Hybrid Radio over Fiber System for Generation and Distribution of UWB Signals

A. Kaszubowska-Anandarajah*, P. Perry and L.P. Barry
School of Electronic Engineering, Dublin City University, Dublin 9, Ireland
*Phone: +353 1 700 7635, Fax: +353 1 700 5508, Email: aleksandra.kaszubowska@dcu.ie**

ABSTRACT
The authors investigate a hybrid radio over fiber system for the generation and distribution of UWB signals. This system is based on gain-switched laser, which is used to generate short optical pulses. The position of these pulses is modulated using electrical data before transmitting them to the Remote Antenna Unit (RAU). At the RAU, the optical signal is detected and undergoes spectral shaping (according to UWB requirements). The resulting Pulse Position Modulated (PPM) electrical impulses are then down-converted to baseband using an electrical mixer. After strong low pass filtering, Bit Error Rate measurements are carried out in order to verify the performance of the system. Error free operation is achieved for optical power levels as low as -16 dBm falling at the detector in RAU. The impact of fiber transmission on the generated UWB signal is also investigated via a simulation model. The evolution of the pulse- and spectral width of the UWB pulses, as the signal travels over different lengths of fiber, is recorded. Results achieved show that the pulse- and spectral width are strongly affected by chromatic dispersion of the fiber. However, these changes can be easily reverted using standard dispersion compensation techniques.
Keywords: UWB signals, radio over fiber, gain switched laser, pulse position modulation, dispersion compensation.

1. INTRODUCTION

Ultra Wide-Band (UWB) systems have attracted a lot of attention in recent years. Their ability to deliver high bit rate data (exceeding 100 Mb/s), good wall penetration, low power consumption, multipath and interference immunity makes them a very promising solution to many communications problems. The signals used for data transmission in such systems have spectral properties similar to noise, hence they could be transmitted using spectral bands already assigned to different systems without causing interference [1]. UWB can provide high-capacity connections over a short range, such as broadband links to a home computer or other Web appliance [2, 3]. The Federal Communications Commission's (FCC) Report and Order defines UWB as any signal that occupies more than 500 MHz in the 3.1 – 10.6 GHz band [4].

One of the main drawbacks of UWB systems is their limited range, typically not exceeding 30 feet. This could be overcome by employment of optical fiber, which could extend the reach of UWB system to anything from meters to kilometers depending on distance between Optical Distribution Center (ODC) and Remote Antenna Unit (RAU). It could also be used for in-building distribution. In such a case it would be natural to generate the UWB signals optically at the central location before distributing them between the RAUs [5-7]. Such a combination of radio and fiber transmission has been widely studied for employment in other wireless systems (such as 4G) and is often referred to as Radio over Fiber (RoF) technology [8-10].

To date, commercially available systems use a Multi-Carrier Orthogonal Frequency Division Multiplexing (MC-OFDM) solution for bit rates of the order of 100 Mbps with near term plans to extend this up to 480 Mbps. Such products are certified by the WiMedia Alliance and typically carry Wireless USB certification.

This paper addresses a different approach, which uses a pulsed modulation format generally known as Impulse Radio UWB (IR-UWB), which can deliver higher bit rates. It appears that the business case for using pulse-based schemes in the 3.1 GHz to 10.6 GHz band is not currently viable as the cost/performance ratio is too high for current demand. It also appears to be technically challenging and expensive to use this band for High Definition Multi-media Interface (HDMI) applications operating at bit rates of up to 4.2 Gb/s. Nevertheless, a new band, 57 GHz to 64 GHz, is expected to become available for similar technology that is expected to support higher bit rates. Consequently, the possibility of using IR-UWB systems requires fresh investigation.

This paper presents a proof-of-concept simulation and experiment that shows the possible use of Gain-Switching (GS) a laser diode to generate optical Pulse Position Modulation (PPM) signals that can be distributed through a building and easily converted to UWB radio signals at RAU to create a patchwork of UWB coverage areas that is analogous to a femto-cellular radio system. GS is a simple and reliable method [11] that allows the generation of short optical pulses at any bit rate (limited only by the modulation bandwidth of the laser).

Initially, experimental demonstration of optical generation of IR-UWB signals using GSL is presented. This is followed by the investigation of the distribution of the optical UWB signal over the transmission fiber using a simulation tool VPI Transmission Maker. The impact of the fiber chromatic dispersion on the pulse- and the spectral- width of the signal is examined.

978-1-4244-2626-3/08/$25.00 ©2008 IEEE

Authorized licensed use limited to: DUBLIN CITY UNIVERSITY. Downloaded on January 12, 2009 at 06:00 from IEEE Xplore. Restrictions apply.

