# PHOTONIC GENERATION OF ULTRA-WIDEBAND SIGNAL FOR RADIO-OVER-FIBER SYSTEMS

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This work presents method for generation of ultra-wideband (UWB) signal for radio-over-fiber (RoF) systems. We consider the using sharing of ultra-wideband signal technology and RoF technology for third-channel transmission. However, there is a problem of choice of method for UWB radio signal generation that provides the most effective utilization over installed FTTx-networks for data transmission of multimedia high bit rate content. We developed the scheme of simulation that generates the UWB radio impulse (IR-UWB) conforming to spectral mask approved by State Committee of Radio Frequencies. Three separate IR-UWB channels are generated over fiber optic interface with following frequency shifts 4.5 GHz, 7 GHz and 9.5 GHz are realized in proposed scheme. Correlation between bit error ratio and received optical power for different singlemode fiber lengths was computed and represented in this work.

***Keywords:*** ultra-wideband signal, radio-over-fiber, impulse-radio-ultra-wideband, Gaussian impulse, bit error ratio, SCRF mask, spectral power density, Mach-Zehnder modulator.

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## Introduction

UWB transmission technology is advanced short range high speed wireless communication technology due to its very low signal-to-noise ratio (SNR), extremely low effective isotropic radiated power (EIRP) –45dBm/MHz and ultra-wideband bandwidth (2,85 … 10,6 GHz). UWB systems have small coverage area radius (up to 10 m). FTTX technology has such advantages as low loss, large bandwidth, long distance transmission (more than 100 km). According to this shared use of UWB technology and FTTX technology is advanced research area in infocommunication technologies. It allows to increase access rate to multimedia services in the conditions of avalanche data transmission traffic increasing in the world.

Key advantages of UWB systems are low radiated power, large unlicensed bandwidth, low level of self-interference, multi-path fading tolerance, low level of intermodulation interference, low probability of intercept. The consolidation of UWB and RoF technologies gives additional advantages such as: a) no trans-modulation in optical cable; b) no frequency up-conversion is required at customer premises. This research area can be attractive in the future for transmission in one optical and wireless channel several information channels, which will be used to transmit different standards (LTE, Wi-Fi, HD, 4K digital television, UWB and etc.).

To implement this broadband access systems, there are technical issues to tackle: a) simple and cost effective UWB signal generation at provider's base station; b) from a quality of service (QoS) point of view, high speed IR-UWB modulation of multi-Gigabit is expected to meet high bandwidth requirements of the end-users; c) high data rate in optical and wireless channel should be implemented; d) integration of the photonically generated IR-UWB system into wavelength division multiplexed passive optical networks (WDM-PON) infrastructure is highly desirable to provide various types of telecommunication services [1].

## Analysis of existing ultra-wideband signal photonic generation methods in RoF systems

There are two UWB signal generation methods: electrical and optical. There is a difficulty with signal shaping due to large bandwidth (2,85 … 10,6 GHz) when generating UWB signal electrically. This leads to significant increase in cost of transmission equipment because analog-to-digital conversion and digital-to-analog conversion of electronic devices rarely exceeds 160 MHz. For that reason UWB signal photonic generation is of interest due to simple implementation by using passive and active optical elements.

Today several UWB signal photonic generation methods are known: a) direct laser modulation by

UWB signal generator [2-7]; b) dispersive element use for optical impulse widening with necessary period [8]; c) use of relaxation oscillations of DFB laser [1, 9]; d) fiber Bragg grating use including chirping fiber Bragg gratings [10-11]; e) use of different passive optical conversions for output UWB signal changing [12].

All methods of UWB signal photonic generation that mentioned above are submitted for Federal Communication Commission (FCC) spectral mask. In the Russian Federation accepted spectral mask is recommended by State Committee of Radio Frequencies (SCRF spectral mask), Fig. 1 [13]. Currently there are not any works on photonic generation of UWB signal relevant to SCRF spectral mask.

