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Radio-over-Fibre Techniques and Performance

Roberto Llorente and Marta Beltrán
Universidad Politécnica de Valencia
Spain

1. Introduction

Radio-over-fibre (RoF) techniques have been subject of research during the last decades and find application in optical signal processing (photonic analogue-to-digital converters, photonic-microwave filters, arbitrary waveform generation), antenna array beamforming, millimetre-wave and THz generation systems, or photonic up- and down-converting links for applications such as broadband wireless access networks, electronic warfare and RADAR processing, imaging and spectroscopy or radio-astronomy (Seeds & Williams, 2006; Capmany & Novak, 2007). In these applications a radio signal typically in the millimetre-wave band is transmitted through optical fibre employing laser sources and electro-optical devices.

The use of optical fibre links to distribute telecommunication standards is the more successful application of RoF technology, usually known as hybrid fibre-radio (HFR) networks (Jager & Stohr, 2001). HFR networks have been deployed in the last decade due to the increasing demand of high-bitrate communication services in today's access network. This demand is based on the steady market introduction of services requiring the transmission of massive data quantities, like high-definition movie distribution, on-line gaming and rich Internet experience by example (Merill Lynch, 2007).

The HFR concept applied to the enhancements of community antenna television (CATV) networks reflected in the so-called hybrid-fibre coax (HFC) network, in which a combination of digital and analogue channels is distributed from a central location to many users distributed geographically (Darcie & Bodeep, 1990; Wilson et al., 1995). In HFC networks the last mile connection is provided through coaxial cable whilst in HFR networks the last mile connection is always a wireless link. This is not a minor difference, as the wireless environment is much more hostile than cable imposing restrictive RoF link performance requirements in terms of linearity, noise and power handling capabilities, key parameters to guarantee a spurious free dynamic range (SFDR) for the whole link high enough to cope with geographical dispersion of users and complex modulation formats used by current wireless standards. A simplified schematic of a HFR network is shown in Fig. 1.

RoF technology allows centralising the required RF signal processing functions in one shared location (Central Office, CO) and then to use optical fibre to distribute the RF signals to the remote access units (RAU). This allows important cost savings as the RAUs can be simplified significantly, as they only need to perform optoelectronic conversion and filtering and amplification functions. It is possible to use wavelength multiplexing techniques (WDM) in order to increase capacity and to implement advanced network features such as

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dynamic allocation of resources. This centralised and simplified RAU scheme allows lower cost system operation and maintenance, which are reflected into major system OPEX savings, especially in broadband wireless communication systems where a high density of RAUs is necessary.

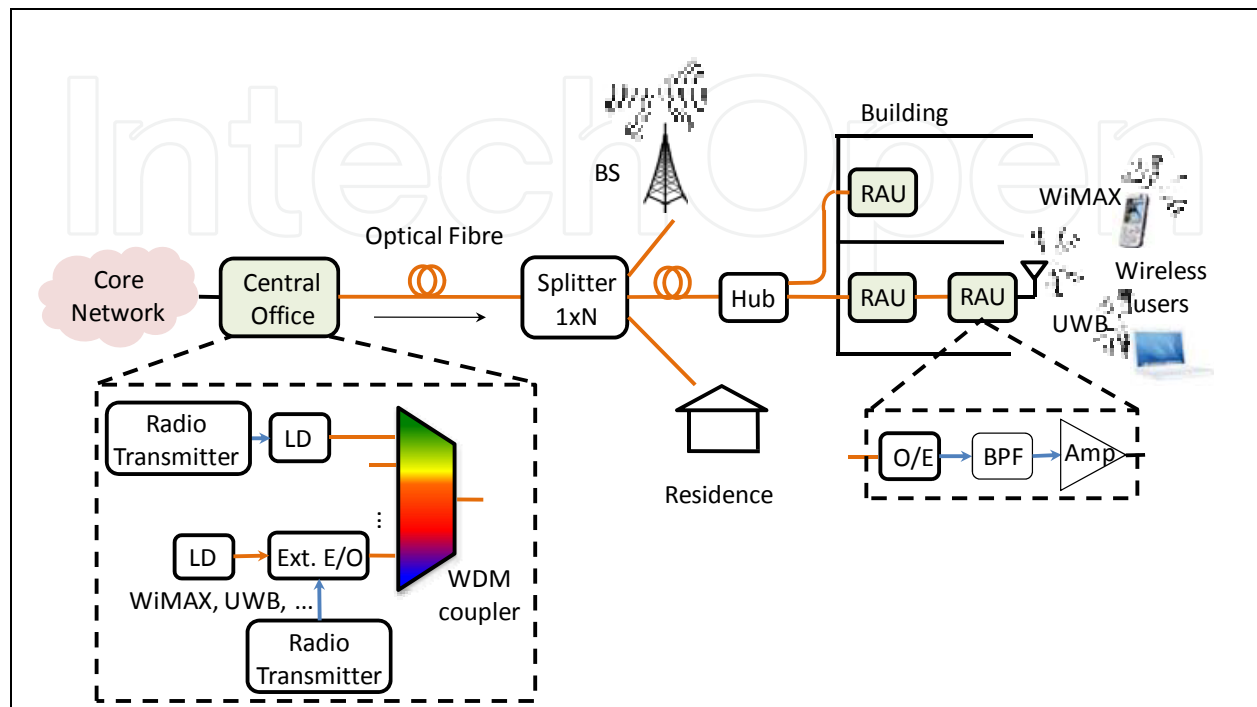


Fig. 1. Simplified schematic of a RoF system. LD: Laser diode. BS: Base Station. RAU: Remote Access Unit. BPF: Band-pass filter. Amp: Electrical amplifier.

The CO and the RAU perform electro-optical (E/O) and opto-electronic (O/E) conversion of wireless signals respectively. E/O conversion is achieved employing either directly modulated laser sources or external electro-optic modulators. O/E conversion is done employing photodetectors or photoreceivers (Seeds & Williams, 2006). Regarding the RF transport, when the signal is transported directly at the frequency of operation there are benefits regarding cost, complexity and upgradeability, as there is no need for complex RF signal processing at the RAU involving up/down conversion or base-band mux/demux (Capmany & Novak, 2007; Jager & Stohr, 2001).

RoF techniques and complete transmission systems have been demonstrated for frequencies up to 120 GHz (Hirata et al., 2003). As mentioned before, the most successful application of RoF technologies has been the transmission of wireless standards over optical fibre links in centralized architectures, also known as distributed antenna systems (DAS) for both indoor and outdoor applications. The broad bandwidth of the optical fibre facilitates standard-independent multiservice operation for cellular systems, such as GSM (Owaga et al., 1992), UMTS (Persson et al., 2006), wireless LAN (WiFi 802.11 a/b/g/n) (Chia et al., 2003; Niiho et al., 2004; Nkansah et al., 2006) and also for emerging technologies WiMAX (Pfrommer et al., 2006) and Ultra-wideband (UWB) (Llorente et al., 2007). Available commercial systems however are typically limited to frequency ranges between 800-2500 MHz. Demonstrations of such DAS systems include their deployment to provide uniform wireless coverage in important sportive events such as the 2000 Olympic games and 2006 world cup (Rivas & Lopes, 1998; Cassini & Faccin, 2003). For indoor applications where picocell configurations

are envisaged, advanced multi-function devices such as waveguide electro-absorption modulator (Wake et al., 1997) or polarization independent asymmetric Fabry-Perot modulators (Liu et al., 2003; Liu et al., 2007) are used as detector/modulator.

Two key factors limiting the overall transmission performance in RoF systems are the optical source and the electro-optic modulation technique employed. Regarding the laser source, at frequencies used for major wireless standards (GSM, WiFi 802.11 a/b/g, UMTS) and also WiMAX up to 5-6 GHz, directly modulated semiconductor lasers are preferred due to lower cost (Qian et al., 2005). For higher frequencies, the required performances can be satisfied only by externally modulated transmitters. Devices with bandwidth handling capabilities in excess of those required by near-term WIMAX deployments, in particular distributed feedback (DFB) lasers offering the required bandwidth and performances, exist commercially, but normally at a high cost taking into account the number of devices required for typical applications. Recently, a lot of research efforts have been devoted to the development of low-cost/high-performance transmitters, for instance uncooled lasers (Ingham et al., 2003; Hartmann et al., 2003) or vertical-cavity surface-emitting lasers (VCSEL) (Persson et al., 2006; Chia et al., 2003). Probably, the most restrictive requirement for wireless services provision over RoF systems is the SFDR. Nowadays SFDRs in excess of $100 \text{ dB} \cdot \text{Hz}^{2/3}$ have been demonstrated experimentally, providing enough dynamic range to be employed in real applications (Seeds & Williams, 2006).

2. Ultra-wideband radio-over-fibre

2.1 Optical generation

The basic elements of RoF systems are broadband laser sources either employing direct or external modulation, a suitable transmission media such as multi-mode fibre (MMF), single-mode fibre (SMF) or plastic optical fibre (POF), and broadband photodetectors or photoreceivers (Seeds & Williams, 2006; Capmany & Novak, 2007; Dagli, 1999). The laser source and modulation method is the key element in the performance of RoF applications.

The generation of the optical signal to be transmitted in the RoF system is of special difficulty in the case of UWB signals. UWB is a radio technology intended for cable replacement in home applications within a range of tens of meters (picocell range), with high-definition video and audio communications a potential application (Duan et al., 2006). UWB is also attractive in many other applications including medicine, sensor networks, etc. UWB radio offers: High data rate capability ($>1 \text{ Gbit/s}$), low radiated power spectral density (PSD) minimising the interference, low-cost equipment commercially available. UWB is available in two main implementations: Multi-band orthogonal frequency-division multiplexing (MB-OFDM) and impulse radio. The ECMA standard (ECMA-368, 2007) uses MB-OFDM in 528 MHz individual sub-bands, whilst the impulse-radio implementation employs short pulses (in the range of hundreds of picoseconds) modulated in amplitude, time, polarity or shape to fill a desired bandwidth. MB-OFDM generally shows superior performance to the impulse-radio approach in terms of multi-path fading and intersymbol interference (ISI) tolerance, whilst impulse-radio is able to provide simultaneously communications, localization and ranging to a sub-centimetre resolution.

