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First Experimental Impulse-Radio Ultra-Wideband Transmission Under the Russian Spectral Emission Mask

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Ultra-wideband impulse-radio wireless transmission under the stringent conditions and complex shape of the Russian spectral emission mask is experimentally demonstrated for the first time. Transmission of 1Gbit/s and 1.25Gbit/s signals over distances of 6m and 3m is achieved with a BER below 3.8×10^{-3}.

Introduction: Ultra-wideband (UWB) wireless is a promising technology for short range and high speed communications, combining signals with large bandwidths in the frequency range of 2.85–10.6 GHz and low radio frequency (RF) power spectral density emission [1]. The use of such low power levels ensures non-problematic coexistence with other already deployed wireless technologies – e.g. WiFi, GPS and mobile services – and allows deployment in environments sensitive to RF interference, such as aicraft cabins and hospitals [2, 3]. Regulations on the use of the UWB spectrum vary between countries, with those set by the US Federal Communications Commission (FCC) [4] being the most lenient and those of the Russian State Commission for Radio Frequencies (SCRF) [5] the most stringent with significantly lower allowed power levels and a complex spectral shape. License free operation is generally allowed, provided strict regulations on the emitted power levels are satisfied.

Impulse-radio ultra-wideband transmission (IR-UWB), where a series of pulses form the basis for data transmission, has become the most widely studied approach [6, 7]. Most of the recent work on pulse shaping has focused on transmission under the FCC mask and records of as much as 4 Gbit/s over 4 m have been achieved [6]. Due to the more stringent radiated power limitations and significantly more complex shape of the SCRF spectral emission mask, the reuse of results obtained under the FCC mask is impossible. Consequently dedicated pulse shaping techniques are required for transmission under the Russian SCRF mask.

Simple, basic pulse shapes as previously employed can not effectively adapt to the SCRF mask shape, resulting in a loss of either spectral or power efficiency, or even both. The dedicated design of pulses for transmission under the SCRF mask has been addressed in [8, 9, 10] – including multi-carrier transmission [11] – their performance in wireless transmission has however not been experimentally confirmed.

In this Letter, the first experimental demonstration of a transmission under the SCRF mask is reported, achieving data rates of 1.25 Gbit/s and 1 Gbit/s signals over respective distances of 3 m and 6 m while maintaining a bit error rate below the limit for a commercial 7 % overhead forward error correction.

Ultra-Wideband Signal Shaping for Transmission Under the SCRF Mask: The spectral emission mask for indoor ultra-wideband communication systems defined by the Russian State Commission for Radio Frequencies (SCRF) [5] has two major additional restrictions when compared to the mask defined by the US Federal Communications Commission (FCC) [4] as shown in Fig- 1. First, even at its highest point, the allowed power spectral density of −45 dBm/MHz is more than 3 dB below the level of −41.3 dBm/MHz allowed by the FCC mask; second, its shape is significantly more complex, introducing major challenges for

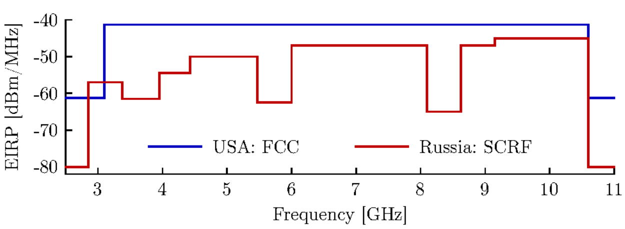

Fig. 1 *Comparison of the effective isotropic radiated powers (EIRP) allowed by the UWB spectral emission masks for the USA and Russia, as defined by the respective FCC and SCRF decisions*

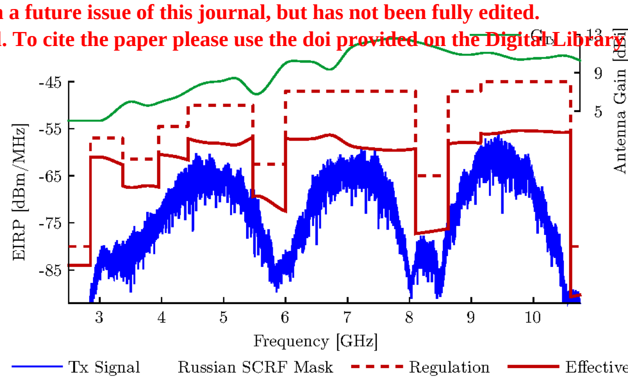

Fig. 2 *SCRF regulation and effective EIRP masks, antenna gain and spectrum of generated 1 Gbit/s IR-UWB signal*

pulse shaping. The SCRF mask is characterized by two sharp dips – defining three distinct spectral windows which are available to UWB communications – and thus requires dedicated pulse design.