2. EXPERIMENTAL SET-UP AND RESULTS

In this section, we present a proof-of-concept experiment on UWB signal generation, using the GSL, at a bit rate of 1.25 Gb/s. The set up in Fig. 1(a) shows the equipment used in the ODC for this experiment. It consists of a GSL that is driven from a sinusoidal RF generator at the clock frequency of 1.25 GHz. The resulting optical pulses were approximately 70 ps wide and were fed to a pair of Mach Zehnder Modulators (MZMs).

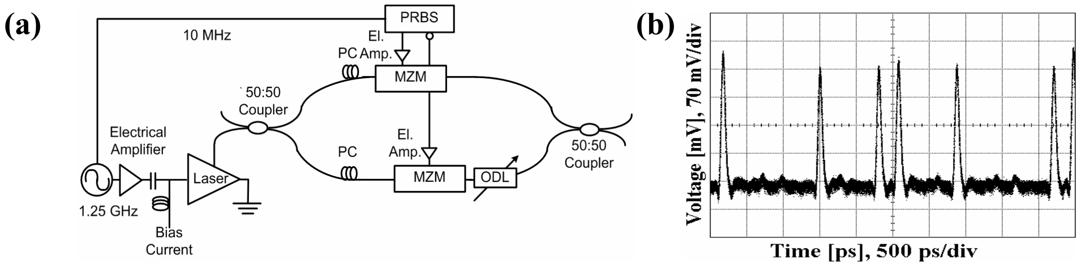

Fig. 1. (a) Optical Distribution Centre set up; (b) PPM modulated optical pulses

The 1.25 Gb/s electrical data stream was generated with a 50:50 mark space ratio with sufficient amplitude to drive the MZMs with both data and inverted data. As a result one MZM passed an optical pulse in the presence of a logical '1' and the other MZM passed an optical pulse in the presence of a logical '0'. An Optical Delay Line (ODL) was used to delay the pulses from the lower MZM before recombining them, so that a 1.25 Gbit/s PPM data signal is created. The trace shown in Fig. 1(b) shows this measured signal and, with a bit period of 800 ps, the data illustrated here is the sequence '1001101', with the final '1' being at the very edge of the screen. The trace shows a high SNR and very low duty cycle.

The RAU (Fig. 8) in this experiment was simply a photo-detector, electrical amplifier and an electrical band pass filter with a pass-band of 3.1 GHz to 10.6 GHz that was designed to shape the spectrum to the FCC mask for UWB transmissions. This filter was a simple Π network with the shunt inductive components transformed to a number of parallel short circuit stubs designed to yield additional suppression at the band edges. The circuit was realised using Taconics RF-35 substrate to yield a low cost, high performance filter.

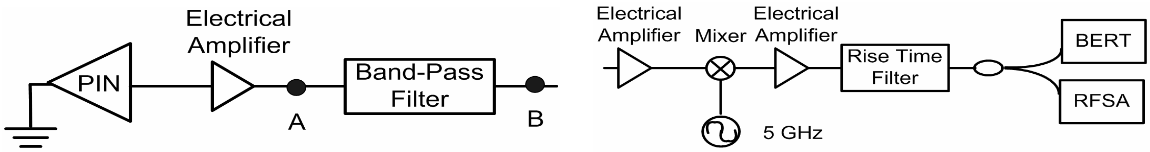

Fig. 2. (a) Remote Antenna Unit, (b) Radio Terminal set-up.

The RF spectrum of the detected optical pulses directly after the electrical amplifier is shown in Fig. 3(a). It can be seen that the signal does not comply with the FCC spectral mask and it includes both the low (DC to 2.5 GHz) and high (above 10 GHz) frequency components. This means that the signal contains sufficiently strong spectral components to fill the UWB spectrum, but electrical filtering is clearly required before the signal can be transmitted to the Radio Terminal (RT) over the air interface.

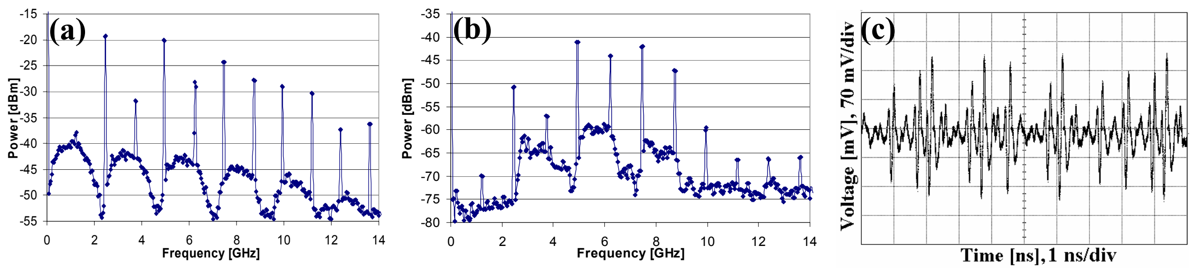

Fig. 3. (a) RF spectrum of the detected optical pulses (point A in Fig. 8), (b) RF spectrum after electrical BPF, (b) temporal waveform of the UWB signal.