Currently, UWB uses the unlicensed band from 3.1 to 10.6 GHz mainly for indoor communications (FCC 04-285, 2004; ECMA-368, 2007) and the 24 GHz band for vehicular short-range radar applications (SARA Group, 2009), with a bandwidth larger than 20% of the centre frequency or a 10-dB bandwidth of at least 500 MHz as in FCC regulation (FCC

04-285, 2004) or at least 50 MHz as in ETSI regulations (ETSI, 2008) and a maximum radiated PSD of -41.3 dBm/MHz to guarantee spectral coexistence with other wireless narrowband services complementary in terms of range and bitrate such as WiMAX. Nevertheless, the whole UWB band 3.1-10.6 GHz is not available worldwide due to coexistence concerns (WiMedia, 2009). Outside the United States, available effective bandwidth is 1.5 GHz which only supports hundreds of Mbit/s. However, the unlicensed 60 GHz band enables UWB multi-Gbit/s wireless communications worldwide, as shown in Fig. 2, while challenges related to wireless channel and transceiver design have to be addressed (Daniels & Heath, 2007).

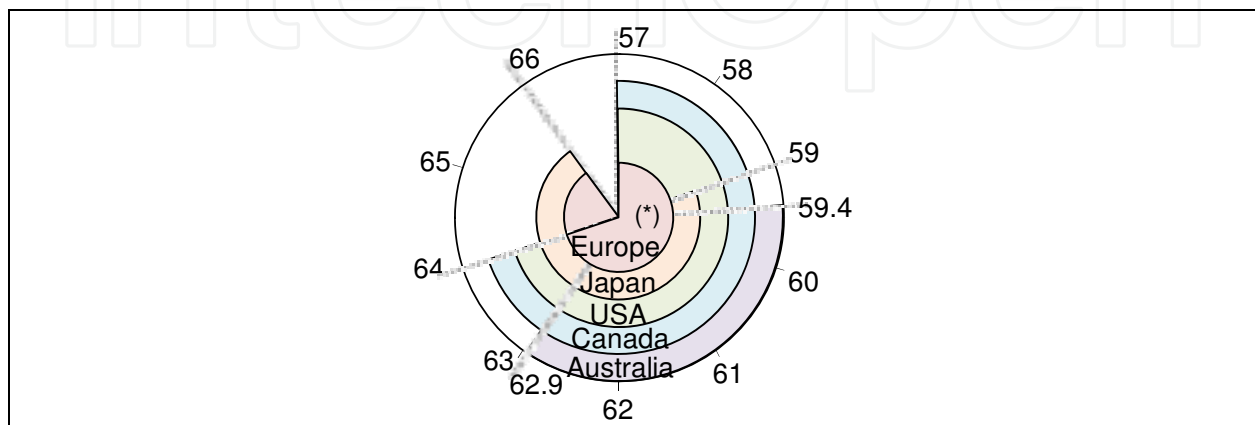


Fig. 2. International frequency allocations in the 60 GHz band (as of January 2009). (*) (ECC, 2009)

RoF distribution of UWB signals, termed UWB-over-fibre, has received great interest to extend the UWB range exploiting the advantages of the broad bandwidth, low loss, light weight, and immunity to electromagnetic interference offered by optical fibres.

In this section, different techniques for generating impulse-radio UWB signals in the optical domain is reported, featuring frequencies ranging from baseband up to millimetre-wave bands, including 24 GHz and 60 GHz. Some laser source characteristics are also discussed.

2.1.1 Impulse-radio ultra-wideband baseband

For UWB-over-fibre systems, it is desirable to generate UWB signals directly in the optical domain, avoiding the use of additional E/O and O/E conversions and exploiting the advantages provided by optics such as broadband processing, light weight, small size, and immunity to electromagnetic interference. Many techniques have been proposed to generate impulse-radio UWB signals in the 3.1-10.6 GHz band in the optical domain. These techniques have mainly focused on generating Gaussian monocycle and doublet pulse shapes, which have been demonstrated to provide better bit error rate (BER) and multipath performance among different pulse types (Chen & Kiaei, 2002).

RoF distribution of UWB signals in the band from 3.1 to 10.6 GHz for high-definition audio/video broadcasting in optical access networks, e.g. in fibre-to-the-home (FTTH) networks has been proposed (Llorente et al., 2008). The performance of both MB-OFDM and impulse-radio UWB implementations at 1.25 Gbit/s is experimentally analysed and compared for different SMF links, ranging from 25 km up to 60 km. Both UWB implementations exhibit error-free operation ($BER < 10^{-9}$) up to 50 km without dispersion compensation. The impulse radio technology exhibits degraded performance compared

with OFDM although other optimized impulse-radio generation and detection schemes could lead to different results. OFDM-UWB degrades quickly with fibre length, due to the carrier suppression effect (Schmuck, 1995).

Several demonstrations on optical generation of impulse-radio UWB in the band from 3.1 to 10.6 GHz including fibre and/or wireless transmission have been reported achieving 65 cm wireless distance at 500 Mbps data employing on-off keying (OOK) amplitude modulation (Abtahi et al., 2008); 20 cm at 1.025 Gbit/s OOK-modulated data after up to 10 km of dispersion-compensated SMF (Hanawa et al., 2009); 5 cm at 1.6875 Gbit/s OOK-modulated data after 24 km of SMF (Pan & Yao, 2009a); at 1.625 Gbit/s data employing pulse-position modulation (PPM) after up to 200 m of SMF (Shams et al., 2009a), or 37 km of SMF with no wireless transmission (Shams et al., 2009b); and at 781.25 Mbit/s data employing binary phase-shift keying (BPSK) modulation after 30 km of SMF (Yu et al., 2009). In addition, techniques have been reported capable of pulse shape modulation (PSM) (Dong et al., 2009), or reconfigurable for multiple modulation formats (Pan & Yao, 2009b).

Photonic generation of Gaussian monocycle pulses based on balanced photodetection of data Gaussian pulses has been proposed (Hanawa et al., 2007; Beltrán et al., 2008). Data Gaussian pulses are first generated by intensity modulation of an electrical data sequence with optical Gaussian pulses from a pulsed laser. This technique is shown in Fig. 3. Optical

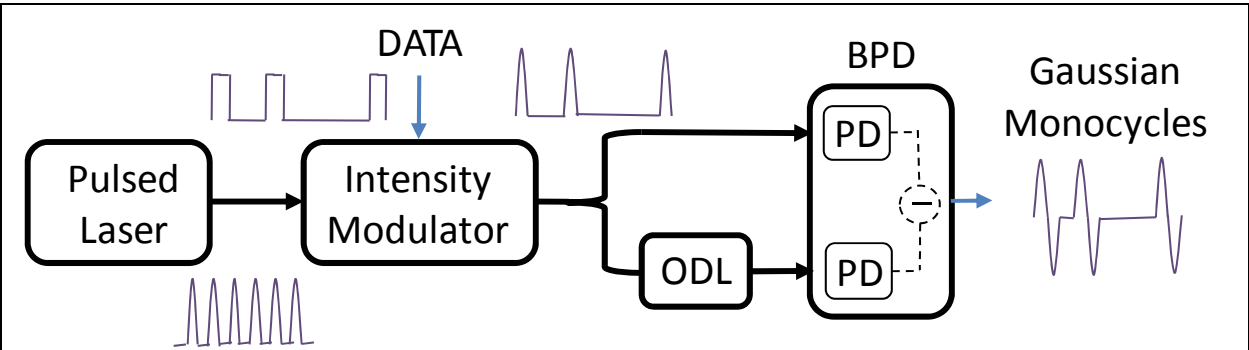


Fig. 3. Gaussian monocycle pulse generation based on balanced photodetection. ODL: Optical delay line. BPD: Balanced photodetector. PD: Photodetector.

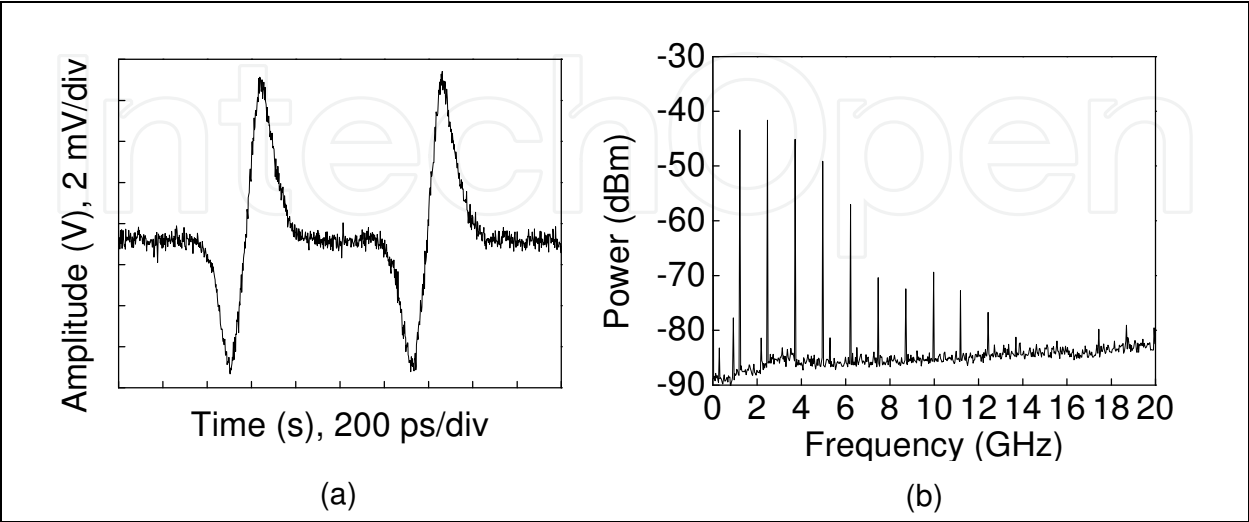


Fig. 4. Monocycle pulses generated employing the technique in Fig. 3; (a) the temporal waveform and (b) its spectrum (resolution bandwidth: 30 kHz).

data pulses are split into two equal parts to drive the two inputs of the balanced photodetector. Optical delay is employed to adjust the relative time delay between the two signals. The pulse width of Gaussian pulses and the time-delay difference are adjusted so as to generate the desired UWB bandwidth. This approach has been experimentally demonstrated employing an actively mode-locked fibre laser and a Mach-Zehnder modulator (MZM) (Beltrán et al., 2008). To control the pulse width, a spool of standard SMF is included after the MZM. Fig. 4 shows monocycles generated based on balanced photodetection exhibiting a UWB 10-dB bandwidth of 6 GHz at 1.25 Gbit/s. Gaussian monocycle pulses can also be generated based on differential photoreception of data Gaussian pulses (Beltrán et al., 2009b) targeting to reduce cost and complexity. Fig. 5 shows this technique. Again, data Gaussian pulses are first generated by intensity modulation of an electrical data sequence with optical Gaussian pulses from a pulsed laser. Optical data pulses are photodetected and amplified by an electrical amplifier providing complementary outputs. The two outputs are combined after adjusting their relative time delay to generate monocycles. The pulse width of Gaussian pulses and the time-delay difference are adjusted so as to generate the desired UWB bandwidth. This approach has been experimentally demonstrated employing an actively mode-locked fibre laser and a