The limiting factor that affects channel bandwidth is the existence of «windows» in spectral mask in the range of 3,95 … 4,425 GHz – first «window», 6 … 8,1 GHz – second «window», 8,625 … 10,6 GHZ – third «window». The existence of these «windows» prevents the forming of one IR – UWB signal with high data rate. Wherein it is necessary to follow the criteria of maximum spectral power density which limits the effective use of SCRF spectral mask.

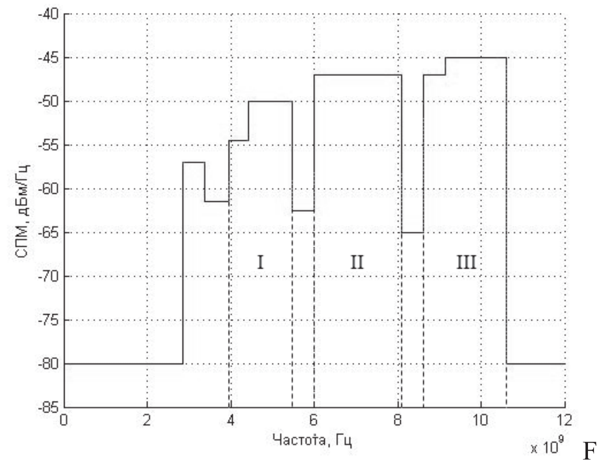



Fig 1. SCRF spectral mask [13]

When using the whole SCRF spectral mask, spectral power density level won't be at maximum point, thus the coverage area radius of wireless personal network will significantly be limited. According to this, the generation of three signals that are relevant to the SCRF spectral mask «windows» with maximum level of power spectral density is of interest.

In [14] the authors offered the method of signal forming for RoF system, using OSSB (Optical single sideband) signal by adding optical carrier and optical signal.

## Ultra-wideband signal photonic generation for RoF systems

Implementation scheme of proposed UWB signal transmission technology using RoF technology is shown in Fig. 3a.

This simulation model scheme generates three narrowband signals, which frequencies are shifted relatively to the carrier frequency to 4,5 GHz, 7 GHz and 9,5 GHz. 4,5 GHz, 7 GHz and 9,5 GHz – are the central frequencies of so called «windows» of SCRF spectral mask, accepted in the Russian Federation. To realize the approach mentioned above, four continuous wave (CW) lasers are used. Their technical characteristics are shown in Fig. 4a. The first CW laser generates the signal for the third «window» of SCRF spectral mask. His central frequency is shifted relatively to the carrier frequency to 9,5 GHz. The laser power is –1 dBm. The optical signal from CW laser goes to Mach-Zehnder modulator (MZM). The optical signal modulation is perfomed by electrical Gaussian impulse, which is fed to the electrical input of Mach-Zehnder modulator.

The Gaussian impulse was chosen because his spectrum doesn't have sidebands. Impulse period is 0,8 ns. Pseudo random bit sequence (PRBS) generator sample rate is 1,25 Gb/s. Random bit sequence from PRBS generator goes to Gaussian impulse generator. After that the electrical Gaussian impulse sequence goes to Mach – Zehnder modulator. Generation of two other signals is similar. The power of CW laser that generates carrier frequency is 5 dBm and central frequency is 192,986 THz. Linewidth of four CW lasers are 100 kHz. The carrier power over the signal power is almost three times more. Such characteristics were chosen to obtain the signal level at photodiode output corresponding the maximum level of power spectral density of SCRF spectral mask. The carrier power and signals power were selected so that the total power at coupler output was 0 dBm. With such power, dispersion and nonlinear distortion affect less. When the carrier power is increasing and the signal power is decreasing, noise level prevents appropriate signal detection. And when increase signal power is increasing and carrier power is decreasing there is challenge to obtain the signal spectrum at the photodiode output.

After that three signals and carrier go to optical coupler. Optical signal spectrum at the optical coupler output is shown in Fig. 2. The optical signals go to optical line, amplified by optical amplifier and go to PIN – photodiode. The overall –3dB bandwidth of output signal is 1,25 GHz, it is shown in Fig. 3b. The spectral efficiency is 0,52 b/s/Hz. The output signal electrical spectrum after photodiode is shown in Fig. 3c. The output signal in time domain after photodiode is shown in Fig. 3d.