The signal employed for transmission performance analysis in this Letter is defined through digital signal processing and based on an overlay of four Nyquist type pulses – the first designed to cover the entire UWB range and the other three centered within the three windows defined by the SCRF mask. The pulses share a large roll-off factor and are assigned different weights in order to best fit within the shape of the SCRF mask. Good approximation of the latter is achieved with pulse durations of 0.8 ns and 1 ns, corresponding to pulse repetition rates of 1.25 GHz and 1 GHz, respectively. Modulation is performed using pulse flipping to prevent the occurrence of spectral spikes at multiples of the repetition rate.

The resulting signal is recorded on an electrical spectrum analyzer with a resolution of 1 MHz and an averaging time of 1 ms and compared to the effective spectral emission mask obtained from the SCRF regulations by deducting the antenna gain over frequency. The obtained spectrum and masks are shown in Fig. 2, confirming signal compliance with the SCRF mask.

Experimental Setup: The setup employed for the UWB transmission under the SCRF spectral emission mask is shown in Fig. 3 and consists of an arbitrary waveform generator (AWG) with a sampling speed of 65 GSa/s, generating the described pulse sequence modulated with a pseudo random bit sequence (PRBS) of length $2^9 - 1$. A set of RF attenuators (−22 dB at 1 Gbit/s and −23 dB at 1.25 Gbit/s) at the output of the AWG reduces signal levels below the limits of effective isotropic radiated power (EIRP) set by the SCRF spectral emission mask, while a lowpass filter with a 3 dB cutoff frequency of 9.6 GHz suppresses high frequency noise at 10.6 GHz and above – i.e. outside the UWB mask range.

The signal is transmitted using a pair of bow-tie phased array antennas with an antenna gain over frequency performance as shown in Fig. 2. The received signal is highpass filtered with a 3 dB cutoff frequency of 3.5 GHz and amplified by two wideband amplifiers with a gain of 26 dB each and a typical noise figure of 3 dB; a lowpass identical to that at the transmitter limits received noise bandwidth. Finally the signal is recoded on a digital storage oscilloscope (DSO), processed offline through digital signal processing and bit error rates (BER) are determined.

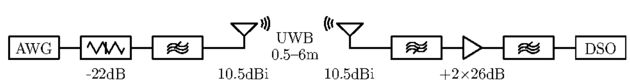

Fig. 3 *Impulse-radio ultra-wideband transmission setup. AWG: arbitrary waveform generator, DSO: digital storage oscilloscope*

Experimental Results and Discussion: Wireless transmission of the generated 1 Gbit/s and 1.25 Gbit/s UWB signals is performed over wireless distances of 0.5–10 m and corresponding bit error rates are shown in Fig. 4. Assuming a reference BER of 3.8×10^{-3} – i.e. the limit of a commercial forward error correction with 7 % overhead (7 % OH FEC) – wireless transmission distances of 3 m and 6 m are achieved for data rates of 1.25 Gbit/s and 1 Gbit/s respectively.

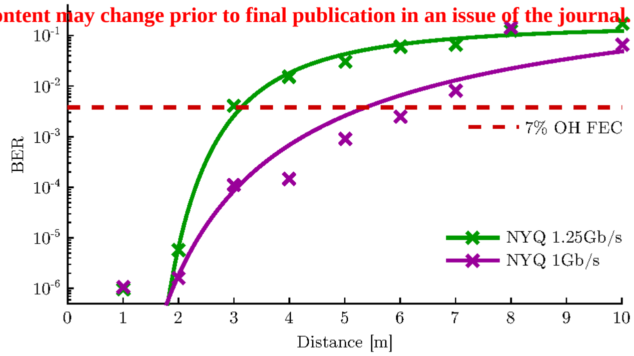

Fig. 4 *BER over distance for UWB transmission with data rates of 1 Gbit/s and 1.25 Gbit/s*

The sharp decline in achievable transmission distance with increased data rate is found to be due to the reduced energy per pulse, resulting from both the reduced pulse duration and the corresponding loss in flexibility for spectral shaping. The latter results in a requirement for an increase in roll-off factor from 0.9 to 1 and in the use of 1 dB more attenuation at the output of the AWG.

To the best of our knowledge this is the first experimental demonstration of ultra-wideband wireless transmission under the strict regulations of the SCRF mask for UWB systems in Russia. Considering the complex shape of the SCRF mask and a 4 dB lower spectral emission limit even at its maximum point compared to the FCC mask, these results compare favourably to the current record under the FCC mask in [6].

Conclusions: High data-rate ultra-wideband transmission under the strict regulations of the SCRF mask has been demonstrated for the first time, using impulse-radio based on pulses designed to make efficient use of the spectral emission levels allowed. Wireless transmission distances of 3 m and 6 m for data rates of 1.25 Gbit/s and 1 Gbit/s respectively are achieved with bit error-rates below the limit of 3.8×10^{-3} for a commercial forward error correction with 7 % overhead.

These results obtained confirm the viability of impulse-radio ultra-wideband transmission for high-speed communications, even under the stringent and complex regulation of the Russian State Commission for Radio Frequencies.

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