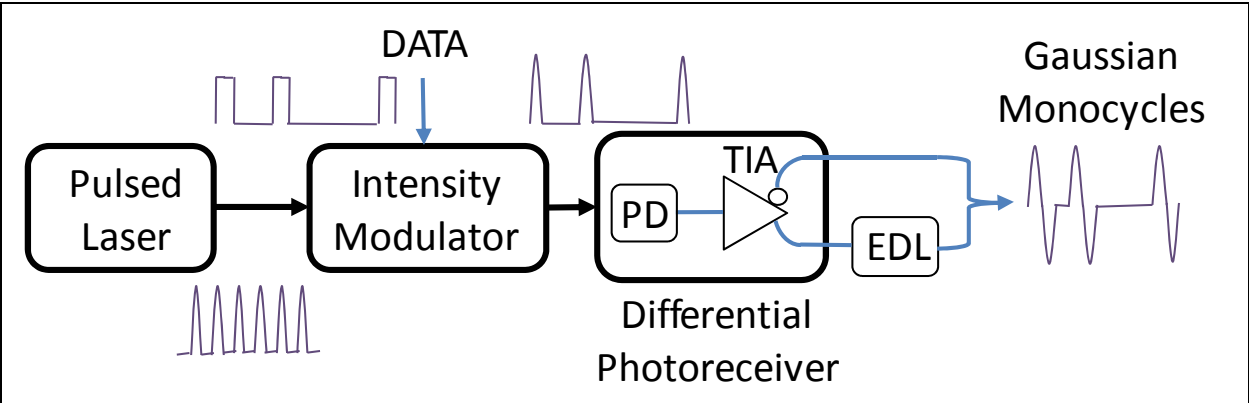


Fig. 5. Gaussian monocycle pulse generation based on differential photoreceiver. PD: Photodetector. TIA: Transimpedance amplifier. EDL: Electrical Delay Line.

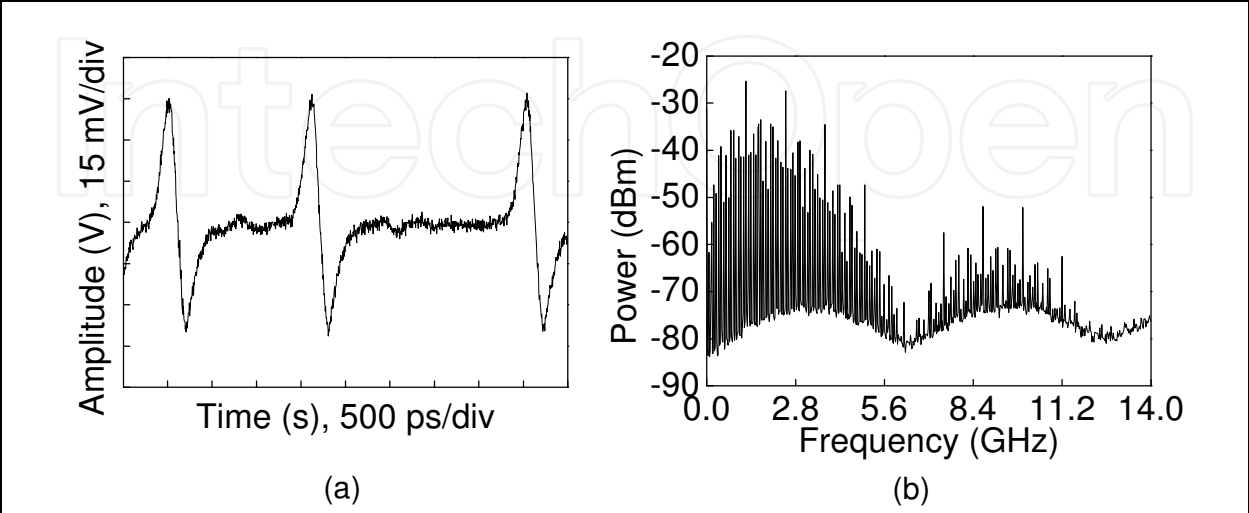


Fig. 6. Monocycle pulses generated employing the technique in Fig. 5; (a) the temporal waveform and (b) its spectrum (resolution bandwidth: 300 kHz).

MZM. To control the pulsewidth, a spool of standard SMF is included after the MZM. Fig. 6 shows monocycles generated based on differential photoreception exhibiting a UWB 10-dB bandwidth of 3.8 GHz at 1.244 Gbit/s.

The photonic techniques for Gaussian monocycle generation shown in Fig. 3 and Fig. 5 are capable of providing high-quality pulses covering the whole UWB band with simple and flexible configuration compared with other techniques employing custom fibre Bragg gratings, nonlinear optical processes or spectrum shaping components.

UWB generation requires a pulse width in the order of hundreds of picoseconds to generate a suitable UWB bandwidth and a multi-gigahertz pulse repetition rate equal to the target data rate of the system. Gain-switched laser diodes, as used in (Hanawa et al., 2007; Kaszubowska-Anandarajah et al., 2008), passive or active mode-locked fibre lasers, e.g. (PriTel, 2009), and emerging optically pumped passively mode-locked vertical-external-cavity surface-emitting lasers (VECSEL) can provide repetition rates suitable for UWB systems. In contrast to mode-locked lasers, gain switched lasers are simpler and more compact. However, timing jitter and also fluctuations of other pulse parameters are larger than for mode-locked lasers. Optically pumped VECSELs have the potential for very compact and cheap. In addition, suitable pulses for UWB applications could also be generated by modulating a continuous-wave light source, e.g. (Wu et al., 2007).

2.1.2 Impulse-radio ultra-wideband in the millimetre-wave band

For UWB optical transmission in RoF operating in the millimetre-wave bands, 24 GHz and 60 GHz, broadband optical frequency up-conversion centralized in the CO appears as a cost-effective solution instead of employing broadband electrical mixing at each RAU. A number of techniques have been reported for millimetre-wave impulse-radio UWB signal generation based on optical up-conversion. These techniques have been demonstrated in the 24 GHz band regulated for vehicular radar and also used in communications. One approach (Kuri et al., 2006) up-converts electrical rectangular pulses based on a complex self-heterodyne technique employing an arrayed waveguide grating (AWG) and a special MZM with high extinction ratio to suppress the residual RF carrier to meet the UWB emission mask. Another approach (Guennec & Gary, 2007) up-converts monocycle or doublet pulses generated by electrical transmitters commercially available by modulation in a MZM biased in nonlinear regime. This technique is simple, however it requires high-frequency electro-optic devices which make it difficult to be upgraded to higher frequency bands. The approaches demonstrated in (Fu et al., 2008; Li et al., 2009) serve as both frequency up-conversion and optical amplification and up-convert monocycle pulses generated employing electrical Gaussian pulses and a frequency discriminator. The former method is based on nonlinear polarization rotation in a semiconductor optical amplifier (SOA) exhibiting limited performance at high frequencies, whilst the latter method employs a more complex architecture based on a fibre optical parametric amplifier (OPA) but can be extended to higher frequency bands. An approach based on up-conversion of optical pulses in a MZM biased in non-linear regime has also been demonstrated (Chang et al., 2008). Optical monocycle and doublet pulses are generated by driving a dual-parallel MZM with electrical Gaussian pulses. In this demonstration, the performance of the millimetre-wave UWB signal after fibre transmission is analyzed showing the doublet pulse has better tolerance to fibre dispersion than the monocycle pulse.

Gaussian monocycle pulses do not meet the FCC spectrum mask in the 3.1-10.6 GHz band. However, these pulses have been demonstrated to be suitable for further frequency up-

conversion (Guennecc & Gary, 2007). Optical up-conversion to 20 GHz of the generated baseband monocycles shown in Fig. 4 based on the technique in (Guennecc & Gary, 2007) was also demonstrated in (Beltrán et al., 2008). A simpler approach to generate UWB monocycles in the millimetre-wave band based on frequency up-conversion of data Gaussian optical pulses in a MZM at the CO and monocycle shaping at RAUs has been proposed (Beltrán et al., 2009a; Beltrán et al., 2009c). This technique is depicted in Fig. 7.

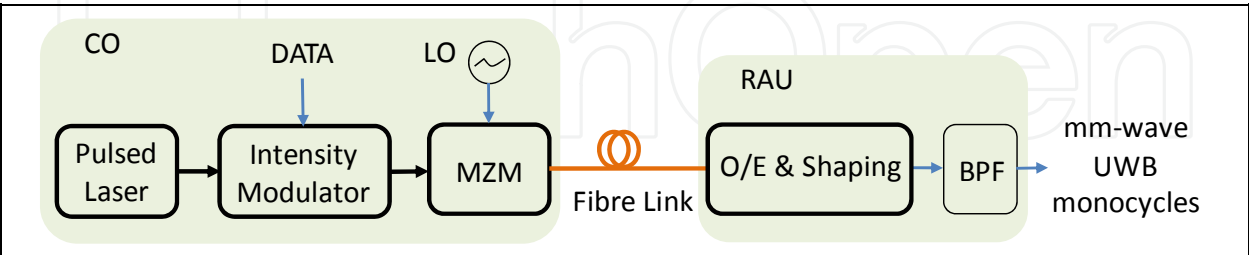


Fig. 7. Millimetre-wave impulse-radio UWB-over-fibre based on up-conversion in a Mach-Zehnder modulator at the CO and monocycle shaping at the RAU. LO: Local oscillator.

This method has been demonstrated in two proof-of-concept experiments by modulating Gaussian optical pulses from an actively mode-locked fibre laser with data in a MZM to generate data Gaussian pulses whose pulse width is subsequently controlled by standard SMF. A second MZM driven by a local oscillator (LO) signal and biased at quadrature point (linear regime) generating an optical double-sideband signal with carrier is employed for up-conversion. The millimetre-wave signal is so obtained after photodetection and filtering at the RAU. In order to verify appropriate operation, the millimetre-wave signal is down-converted with the same LO signal employed for up-conversion in an electrical mixer (conventional homodyne detection) and further low-pass filtered, with no fibre and no air transmission.

