Concept of Compatibility Region for the Evaluation of IR UWB Electromagnetic Compatibility

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***Abstract*— This paper presents a new proposal for the unified evaluation of ultra wideband and narrowband radio communication systems electromagnetic compatibility, called "compatibility region". The idea of compatibility region is based on the relation between the ratio of narrowband to ultra wideband signal power in a receiver and some transmission quality indicators (bit error rate, effective data rate).**

Keywords—Electromagnetic compatibility, coexistence measurements, coexistence improvement, interference mitigation.

I. INTRODUCTION

Narrowband (NB) and ultra wideband (UWB) radio transmissions may share the same spectrum only under certain restrictions. That's why regulatory offices in different regions of the world set certain limitations for the UWB technique: the limits are usually the highest possible power spectral density for continuous transmission or transmission with additional detect and avoid mechanisms. Unfortunately in some cases these limitations are not sufficient and interference may occur. To reduce the risk of interference several coexistence improvement methods were presented in the literature during last years. Some of them are based on band rejection filters in UWB transmitters or band-notched antennas, others rely on UWB signal spectrum shaping or UWB receiver immunity to narrowband interference. Different approaches to the compatibility problem are described in these papers usually connected with different concepts for the presentation of results, which makes comparison between them quite difficult. For example, in papers [1] and [2], coexistence of OFDM-based (Orthogonal Frequency Division Multiplexing) UWB and WLAN (Wireless Local Area Networks) is measured using the relation between the NB carrier to interference ratio or the carrier to noise ratio and real throughput in the NB link, while [3] presents bit error rate (BER) of 3G transmission as a function of 3G to UWB interference and noise level. Publication [4] focuses on measurements of BER in a CDMA (Code Division Multiple Access) system as a function of the power spectral density of UWB interference. The same type of charts can be found in [5] where the authors describe results of their work on OFDM-based systems: IEEE 802.11n, WiMax, and LTE (Long Term Evolution) in presence of different types of UWB interference, but results of the survey described in [6] are presented as ECMA368 UWB BER chart of the signal to interference ratio where interference is caused by an IEEE 802.16 signal. Similar types of charts were used in [7] to present the BER of an impulse-type UWB system in the presence of NB interference, while [8] which describes WiMedia OFDM UWB interference mitigation to 3GPP LTE and WiMAX NB systems includes different charts of NB system BER. Additionally, definition of the signal to noise ratio in [8] is just the opposite of the signal to noise ratio defined in [7]. While it is not very difficult to recalculate results obtained by different signal to noise definitions, it is much more difficult to get similar data from results presented in [9]: the authors of this paper measured BER of a UMTS (Universal Mobile Telecommunications System) downlink with a UWB transmitter placed nearby a UMTS receiver, but presented all results in form of BER charts as a function of the distance between UMTS terminal, UWB terminal, and UMTS base station, or as a function of the coefficient K which depends on the ratio between UMTS and UWB transmitter power for selected distances between both terminals and the UMTS base station. The distance between nodes was also used in [10] to present packet error rate (PER) in MB-OFDM (Multi Band OFDM) and IR (impulse radio) type UWB devices. Results of computer simulations of NB OFDM system BER in the presence of an impulse radio UWB radar are presented in [11] as a function of E_b/N_0 for selected ratios between desired (NB) and undesired (UWB) signals.

Most of the publications mentioned above used simple AWGN channel models or measurements taken in good propagation conditions (LOS). In contrast [12] contains results of OFDM UWB transmission quality simulations in the presence of OFDM WiMax interference obtained using the Saleh-Valenzuela multipath propagation channel model with different channel parameters (LOS and NLOS conditions), and [13] presents the improvement of the BER value for IR UWB in the presence of 802.11a narrowband interference caused by a digital delay filter, also in the S-V channel model.

The publications mentioned above are just examples of different methods for results presentation which can be found in thousands of papers published in last years. Such variety of UWB intersystem electromagnetic compatibility evaluation methods complicates any comparison of results presented in these publications. Some simple way of NB and UWB systems coexistence evaluation is needed to reduce the effort required to compare data from different research groups working on similar topics in the field of intersystem electromagnetic compatibility (EMC).