Figure 3(b) shows the RF spectrum of the signal after the band pass filter. It can be seen that the spectral components below 3 GHz have been greatly reduced, nevertheless further filtering would be required to satisfy the stringent requirements of the FCC mask (specifically to attenuate the spectral component at 2.5 GHz). Figure 3(c) displays the temporal waveform of the 1.25 Gb/s UWB signal.

The output from the RAU was fed directly into the RT (in a real system the RAU would be connected to the RT by the radio link). The RT (Fig. 2(b)) for this experiment was composed of an amplifier with 30 dB gain driving a high bandwidth mixer. The mixer received a 7 dBm Local Oscillator (LO) signal at 5 GHz that was frequency locked to the data clock in the ODC and had manual phase shifting capability. The Intermediate

Authorized licensed use limited to: DUBLIN CITY UNIVERSITY. Downloaded on January 12, 2009 at 06:00 from IEEE Xplore. Restrictions apply.

Frequency (IF) output therefore contained the 4th harmonic of the data signal at DC, with the upper and lower sidebands at 3.75 GHz and 6.25GHz being down converted to the base-band data rate of 1.25 Gb/s.

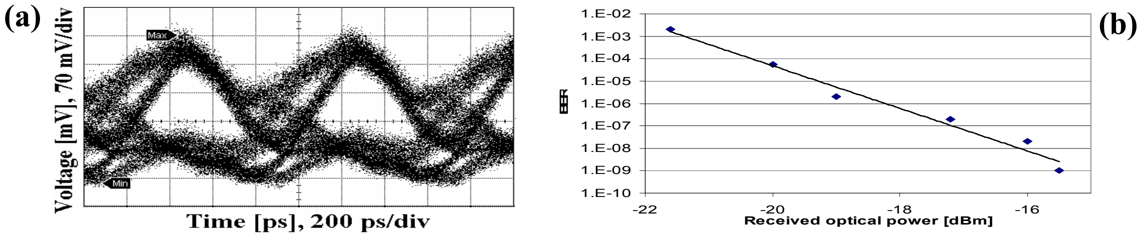

Fig. 4. (a, Received eye diagram of the down-converted signal, (b) BER vs. received optical power at RAU.

The IF signal was then passed through a low pass filter with a corner frequency of 746 MHz to remove additional harmonics and convert the data from Return to Zero (RZ) format to Non-Return to Zero (NRZ) format. This output was then analysed with a Bit Error Rate Tester (BERT) and an oscilloscope. Figure 4(a) displays the received eye diagram of the NRZ signal. It can be seen that a clear eye is received even though no demodulation is performed on the PPM signal. There are two reasons for that: firstly the signal is not a true NRZ, the duty cycle of this signal is around 60%. Secondly, the pulses representing the zeros are delayed exactly by half the bit slot and thus the interference occurs at the crossing point leaving the centre of the eye interference free. In order to quantify the performance of our system the BER measurement vs. optical power received at the RAU was taken. The results are plotted in Fig. 4(b). Optical power levels as low as -16 dBm achieve BER of around 10^{-9} for the received signals.

3. FIBER TRANSMISSION - SIMULATION MODEL AND RESULTS

In order to verify the impact fiber transmission has on the generated UWB signal a simulation model of the system for optical generation an distribution of such signals was built and is shown in Fig. 5(a). Data to be transmitted is encoded using Pulse Position Modulation (PPM)(see Fig. 5(b)), combined with a DC bias current and used to gain-switch a Fabry-Perot (FP) laser. External injection is used to achieve single moded operation of the GSL as well as to reduce the jitter on the pulses [12]. Optical PPM pulses (duration of 17 ps) are transmitted to a RAU, where the optical signal is detected and spectral shaping takes place using an electrical Band Pass Filter (BPF) (center frequency 5.5 GHz, BP 6.75 GHz). The bit rate used in the simulation was 156 Mb/s, but it should be noted that this could be easily adjusted to systems requirements since the method of gain-switching is very flexible in terms of pulse repetition rate.