In the first experiment (Beltrán et al., 2009a), monocycle shaping is based on balanced photodetection as shown in Fig. 3. UWB monocycles are generated at 19 GHz, exhibiting a single-sideband 10-dB bandwidth of 2.5 GHz at 622 Mbit/s, as shown in Fig. 8. Also shown

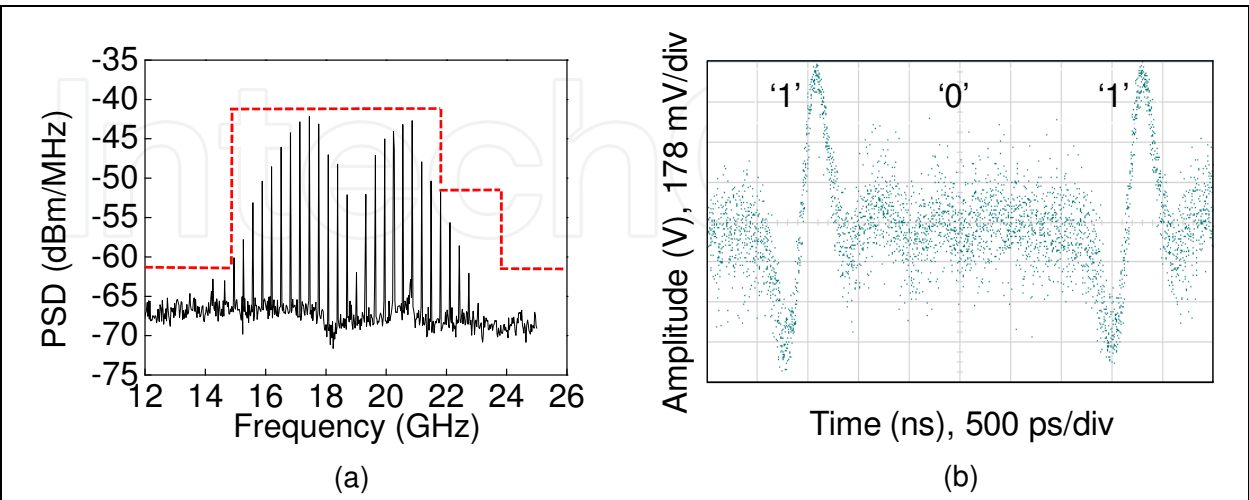


Fig. 8. (a) RF spectrum of UWB monocycles at 19 GHz generated in the setup in Fig. 1 with monocycle shaping as in Fig. 3. The FCC UWB mask is shown as a dashed line translated to 19 GHz; (b) down-converted data monocycles.

in Fig. 8 is the down-converted signal. The monocycles bear OOK-modulated data so that they are suitable for simultaneous vehicular radar and communications in the 24 GHz band to provide traffic safety applications.

Monocycle shaping based on differential photoreception as shown in Fig. 5 is performed in the second experiment (Beltrán et al., 2009c). This technique does not increase significantly the complexity of RAUs. UWB monocycles are generated at 16.85 GHz, exhibiting a single-sideband 10-dB bandwidth of 2.5 GHz and bearing OOK-modulated data at 1.244 Gbit/s, as shown in Fig. 9. Also shown in Fig. 9 is the down-converted signal.

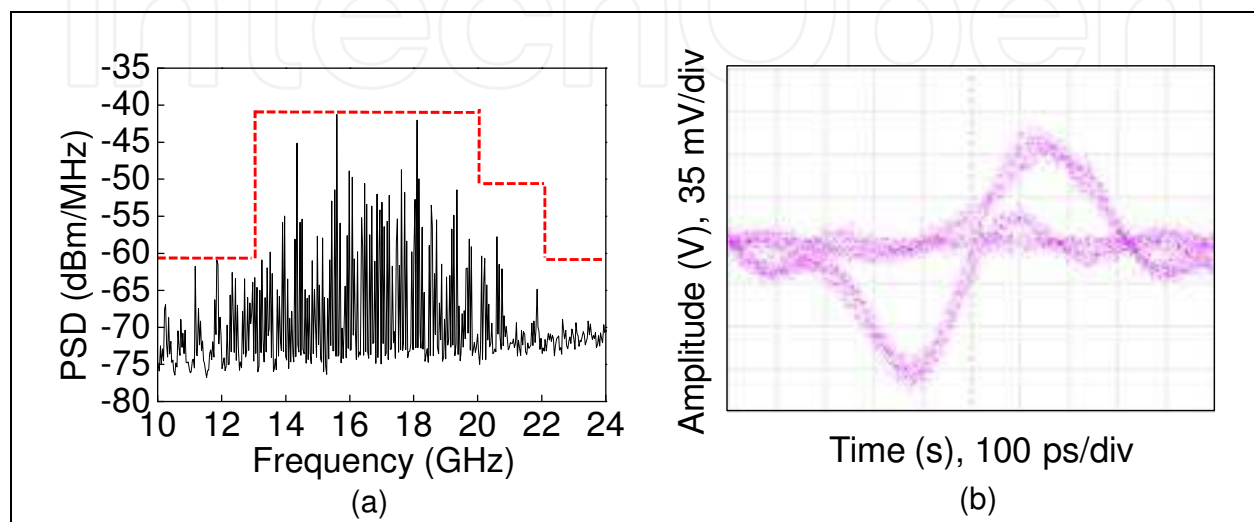


Fig. 9. (a) RF spectrum of UWB monocycles at 16.85 GHz generated in the setup in Fig. 7 with monocycle shaping as in Fig. 5. The FCC UWB mask is shown as a dashed line translated to 16.85 GHz; (b) eye diagram of down-converted data monocycles.

As can be observed in Fig. 8 and Fig. 9, the RF residual carrier does not limit the UWB emission mask. This enables the simultaneous wireless transmission of the two spectral sidebands improving receiver sensitivity at expense of reduced spectral efficiency. The two sidebands could be also filtered separately enabling a simultaneous dual-band generation.

Fig. 10 shows a UWB-over-fibre system where optical data monocycles are frequency up-converted in a MZM in nonlinear regime. This approach has been proposed and demonstrated in a proof-of-concept experiment for millimetre-wave UWB generation in the 60 GHz band (Beltrán et al., 2009b). Electrical Gaussian monocycles are converted to optical domain by external modulation in a MZM to generate optical data monocycles. In the experiment, electrical OOK-modulated monocycles are generated as shown in Fig. 5. Fig. 11 (a) shows the so-obtained optical data monocycles. A low-frequency LO of 14.25 GHz multiplied by 2 is applied to a second MZM biased at minimum transmission point to generate an optical double-sideband signal with a suppressed carrier (optical carrier suppression modulation), resulting in UWB monocycles at 57 GHz after photodetection and filtering at the RAU. The millimetre-wave signal is down-converted by electrical homodyne detection employing the LO signal multiplied by 4 and further low-pass filtered to verify appropriate operation, with no air transmission.

UWB monocycles are generated at 57 GHz, exhibiting a 10-dB bandwidth of 3.8 GHz at 1.244 Gbit/s, as shown in Fig. 11 (b). In this technique it is required to filter the residual RF carrier frequency for wireless transmission in practice. Further transmission over 100 m of

standard SMF is demonstrated with no performance degradation. Fig. 11 (c) shows the demodulated signal after fibre transmission. This UWB RoF system has been proposed for multi-Gbit/s high-definition video/audio distribution within in-vehicle networks, e.g. in aircrafts, where also fibre interconnects RAUs along the vehicle. The impulse-radio UWB approach offers also ranging and localization functionalities of special interest for localization of users potentially interfering and for radio tagging and passenger identification applications.

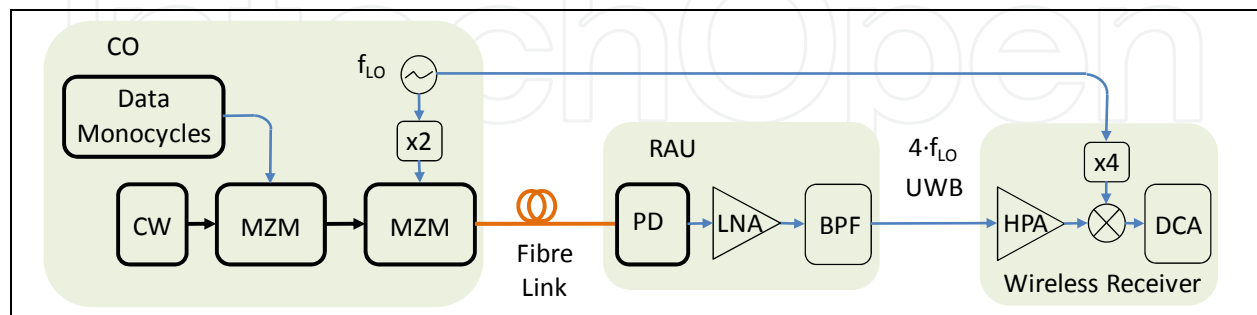


Fig. 10. Setup of the photonic 60 GHz impulse UWB-over-fibre based on up-conversion of data optical monocycles in a Mach-Zehnder modulator in nonlinear regime. CW: Continuous-wave laser. LO: Local oscillator. PD: Photodetector. LNA: Low-noise amplifier. BPF: Band-pass filter. HPA: High-power amplifier. DCA: Digital communications analyzer.

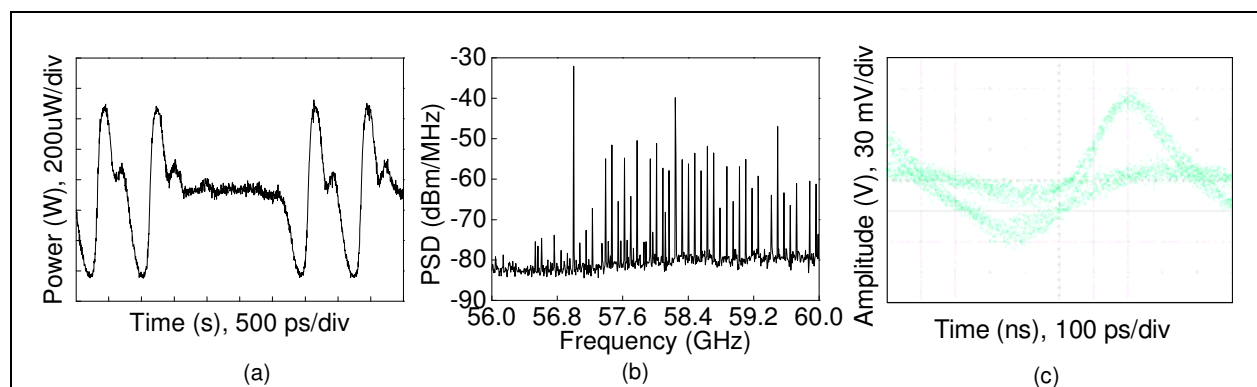


Fig. 11. Measurements in the setup in Fig. 10; (a) optical data monocycles; (b) RF spectrum of UWB monocycles at 57 GHz; (c) eye diagram of down-converted data monocycles.