II. COMPATIBILITY REGION

A. Coexistence Scenario

In order to define "compatibility region", the NB and UWB devices coexistence scenario has to be presented and explained. Assume that we have two receivers, NB and UWB (it can be impulse-type UWB, but not necessarily) located in the same place (see Fig. 1), simultaneously receiving two signals: narrowband with power at the input of both receivers equal PNB and ultra wideband with power PUWB (differences in characteristics of antennas are omitted). We also assume that in both systems the signal to noise ratio is high enough to discard environmental noise or internal noise, so the interference from the coexisting system is the main source of possible degradation to the radio transmission quality.

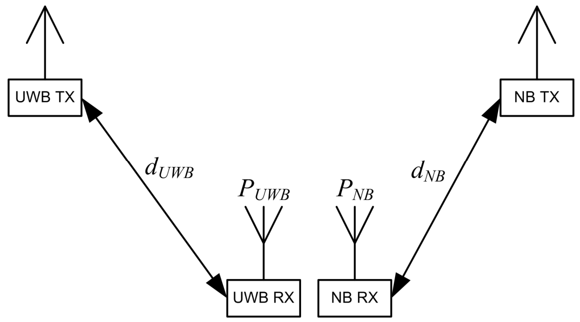

Fig. 1. NB and UWB receivers coexistence scenario.

Both systems will meet the requirements of EMC if the NB receiver is able to receive NB signals with the requested quality (BER and/or data rate) in the presence of UWB interference, while the UWB receiver at the same time is able to receive UWB transmission in the presence of the NB signal with the same quality requirements. Quality of transmission in both systems can be measured in laboratory conditions using the equipment presented in Fig. 2, where the ratio between narrowband and ultra wideband signal power PNB/PUWB at the inputs of both receivers may be changed using variable attenuators.

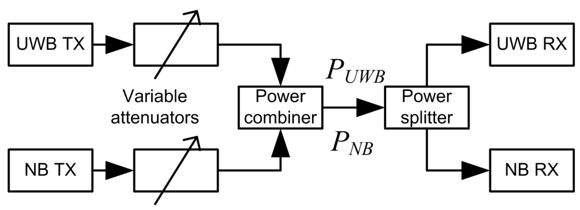

Fig. 2. Measurement of NB and UWB mutual interference.

B. Compatibility Region Concept

Two kinds of radio communication systems, narrowband and ultra wideband may work together in selected areas only if certain PNB/PUWB ratios can be found at which both systems satisfy at least some transmission quality limit. In order to allow simple comparison between different radio communication systems and different methods of coexistence improvements, the author proposes to define the compatibility region as the difference (in dB) between the maximal value of the (PNB/PUWB)max ratio, at which UWB transmission quality reaches a defined limit, and the minimal value of (PNB/PUWB)min, at which a quality limit is reached by the narrowband transmission, all under the following assumptions:

- the noise level during measurements is low enough to neglect it as a source of transmission errors,
- the channel coding gain is not used in receivers, even while transmitted signals are protected by some channel coding (transmission quality measured strictly in physical layer)
- NB and UWB transmissions should be continuous, without inactivity periods or retransmissions, in that case the compatibility region can be read from the BER chart at the selected BER limit, for example 10-3, as presented in Fig. 3,
- for radio systems which implement some ARQ methods, or transmission scheduling based on interference measurements or channel state evaluation, the compatibility region can be read from the real data rate chart at the selected limit, for example 90% of nominal data rate in case of no interference, as presented in Fig. 4.

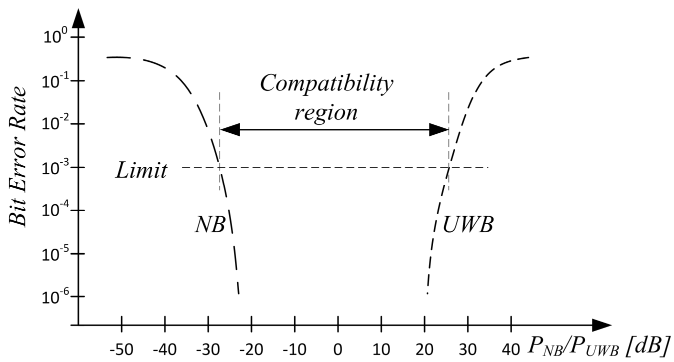

Fig. 3. The compatibility region defined on a NB and UWB transmission BER chart.