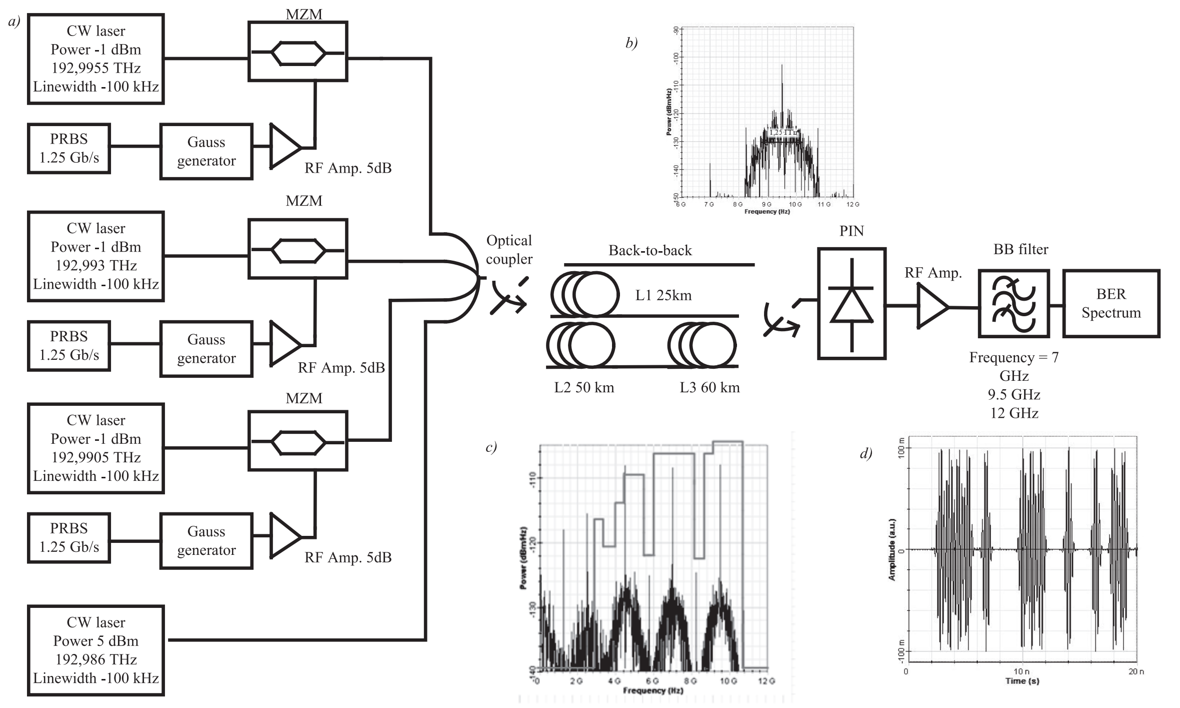
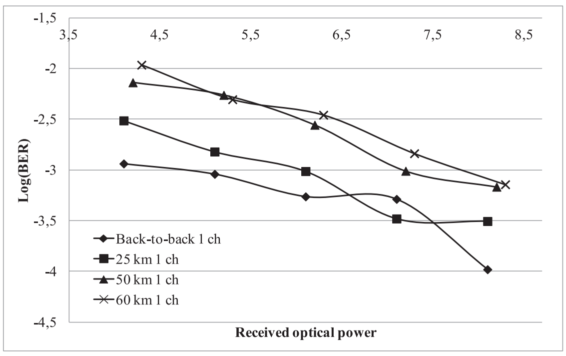
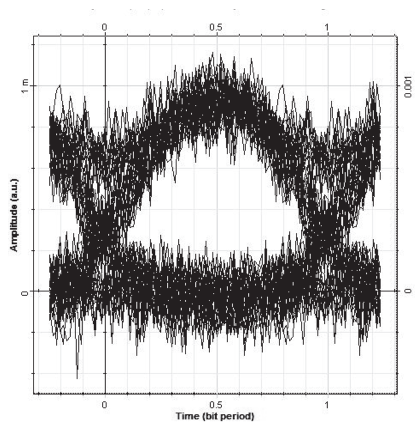