In the techniques in Fig. 7 and Fig. 10, biasing the MZM employed for up-conversion at minimum transmission point requires half of the LO frequency and reduces the RF power fading effect due to fibre chromatic dispersion (Ma et al., 2007), however higher power is required in the system to not degrade performance with respect to bias at quadrature point. In addition, in both techniques baseband signal is also available after photodetection, which could be provided via a wired connection and a user could employ a simple, low-cost receiver to detect the signal by filtering out the millimetre-wave signal. Also, the baseband signal could meet the UWB mask in the 3.1-10.6 GHz band and be radiated employing an antenna with a suitable frequency response (Pan & Yao, 2009a).

2.1.3 Pulsed laser source characterization

As described in the previous section, optical generation of impulse-radio signals can be achieved employing pulsed laser sources. The overall RoF performance depends directly on

the characteristics of the specific pulsed laser employed. In particular, polarization stability i.e. the variation of polarization over time is of special importance when external modulation is employed.

The polarization stability of a pulsed laser source can cause spectrum distortion. The experimental setup for the characterization of the polarization stability of a femtosecond pulsed laser is depicted in Fig. 12. A computer controls the process of capture and storage of data.

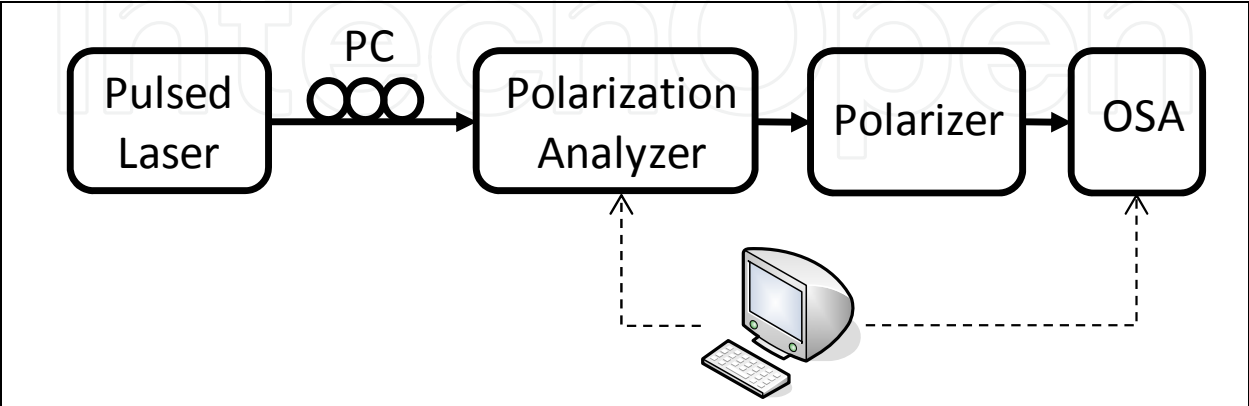


Fig. 12. Experimental setup to characterize the polarization stability of pulsed lasers. PC: Polarization controller. OSA: Optical spectrum analyzer.

The polarization stability and the distortion of the laser spectrum are evaluated for linear horizontal polarization (LH) with an orientation of 0° (launched polarization) adjusted by the polarization controller in Fig. 12. In practice, the orientation adjusted is ~3.6° (LH+3.6°). The optical spectrum analyzer captures the spectrum with 0.05 nm resolution bandwidth and -80 dBm sensitivity. The evaluation is performed at different wavelengths at which the spectrum gets distorted for different launched polarizations. The measurement time is 24 h. Fig. 13 (a) shows the orientation ψ (LH+ ψ) calculated from the normalized Stokes vector (S_1 , S_2 , S_3) given by the polarization analyzer as a function of time. Abrupt changes in the behaviour are due to abrupt temperature changes (disconnection/connection of conditioned air) in the laboratory measurement environment. Fig. 13 (b) is a plot of Poincare sphere showing the evolution over time of the normalized Stokes vector. From the Stokes vector other parameters characterizing polarization such as the degree of polarization (DOP),

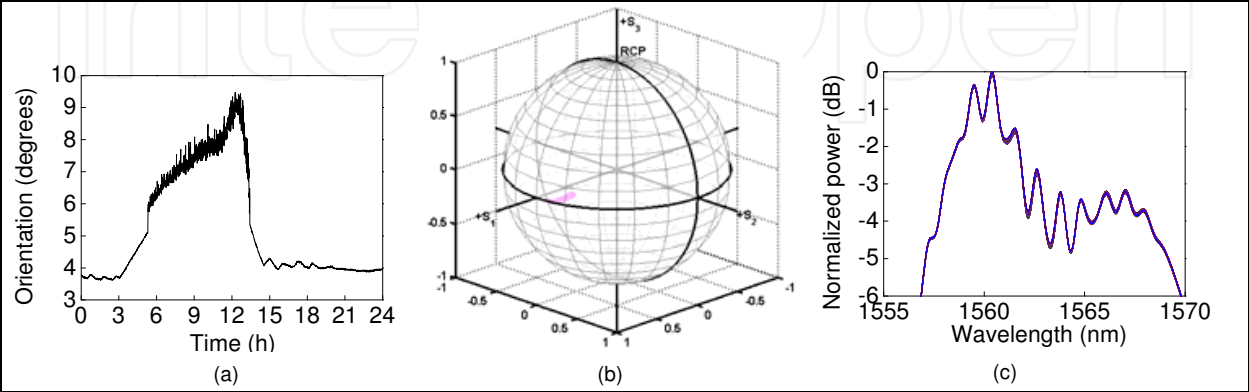


Fig. 13. Characterization of the polarization stability of a femtosecond pulsed laser; (a) Orientation; (b) Poincare sphere; (c) spectra over 1 h.

degree of linear polarization (DOLP), degree of circular polarization (DOCP) and ellipticity can also be calculated. Fig. 13 (c) shows the evolution of spectrum over time for a measurement time of 1 h over a zone in which the temperature is stable. The polarization stability, expressed as the standard deviation of the normalized Stokes parameters, is lower than 0.001 at 1 h independently on the wavelength at which is evaluated.

2.2 Transmission performance

In RoF systems, analog radio signals are modulated on the intensity of the optical signals (E/O conversion) to be transmitted over an optical fibre link employing either directly modulated lasers or external modulators, as shown in Fig. 1. Directly modulated semiconductor lasers such as DFB lasers and VCSELs are preferred due to lower cost whilst for high frequencies the required performance can be satisfied only by externally modulated transmitters.

It has been shown that a VCSEL has higher RF to optical power conversion efficiency than an external MZM and a DFB laser diode for the same output optical power (Gamage et al., 2008a; Gamage et al., 2008b). In addition, in case of the bandwidth is not a limiting factor direct modulation of a DFB laser leads to less distortion on UWB signals than external modulation with MZM because of its less nonlinearity, for the same output power (Jazayerifar et al., 2008). In addition, impulse-radio UWB signals are more sensitive to nonlinear distortion and less sensitive to noise than OFDM UWB signals for the same transmitted energy due to the higher peak-to-peak power. In practice, higher modulated power can be obtained with MZM but increasing the input optical power. The impact of laser chirp on UWB signals is almost negligible, but it affects the amount of dispersion when the UWB signal is transmitted over fibre.

Most of the UWB RoF systems have focused on SMF which is best suited for long-distance access applications. RoF in combination with MMF fibres can be deployed within homes and office buildings for baseband digital data transmission supporting 3.5 GHz wireless signals. The large core diameter of MMF fibres (typically 50 μm or 62.5 μm) offers easier installation and maintenance in within-building environments and reduced cost compared to SMF (Koonen & Garcia, 2008). Note that MMF is also widely used in within-building fibre installations for baseband data transmission systems at far more than 10 Gbit/s. Compared to silica MMF, graded-index plastic optical fibres (GI-POF) offer further advantages such as smaller bending radius, better tolerance to tensile load and stress, and simpler connectorization.

A RoF system employing VCSEL direct modulation of impulse-radio UWB signals in the 3.1-10.6 GHz band has been demonstrated over 100 m MMF (Jensen et al., 2009). Error-free operation employing FEC is achieved at a wireless distance of 8 m at 2.5 Gbit/s or 4 m at 4 Gbit/s. Impulse-radio UWB generation employing DFB direct modulation and transmission over 100 m GI-POF has also been recently demonstrated (Abraha et al., 2009).

In this section, an analysis of impulse-radio UWB propagation on standard SMF is presented. The analysis compares two modulation schemes: External modulation in a MZM at 1550 nm and direct modulation in a VCSEL at 1310 nm. Fig. 14 shows the two UWB radio-over-fibre implementations considered. The analysis targets to evaluate the impact of the modulation index on the reach and has been performed employing the commercial simulation tool VPITransmissionMaker™ (version 7.5).

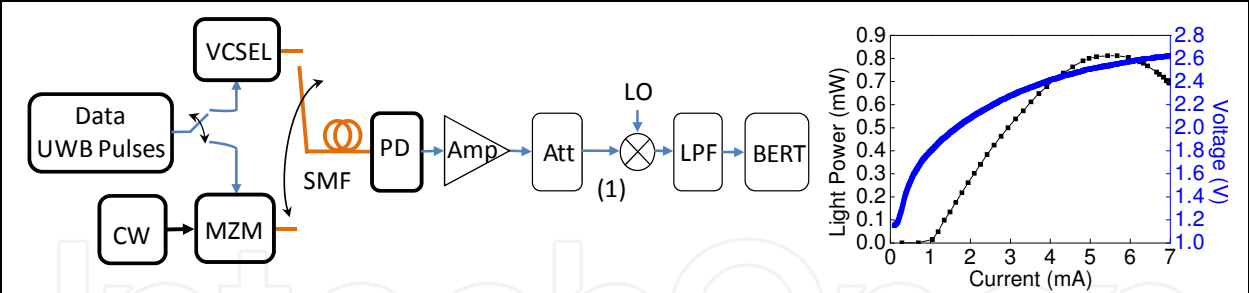


Fig. 14. Impulse-radio UWB RoF optical link configuration and VCSEL characteristics. CW: Continuous-wave laser. PD: Photodetector. Amp: Amplifier. Att: Variable attenuator. LPF: Low-pass filter. BERT: BER test.

Table 1 summarises the parameters of the components shown in Fig. 14 employed in the analysis. Typical parameters of commercially available components are considered.