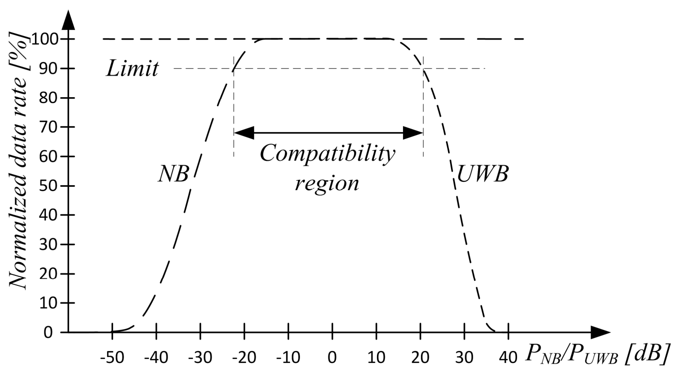

Fig. 4. Fig. 4. The compatibility region defined on a NB and UWB transmission real data rate chart.

C. Change in Compatibility Region Caused by Coexistence Improvement Methods

Full information about (PNB/PUWB)max and (PNB/PUWB)min allows us to calculate, for example, the minimal distance from NB receiver to interfering UWB transmitter based on the NB signal level at the NB receiver location (dUWB on Fig. 1), but also information limited to the width of the compatibility region or even one part of the presented transmission quality charts is valuable, because every method which improves the coexistence of NB and UWB transmissions will increase the compatibility region.

The degree of change in the compatibility region caused by coexistence improvements is proposed to be the simplest method of comparison between different methods to improve coexistence between NB and UWB systems. Because NB transmissions use spectrum on a priority basis, the compatibility problem has to be solved by proper construction of UWB signals and devices. There are two main methods of coexistence improvement:

- UWB signal spectrum shaping, which allow one to reduce UWB power spectral density at the frequency of narrowband transmission, will increase the compatibility region by moving the BER chart for NB transmission to the left (Fig. 5),

- UWB receiver modifications, which allow one to reduce sensitivity to narrowband transmissions, will increase the compatibility region by moving the BER chart for UWB transmission to the right (Fig. 6).

In both cases there is no need for full measurement of the compatibility region, just the measurement of the gain caused by compatibility improvement methods. Full information about the compatibility region can be found by collecting data from different researchers, comparing measurements of NB transmission quality in presence of UWB interference and UWB transmission quality in presence of NB interference of the same kind. In the same way laboratory measurements and computer simulations can be used to create the full chart required to obtain compatibility region data.

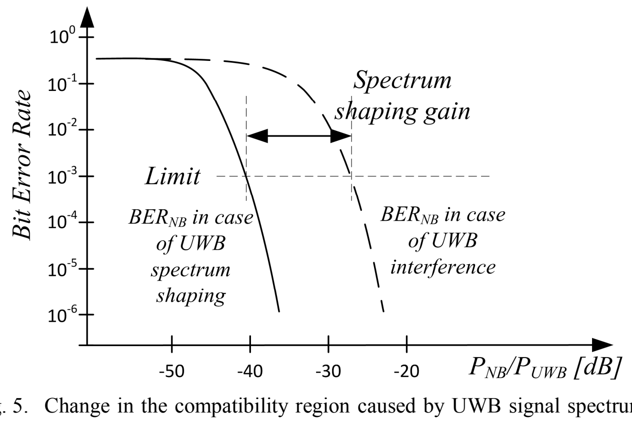

Fig. 5. Change in the compatibility region caused by UWB signal spectrum shaping.

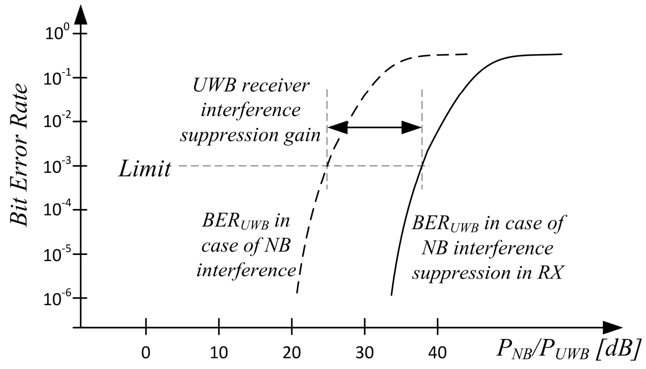

Fig. 6. Change in the compatibility region caused by NB interference suppression in the UWB receiver.

