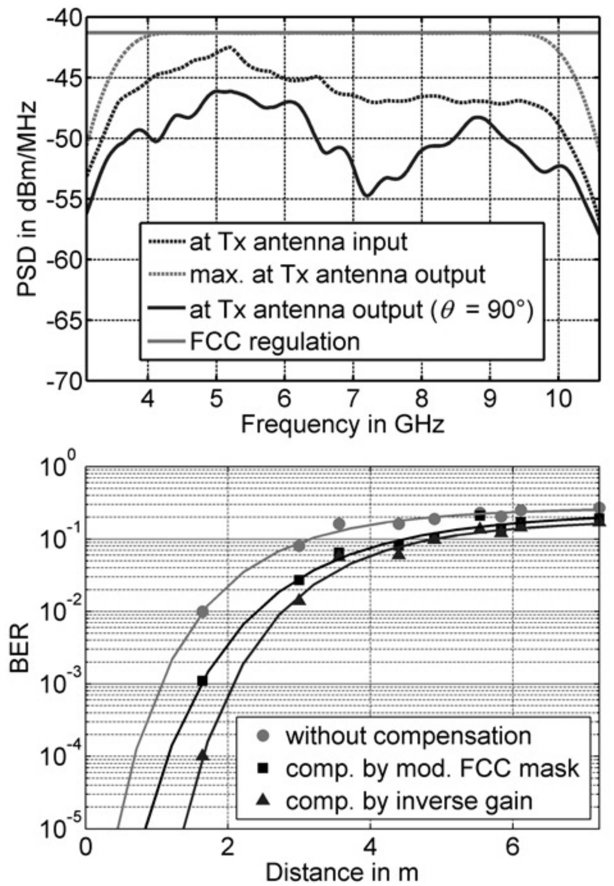

Fig. 6: a) compensation by inverse gain; b) BER versus distance without and with compensation for a LOS channel

5 Conclusions

This contribution presents an optimal pulse design without and with compensation of the frequency dependent transmit antenna characteristics for the optimal exploitation of the allowed UWB spectral power radiation density. Compensation regarding the antenna gain function ensures that the maximal power is radiated within the whole relevant frequency range, without violating the FCC mask. This leads to an improved SNR and hence to a noticeably improved performance, for example higher data rates in UWB communications. The improvement is highly effective for small distances since the BER versus SNR behavior looks like a waterfall curve. The results are verified by a complete system simulation, including the indoor LOS channel. The results achieved here present directly the loss of performance in an UWB system, where an antenna compensation is not realized.

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J. Timmermann, W. Wiesbeck, T. Zwick
Institut für Hochfrequenztechnik und Elektronik
University of Karlsruhe (Karlsruhe Institute of Technology – KIT)
76131 Karlsruhe, Germany
E-mail: Jens.Timmermann@ihe.uka.de

A. Rashidi
Institut für Hochfrequenztechnik
RWTH Aachen University
52074 Aachen, Germany
E-mail: Ajami@ihf.rwth-aachen.de

P. Walk
Institut für Telekommunikationssysteme
Technical University of Berlin
10587 Berlin, Germany
E-mail: Philipp.Walk@mk.tu-berlin.de