CW param	value	MZM param	value	Photodiode PIN param	value
Laser power	10 dBm	Chirp	0	Responsivity	0.65 A/W
RIN	-130 dB/Hz	V _π DC	5 V	Dark current	5 nA
Amplifier param	value	V _π RF	5V	Thermal noise	10pA/√Hz
Gain	40 dB	Insertion losses	6 dB	VCSEL param	value
Noise factor	3.8 dB	Extinction ratio	35 dB	Core radius	2·10 ⁻⁶ m
LO param	value	LPF param	value	Active region	
				Thickness	0.3·10 ⁻⁶ m
Power	7 dBm	LPF type	Bessel 4th order	Confinement factor	0.03
Frequency	3.75 GHz	Bandwidth	3 GHz		

Table 1. UWB radio-over-fibre parameters employed in the setup in Fig. 14.

The impulse-radio UWB signal consists of fifth-derivative Gaussian pulses at 5.4 GHz 10-dB bandwidth, which are compliant with current UWB regulation in the 3.1-10.6 GHz band. This signal is OOK-modulated with $2^{14}-1$ pseudo-random bit sequence (PRBS) data at 1.25 Gbit/s resulting the data UWB pulses to be modulated. Both MZM and VCSEL are biased in linear regime, MZM at its quadrature bias point and VCSEL at the centre of the linear zone of its L-I curve, i.e. at $(I_{th} + I_{sat}) / 2$ where I_{th} is the threshold current of 1 mA and I_{sat} is the saturation current of 3.5 mA which corresponds to the 1-dB compression point. Fig. 14 shows the V-I and L-I curves of the commercial VCSEL at 27 °C in the analysis. At each modulation index, the attenuator sets a maximum PSD of -41.3 dBm/MHz at the radiation point (1) in Fig. 14. This power level would meet the UWB mask in current regulation employing a transmitter antenna with 0 dBi gain. Down-conversion to baseband is performed by electrical mixing (6.5 dB conversion losses) to obtain a suitable eye diagram for BER performance evaluation. Optical noise is predominant at receiver so that a *Chi2* method is employed for BER estimation. BER performance at different fibre lengths is compared with the back-to-back (B2B) configuration (with no fibre transmission) to evaluate the fibre degradation. Fig. 15 shows the BER results. External modulation gives a maximum reach of 50 km at error-free operation ($BER < 10^{-9}$) at 0.25 modulation index. Direct

modulation gives a maximum reach of 25 km at 0.16 modulation index. Higher modulation indexes than these shown in Fig. 15 result in distortion which makes the UWB spectrum non-compliant with regulation. Longer reach could be achieved employing a pre-amplifier at receiver or forward error correction codes (FEC) ($BER < 2.2 \cdot 10^{-3}$) at expense of increased complexity. Fig. 16 and Fig. 17 show examples of UWB signal and down-converted signal for external and direct modulation, respectively.

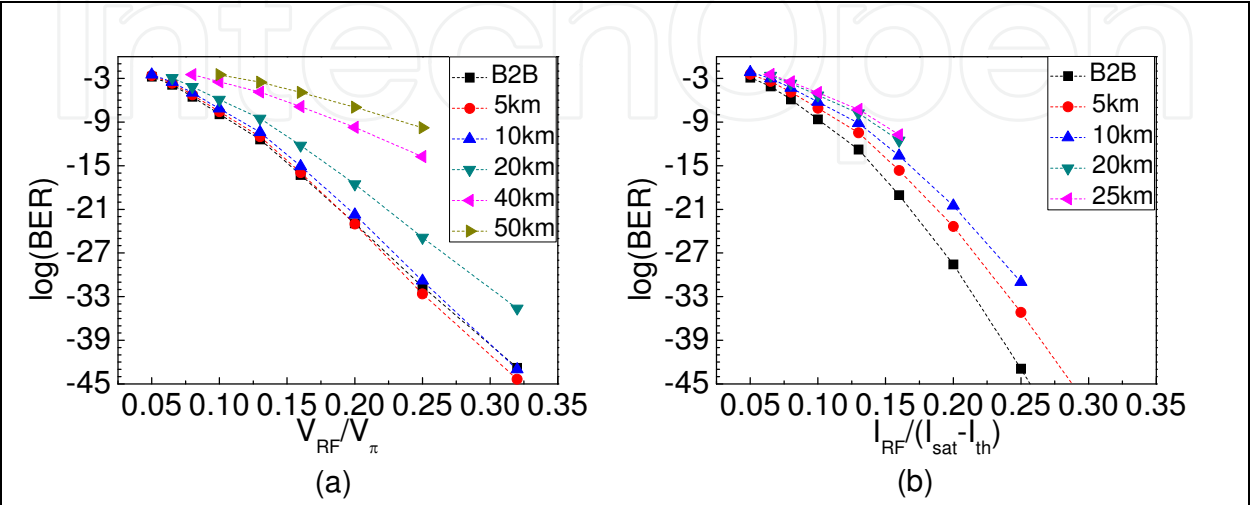


Fig. 15. Performance of impulse-radio UWB over SMF as a function of the modulation index; (a) External modulation in a MZM; (b) Direct modulation in a VCSEL.

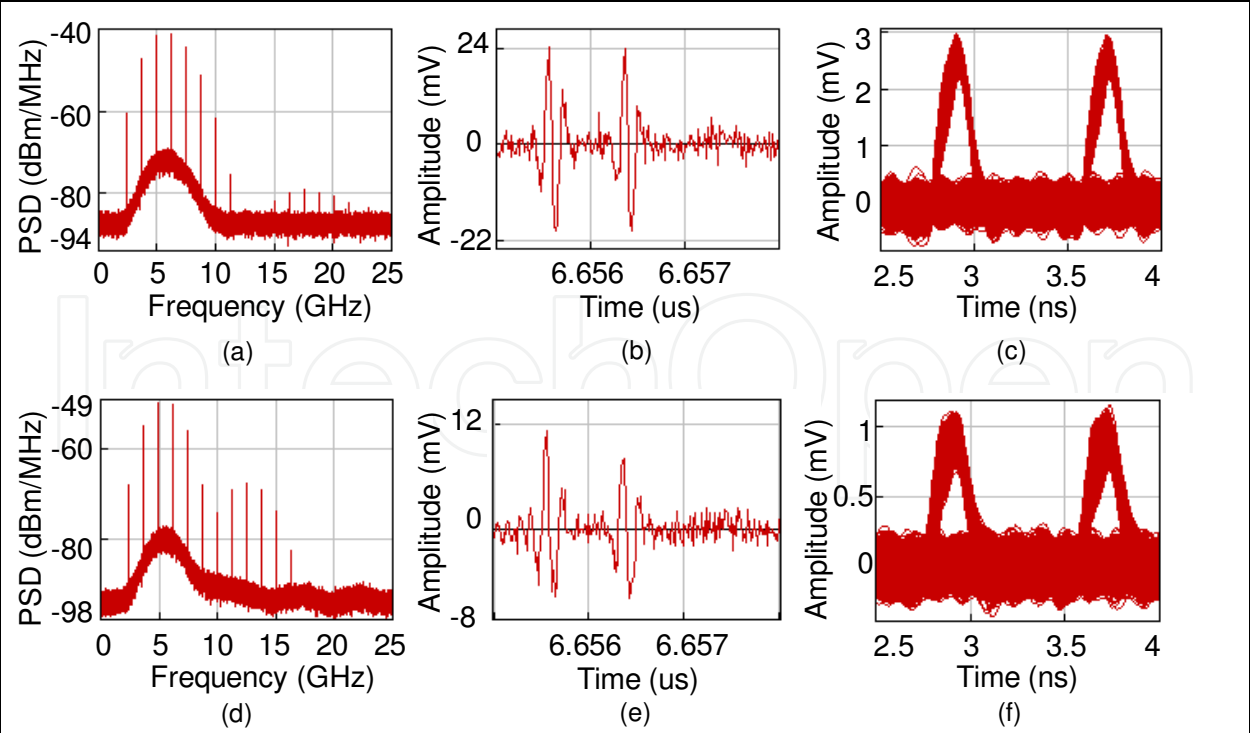


Fig. 16. Impulse-radio UWB signal at point (1) in Fig. 14 (a) RF spectrum and (b) time-domain, (c) down-converted eye diagram at 0.2 external modulation index for B2B configuration. (d-f) the same for 40 km SMF.

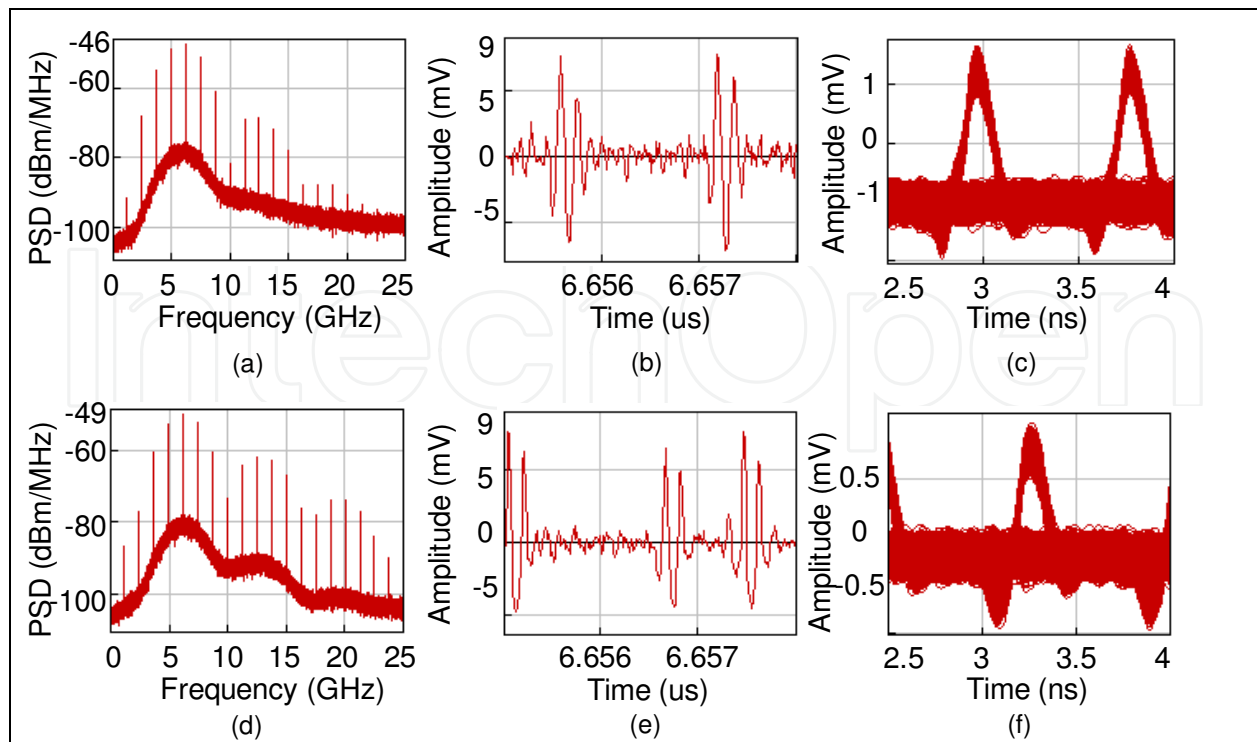


Fig. 17. Impulse-radio UWB signal at point (1) in Fig. 14 (a) RF spectrum and (b) time-domain, (c) down-converted eye diagram at 0.16 direct modulation index for B2B configuration. (d-f) the same for 20 km SMF.