Fig 3. Photonic generation of UWB signal: a) UWB signal generation scheme; b) output signal bandwidth; c) power spectral density of received signal and SCRF spectral mask; d) received signal in time domain




*a*) *b*)

Fig 4. First channel: a) BER; b) eye diagram when the signal power at photodiode input is 8 dBm

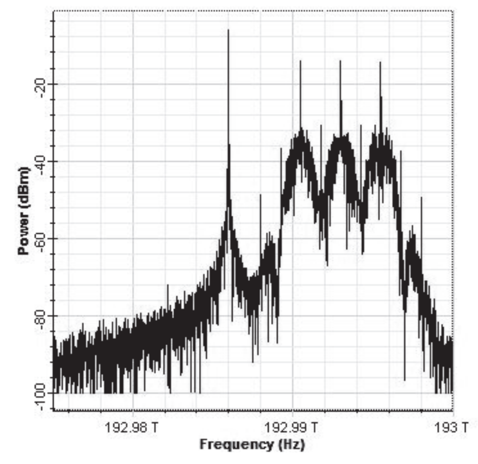



Fig 2. Optical signal spectrum at the optical coupler output

The simulation model scheme shown in Fig. 4 was implement in simulation modeling program Optisystem 13.0. BER measurement results are shown in Fig. 5. The measurements were taken for four cases: back-to-back, 25 km optical line, 50 km optical line and 60 km optical line. SMF fiber with standard characteristics was used. Wherein optical amplifier power was regulated from 0 … 20 dB and with the help of power meter the power after optical amplifier was measured. The power at photodiode was 4 … 8 dBm. UWB signal has to pass through bandpass filter 2,85 … 10,6 GHz to suppress side emission and to transmit along the wireless link.

## Conclusions

Photonic generation scheme of UWB signal relevant to SCRF spectral mask was proposed in the paper. The key feature of proposed scheme is the generation of three separate signals which frequencies are shifted to 4,5 GHz, 7 GHz and 9,5 GHz. BER measurements were taken for four cases: back-to-back, 25 km optical line, 50 km optical line and 60 km optical line.

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## ОПТИЧЕСКАЯ ГЕНЕРАЦИЯ СВЕРХШИРОКОПОЛОСНОГО СИГНАЛА ДЛЯ ROF СИСТЕМ

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В статье предлагается метод генерации сверхширокополосного (СШП) сигнала для Radio-over-Fiber (RoF) систем. Рассматривается совместное использование СШП технологии передачи данных и технологии RoF для передачи трех независимых каналов. При использовании СШП технологии совместно с технологией RoF возникает проблема выбора метода генерации СШП радиоимпульса, который бы позволил максимально эффективно использовать существующие сети FTTX (fiber to the x – оптоволокно до точки x) для передачи мультимедийного высокоскоростного контента. В работе схема имитационной модели, позволяющая сгенерировать IR-UWB (impulse radio ultra-wideband – сверхширокополосный радиоимпульс) сигнал, соответствующий спектральной маске Государственной комиссии по радиочастотам (ГКРЧ). В схеме реализуется оптическая генерация трех отдельных IR-UWB каналов, частоты которых смещены на 4,5 ГГц, 7 ГГц и 9,5 ГГц. Приводится зависимость коэффициента битовых ошибок (BER – bit error rate) от принимаемой оптической мощности для разных длин SMF - волокна.

***Ключевые слова:*** *сверхширокополосный сигнал, radio-over-fiber, передача сверхкоротких импульсов, гауссовский импульс, коэффициент битовых ошибок, маска ГКРЧ, спектральная плотность мощности, модулятор Маха-Цендера.*

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## ИССЛЕДОВАНИЕ ПОВЕДЕНИЯ ОПТИЧЕСКИХ ВОЛОКОН В МОДУЛЯХ КАБЕЛЯ ПРИ ДЕФОРМАЦИИ

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Рассматривается поведение оптических волокон в модуле при его деформации. Показано, что резкое увеличение затухания волокон модуля вызвано перегибами волокна на волокне. Определены радиусы таких изгибов.

***Ключевые слова:*** оптический кабель, модуль, изгиб, оптическое волокно.