III. EXAMPLES

The idea of the compatibility region was used by the author to evaluate methods of IEEE 802.15.4a UWB impulse radio signal spectrum shaping, described in [14] and [15]. Spectrum shaping, presented in these papers, can reduce power spectral density of the IR UWB signal at any frequency of narrowband transmission to reduce interference from UWB devices to a NB system. The same spectrum shaping applied to reference signals in IR UWB correlation receivers reduces their sensitivity to narrowband interference.

Fig. 7 presents sample results for UWB signal spectrum shaping. A NB signal was QPSK modulated with data rate 1 Mb/s, without channel coding and framing (continuous data stream). The UWB signal was generated in accordance with IEEE 802.15.4a framing and modulation, but transmitted without any gaps between frames. The parameters of the UWB modulation are: Ncpb=16, Nhop=8, radio channel number 0 (center frequency 499,2 MHz, sub-gigahertz band). The NB signal center frequency was chosen in the flat part of the UWB spectrum (350MHz). UWB spectrum shaping using the first method described in [14] and [15] allows one to increase the compatibility region by 15 dB by improving NB transmission quality in low PNB/PUWB ratio range without any significant change in the BER chart for UWB transmission. BER for NB transmission was measured in a laboratory using equipment presented in [15] while BER for UWB transmission was estimated using computer simulations.

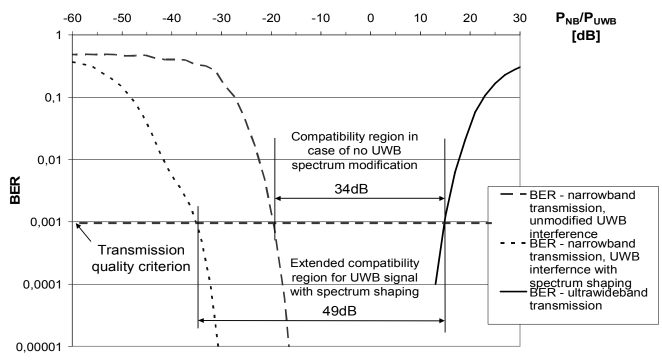

Fig. 7. Sample results of NB and UWB transmission coexistence improvement by UWB signal spectrum shaping.

The same spectrum shaping method, applied to reference signals in a UWB correlation receiver allows one to increase the compatibility region by approximately 10 dB for signals with the same transmission parameters as in the previous example. A change in the time structure of reference signals increases UWB reception quality for a high PNB/PUWB ratio (see Fig. 8), but this operation is not as effective as UWB signal spectrum shaping in the transmitter.

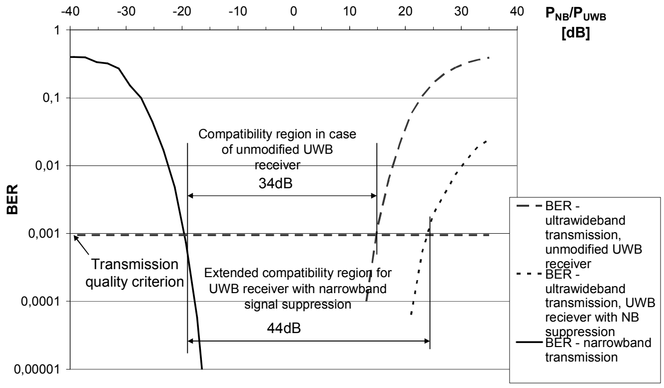

Fig. 8. Fig. 8. Sample results of NB and UWB transmission coexistence improvement by NB interference suppression in IR UWB receiver.

By comparing data from charts in Fig. 7 and Fig 8 we can see that it is possible to extend the compatibility region to 59 dB by applying the IR UWB spectrum shaping method in both: UWB transmitter (moves NB BER chart to the left) and UWB receiver (moves UWB BER chart to the right) without need to make other measurements or simulations.

IV. CONCLUSIONS

The concept of a compatibility region may simplify comparison between different methods of narrowband and ultra wideband coexistence improvement. At least half of publications, cited in section I of this letter can be used to get data suitable for calculation of the compatibility region, but in order to disseminate this way of compatibility evaluation some additional examples of real applications are needed together with global agreement on the transmission quality limits used to calculate the value of compatibility region.

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