3. Conclusion

In this chapter, the principles and state-of-the-art of RoF technology has been presented. The use of optical sources for the generation of impulse-radio UWB RoF, as one of the most challenging applications to date, has been described and the expected performance after optical transmission has been presented. A technique based on frequency up-conversion of optical UWB signals in a MZM in nonlinear regime has been presented. This technique permits the optical generation of UWB monocycles at 57 GHz bearing data at 1.244 Gbit/s. The generation and further transmission of impulse-radio UWB over 100 m of SMF has been demonstrated with good quality pulses. Another technique performing up-conversion in a MZM of optical pulses with subsequent electrical UWB shaping has been demonstrated at 16.85 GHz bearing data at 1.244 Gbit/s with good quality. The polarization stability of a pulsed laser has also been presented as key factor limiting system performance. Finally, the RoF distribution of impulse-radio UWB has been analyzed over long-distance SMF links suitable for access networks. The longest transmission reach is achieved employing external modulation in a MZM.

4. References

- Abraha, S.T.; Yang, H.; Tangdionga, E. & Koonen, A.M.J. (2009). Novel generation and transmission of FCC-compliant impulse radio ultra wideband signals over 100-m GI-POF. *Proceedings of International Topical Meeting on Microwave Photonics*, pp. 1-4, ISBN 978-84-8363-424-0, Valencia, Spain, October 2009

- Abtahi, M.; Mirshafiei, M.; LaRochelle, S. & Rusch, L.A. (2008). All-optical 500-Mb/s UWB transceiver: an experimental demonstration. *IEEE Journal Lightwave Technology*, Vol. 26, No. 15, August 2008, pp. 2795–2802, ISSN 0733-8724
- Beltrán, M.; Morant, M.; Pérez, J.; Llorente, R. & Martí, J. (2008). Photonic generation and frequency up-conversion of impulse-radio UWB signals, *Proceedings of IEEE Lasers and Electro-Optics Society*, pp. 498-499, ISBN 978-1-4244-1931-9, Newport Beach, California, United States, November 2008
- Beltrán, M.; Llorente, R.; Sambaraju, R. & Martí, J. (2009a). 24 GHz UWB-over- fibre system for simultaneous vehicular radar and communications, *Proceedings of ICT-MobileSummit*, pp. 1-6, ISBN 978-1-905824-12-0, Santander, Spain, June 2009
- Beltrán, M.; Llorente, R.; Sambaraju, R. & Martí, J. (2009b). 60 GHz UWB-over-fiber system for in-flight communications, *Proceedings of IEEE MTT-S International Microwave Symposium*, pp. 5-8, ISBN 978-1-4244-2803-8, Boston, United States, June 2009
- Beltrán, M.; Sambaraju, R.; La Porta, A.; Llorente, R. & Perez, J. (2009c). Photonic generation and envelope detection of millimeter-wave ultra-wideband impulse-radio employing Mach-Zehnder modulators, *Proceedings of IEEE International Conference on Ultra-Wideband*, pp. 428-432, ISBN 978-1-4244-2931-8, Vancouver, Canada, September 2009
- Capmany, J. & Novak, D. (2007). Microwave photonics combines two worlds. *Nature Photonics*, Vol. 1, June 2007, pp. 319-330
- Cassini, A. & Faccin, P. (2003). *Proceedings of International Topical Meeting on Microwave Photonics*, pp. 123–128, ISBN 978-1-4244-2168-8, Budapest, Hungary, September 2003
- Chang, Q.; Tian, Y.; Ye, T.; Gao, J. & Su, Y. (2008). A 24-GHz ultrawideband over fiber system using photonic generation and frequency up-conversion. *IEEE Photonics Technology Letters*, Vol. 20, No. 19, October 2008, pp. 1651-1653, ISSN 1041-1135
- Chen, X & Kiaei, S. (2002). Monocycle shapes for ultra-wideband systems, *Proceedings of International Symposium on Circuits and Systems*, pp. 597-600, ISBN 0-7803-7448-7, Scottsdale, Arizona, United States, May 2002
- Chia, M. Y. W.; Luo, B.; Yee, M. L. & Hao, E. J. Z. (2003). Radio over multimode fibre transmission for wireless LAN using VCSELs. *IEEE Electronics Letters*, Vol. 39, No. 15, July 2003, pp. 1143–1144, ISSN 0013-5194
- Dagli, N. (1999). Wide-Bandwidth Lasers and Modulators for RF Photonics. *IEEE Transactions on Microwave Theory and Techniques*, Vol. 47, No. 7, July 1999, pp. 1151-1171, ISSN 0018-9480
- Daniels, R. C. & Heath, R. W. (2007). 60 GHz wireless communications: emerging requirements and design recommendations. *IEEE Vehicular Technology Magazine*, Vol. 2, No. 3, September 2007, pp. 41-50
- Darcie, T.E. & Bodeep, G.E. (1990). Lightwave subcarrier CATV transmission systems. *IEEE Transactions on Microwave Theory and Techniques*, Vol. 38, No. 5, May 1990 pp. 524-533, ISSN 0018-9480
- Dong, J.; Zhang, X.; Huang, D. & Rosas-Fernández, J.B. (2009). All-optical ultra-wideband doublet generation and non-degraded transmission over optical fiber, *Proceedings of Optical fiber communication conference*, pp. 1-3, ISBN 978-1-4244-2606-5, San Diego, California, United States, March 2009

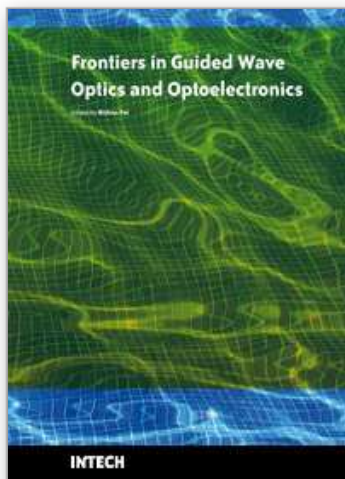
- Duan, C.; Pekhteryev, G.; Fang, J.; Nakache, Y-P.; Zhang, J.; Tajima, K.; Nishioka, Y. & Hirai, H. (2006). Transmitting multiple HD video streams over UWB links, *Proceedings of Consumer Communications and Networking Conference*, pp. 691-695, ISBN 1-4244-0085-6, Las Vegas, United States, January 2006
- ECC/REC/(09)01, Use of the 59 – 64 GHz frequency band for point-to-point fixed wireless systems, January 2009
- ECMA-368 International Standard, High rate ultra wideband PHY and MAC Standard, 2007.
- ETSI EN 302 065, Ultra WideBand (UWB) technologies for communication purposes; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive, February 2008
- FCC 04-285, Revision of part 15 of the commission's rules regarding ultra-wideband transmission systems, December 2004
- Fu, S.; Zhong, W.; Wen, Y.J. & Shum, P. (2008). Photonic monocycle pulse frequency up-conversion for ultrawideband-over-fiber applications. *IEEE Photonics Technology Letters*, Vol. 20, No. 12, June 2008, pp. 1006-1008, ISSN 1041-1135
- Gamage, P.A.; Nirmalathas, A.; Lim, C.; Wong, E.; Novak, D. & Waterhouse, R. (2008a). Multi-services distribution using power-efficient low-cost VCSELs, *Proceedings of International Topical Meeting on Microwave Photonics*, pp. 169-172, ISBN 978-1-4244-2168-8, Gold Coast, Australia, October 2008
- Gamage, P.A.; Nirmalathas, A.; Lim, C.; Wong, E.; Novak, D. & Waterhouse, R. (2008b). Performance comparison of directly modulated VCSEL and DFB lasers in wired-wireless networks. *IEEE Photonics Technology Letters*, Vol. 20, No. 24, December 2008, pp. 2102-2104, ISSN 1041-1135
- Hanawa, M.; Nakamura, K. & Nonaka, K. (2007). High-quality electrical Gaussian-monocycle pulse generation by electrical-optical hybrid signal processing, *Proceedings of Optoelectronics and Communications Conference*, pp. 138-139, Kanagawa, Japan, July 2007
- Hanawa, M.; Mori, K.; Nakamura, K.; Matsui, A.; Kanda, Y. & Nonaka, K. (2009). Dispersion tolerant UWB-IR-over-fiber transmission under FCC indoor spectrum mask, *Proceedings of Optical Fiber Communication conference*, pp. 1-3, San Diego, California, United States, March 2009
- Hartmann, P.; Webster, M.; Wonfor, A.; Ingham, J.D.; Penty, R.V.; White, I.H.; Wake, D. & Seeds, A.J. (2003). Low-cost multimode fibre-based wireless LAN distribution system using uncooled directly modulated DFB laser diodes, *Proceedings of European Conference on Optical Communication*, pp. 804-805, Rimini, Italy, September 2003
- Hirata, A.; Harada, M. & Nagatsuma, T. (2003). 120-GHz wireless link using photonic techniques for generation, modulation, and emission of millimeter-wave signals. *IEEE Journal of Lightwave Technology*, Vol. 21, No. 10, October 2003, pp. 2145-2153, ISSN 0733-8724
- Ingham, J.; Webster, M.; Wonfor, A.; Penty, R.; White, I. & White, K. (2003). Wide-frequency-range operation of a high linearity uncooled DFB laser for next-generation radio-over-fibre, *Proceedings of Optical Fiber Communication conference*, pp. 754-756, ISBN 1-55752-746-6, Atlanta, Georgia, United States, March 2003

- Jager, D. & Stohr, A. (2001). Microwave Photonics, *Proceedings of European Microwave conference*, pp. 1-4, London, United Kingdom, September 2001
- Jazayerifar, M.; Cabon, B. & Salehi, J.A. (2008). Transmission of multi-band OFDM and impulse radio ultra-wideband signals over single mode fiber. *IEEE Journal Lightwave Technology*, Vol. 26, No. 15, August 2008, pp. 2594-2603, ISSN 0733-8724
- Jensen, J.B.; Rodes, R.; Caballero, A.; Yu, X.; Gibbon, T.B. & Monroy, I.T. (2009). 4 Gbps impulse radio (IR) ultra-wideband (UWB) transmission over 100 meters multi mode fiber with 4 meters wireless transmission. *Optics Express*, Vol. 17, No. 19, September 2009, pp. 16898-16903, ISSN 113626
- Kaszubowska-Anandarajah, A.; Perry, P.; Barry, L.P. & Shams, H. (2008). An IR-UWB photonic distribution system. *IEEE Photonics Technology Letters*, Vol. 20, No. 22, November 2008, pp. 1884-1886, ISSN 1041-1135
- Koonen, A.M.J. & Garcia, L.M. (2008). Radio-over-MMF techniques Part II: Microwave to millimeter-wave systems. *IEEE Journal Lightwave Technology*, Vol. 26, No. 15, August 2008, pp. 2396-2408, ISSN 0733-8724
- Kuri, T.; Omiya, Y.; Kawanishi, T.; Hara, S. & Kitayama, K. (2006). Optical transmitter and receiver of 24-GHz ultra-wideband signal by direct photonic conversion techniques, *Proceedings of International Topical Meeting on Microwave Photonics*, pp. 1-4, ISBN 1-4244-0204-2, Grenoble, France, October 2006
- Le Guennec, Y. & Gary, R. (2007). Optical frequency conversion for millimeter-wave ultra wideband-over-fiber systems. *IEEE Photonics Technology Letters*, Vol. 19, No. 13, July 2007, pp. 996-998, ISSN 1041-1135
- Li, J.; Liang, Y. & Kin-Yip Wong, K. (2009). Millimeter-wave UWB signal generation via frequency up-conversion using fiber optical parametric amplifier. *IEEE Photonics Technology Letters*, Vol. 21, No. 17, September 2009, pp. 1172-1174, ISSN 1041-1135
- Liu, C.; Seeds, A.; Chadha, J.; Stavrinou, P.; Parry, G.; Whitehead, M.; Krysa, A. & Roberts, J. (2003). Bi-directional transmission of broadband 5.2 GHz wireless signals over fibre using a multiple-quantum-well asymmetric Fabry-Pérot modulator/photodetector, *Proceedings of Optical Fiber Communication conference*, pp. 738-740, ISBN 1-55752-746-6, Atlanta, Georgia, United States, March 2003
- Liu, C.; Polo, V.; Van Dijk, F.; Pfrommer, H.; Piqueras, M.A.; Herrera, J.; Martinez, A.; Karlsson, S.; Kjebon, O.; Schatz, R.; Enard, A.; Yichuan Yu; Tsegaye, T.; Chin-Hsiu Chuang; Seeds, A.J. & Marti, J. (2007). Full-Duplex DOCSIS/WirelessDOCSIS Fiber-Radio Network Employing Packaged AFPMs as Optical/Electrical Transducers. *IEEE Journal Lightwave Technology*, Vol. 25, No. 3, March 2007, pp. 673-684, ISSN 0733-8724
- Llorente, R.; Alves, T.; Morant, M.; Beltran, M.; Perez, J.; Cartaxo, A. & Marti, J. (2007). Optical distribution of OFDM and impulse-radio UWB in FTTH networks. *Proceedings of Optical Fiber Communication conference*, pp. 1-3, ISBN 978-1-55752-856-8, San Diego, California, United States, February 2008
- Llorente, R.; Alves, T.; Morant, M.; Beltran, M.; Perez, J.; Cartaxo, A. & Marti, J. (2008). Ultra-wideband radio signals distribution in FTTH networks. *IEEE Photonics Technology Letters*, Vol. 20, No. 11, June 2008, pp. 945-947, ISSN 1041-1135
- Ma, J.; Yu, J.; Yu, C.; Xin, X.; Zeng, J. & Chen, L. (2007). Fiber dispersion influence on transmission of the optical millimetre-waves generated using LN-MZM intensity

- modulation. *IEEE Journal of Lightwave Technology*, Vol. 25, No. 11, November 2007, pp. 3244-3256, ISSN 0733-8724
- Meryll Lynch (2007). Telecom services-wireless/cellular. Available at: <http://www.scribd.com/doc/7656725/ML-Data-Growth>
- Niiho, T.; Nakaso, M.; Masuda, K.; Sasai, H.; Utsumi, K. & Fuse, M. (2004). Multi-channel wireless LAN distributed antenna system based on radio-over-fibre techniques, *Proceedings of IEEE Lasers & Electro-Optics Society*, pp. 57-58, ISBN 0-7803-8557-8, Rio Grande, Puerto Rico, November 2004
- Nkansah, A.; Das, A.; Lethien, C.; Vilcot, J.-P.; Gomes, N.J.; Garcia, I.J.; Batchelor, J.C. & Wake, D. (2006). Simultaneous dual band transmission over multimode fibre-fed indoor wireless network. *IEEE Microwave and Wireless Components Letters*, Vol. 16, No. 11, November 2006, pp. 627-629, ISSN 1531-1309
- Ogawa, H.; Polifko, D. & Banba, S. (1992). Millimetre-wave fibre optic systems for personal radio communication. *IEEE Transactions on Microwave Theory and Techniques*, Vol. 40, No. 12, December 1992, pp. 2285-2293, ISSN 0018-9480
- Pan, S. & Yao, J. (2009a). Photonic generation of chirp-free UWB signals for UWB over fiber applications, *Proceedings of International Topical Meeting on Microwave Photonics*, pp. 1-4, ISBN 978-84-8363-424-0, Valencia, Spain, October 2009
- Pan, S. & Yao, J. (2009b). A photonic UWB generator reconfigurable for multiple modulation formats. *IEEE Photonics Technology Letters*, Vol. 21, No. 19, October 2009, pp. 1381-1383, ISSN 1041-1135
- Persson, K.-A.; Carlsson, C.; Alping, A.; Haglund, A.; Gustavsson, J.S.; Modh, P. & Larsson, A. (2006). WCDMA radio-over-fibre transmission experiment using singlemode VCSEL and multimode fibre. *IEEE Electronics Letters*, Vol. 42, No. 6, March 2006, pp. 372-374, ISSN 0013-5194
- Pfrommer, H.; Piqueras, M. A.; Polo, V.; Herrera, J.; Martinez, A. & Marti, J. (2006). Radio-over-Fibre Architecture for Simultaneous Feeding of 5.5 and 41 GHz WiFi or 4G Access Networks, *Proceedings of IEEE MTT-S International Microwave Symposium*, pp. 301-303, Chicago, United States, June 2006
- PriTel, Inc. 1550-nm Actively Mode-locked Fiber Lasers [Online]. Available: <http://www.pritel.com>
- Qian, X.; Hartmann, P.; Ingham, J.D.; Penty, R.V. & White, I.H. (2005). Directly-modulated photonic devices for microwave applications, *Proceedings of IEEE MTT-S International Microwave Symposium*, pp. 4, ISBN 0-7803-8845-3, Long Beach, California, United States, June 2005
- Rivas, I. & Lopes, L.B. (1998). A microcellular DCA scheme using variable channel exclusion zones, *Proceedings of IEEE Vehicular Technology Conference*, pp. 1395-1399, ISBN 0-7803-4320-4, Ottawa, Canada, May 1998
- SARA Group, Strategic Automotive Radar frequency Allocation, 24 GHz UWB SRR frequency allocation [Online]. Available: http://www.sara-group.org/official_information/specific_decisions_for_different_countries/
- Schmuck, H. (1995). Comparison of optically millimeter-wave system concepts with regard to chromatic dispersion. *IEEE Electronic Letters*, Vol. 31, No. 21, October 1995, pp. 1848-1849
- Seeds, A.J. & Williams, K.J. (2006). Microwave photonics. *IEEE Journal of Lightwave Technology*, Vol. 24, No. 12, December 2006, ISSN 4628-4641

- Shams, H.; Kaszubowska-Anandarajah, A.; Perry, P.; Barry, L.P. (2009a). Optical generation, fiber distribution and air transmission for ultra wide band over fiber system, *Proceedings of Optical fiber communication conference*, pp. 1-3, ISBN 978-1-4244-2606-5, San Diego, California, United States, March 2009
- Shams, H.; Kaszubowska-Anandarajah, A.; Perry, P.; Barry, L.P. & Anandarajah, P. M. (2009b). Fiber distribution of IR-UWB signals based on an externally injected gain switched laser, *Proceedings of European Conference on Lasers and Electro-Optics 2009 and the European Quantum Electronics Conference*, pp. 1-1, ISBN 978-1-4244-4079-5, Munich, Germany, June 2009
- Wake, D.; Johansson, D. & Moodie, D.G. (1997). Passive picocell – A new concept in wireless network infrastructure. *IEEE Electronics Letters*, Vol. 33, No. 5, February 1997, pp. 404-406, ISSN 0013-5194
- Wilson, B.; Ghassemlooy, Z. & Darwazeh, I. (Eds.) (1995), *Analogue Optical Fibre Communications*, Institution of Engineering and Technology (15 Aug 1995), ISBN 978-0852968321, London, United Kingdom
- WiMedia Alliance, Worldwide regulatory status [Online]. Available: <http://www.wimedia.org>
- Wu, X.; Christen, L.; Yang, J.; Nuccio, S.R.; Willner, A. & Paraschis, L. (2007). 40-GHz CSRZ optical pulse generation using a 10-GHz Mach-Zehnder modulator and a 25-ps delay line interferometer, *Proceedings of IEEE Lasers and Electro-Optics Society*, pp. 882-883, ISBN 978-1-4244-0925-9, Florida, United States, October 2007
- Yu, X.; Gibbon, T. B. & Monroy, I. T. (2009). Experimental demonstration of all-optical 781.25-Mb/s binary phase-coded UWB signal generation and transmission. *IEEE Photonics Technology Letters*, Vol. 21, No. 17, September 2009, pp. 1235-1237, ISSN 1041-1135

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As the editor, I feel extremely happy to present to the readers such a rich collection of chapters authored/co-authored by a large number of experts from around the world covering the broad field of guided wave optics and optoelectronics. Most of the chapters are state-of-the-art on respective topics or areas that are emerging. Several authors narrated technological challenges in a lucid manner, which was possible because of individual expertise of the authors in their own subject specialties. I have no doubt that this book will be useful to graduate students, teachers, researchers, and practicing engineers and technologists and that they would love to have it on their book shelves for ready reference at any time.

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Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
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