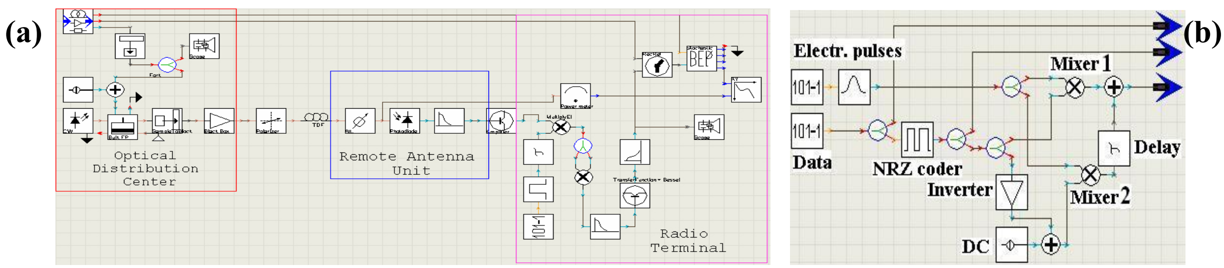

Fig. 5. (a) Simulation model, (b) model of the Pulse Position Modulator.

At the receiver the PPM data is converted to an On-Off signal by gating the UWB signal with a square wave exhibiting a 0.125 duty cycle. The amplitude-modulated signal is then downconverted by self-homodyning. Finally, the signal is converted into a Non Return-to-Zero (NRZ) format by filtering using a Low-Pass Filter (LPF).

In order to verify the influence of fiber transmission on the optically generated UWB signal, different lengths of fiber were inserted between the ODC and the RAU. The optical pulses have a large spectral width, which leads to broadening of these pulses as a result of fiber chromatic dispersion. This in turn reduces the electrical spectral width of the generated UWB signal. Fig. 6(a) presents the dependence of the 3-dB spectral width of the signal at the output of the BPF and the optical pulse width, on the fiber length (fiber dispersion parameter 16 ps/nm·km). It can be seen that the spectral width of the signal drops below 4 GHz after propagating over only 5 km of fiber. Thus it is obvious that chromatic dispersion needs to be compensated for, in order to fulfil the spectral requirements of the UWB standard. 4 km of Dispersion Compensating Fiber (DCF) with a dispersion parameter of -100 ps/nm·km was inserted to counteract the pulse spreading caused by propagating over 25 km of Standard Single Mode Fiber (SSMF). The RF spectrum of the UWB signal without and with dispersion compensation is shown in Fig. 6(b) and (c) respectively. From the figures it can be seen that employing DCF has counteracted the degradation in the UWB spectrum due to fiber transmission.

Authorized licensed use limited to: DUBLIN CITY UNIVERSITY. Downloaded on January 12, 2009 at 06:00 from IEEE Xplore. Restrictions apply.

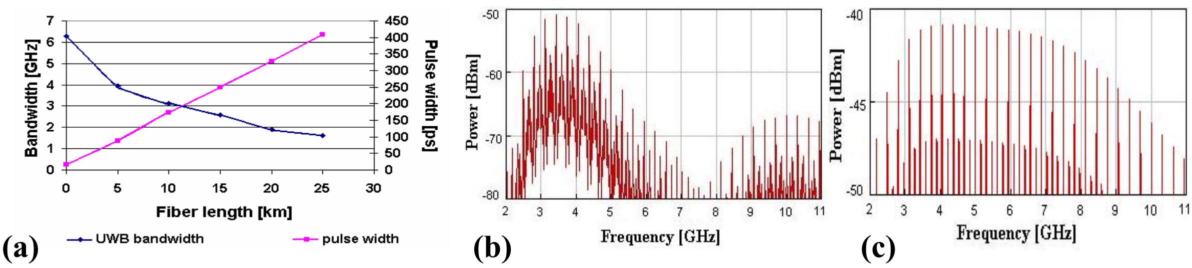

Fig. 6. (a) Evolution of the 3-dB spectrum and pulse width due to fiber transmission, RF spectrum of UWB signal: (b) after propagation over 25 km SSMF fiber, (c) after propagation over 25 km SSMF and 1 km DCF.

4. CONCLUSIONS

In conclusion, a novel system design of a RoF UWB system based on a gain-switched laser has been proposed and demonstrated. This method portrays cost efficiency and reliability, which are assets gained from the technique of GS. Furthermore, it uses a single laser and additional components that lend themselves to integration, thus offering the possibility of a low cost and reliable UWB distribution system for residential or small office deployments.

In addition, the influence of fiber chromatic dispersion on the generated UWB signal has been also investigated. The results show that the spectral width of the detected signal reduces rapidly with an increase in fiber transmission length. These changes can be easily reverted by using simple dispersion compensation techniques, allowing UWB signals to be generated remotely from the RAU and distributed over long fiber lengths.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the support of Science Foundation Ireland Investigator Programme.

REFERENCES

[1] W. Hirt, “Ultra-Wideband Radio Technology: Overview and Future Research,” *Computer Commun.*, vol. 26, no. 1, pp. 46-52, Jan. 2002

[2] M. Ghavami, L. B. Michael and R. Kohno, “*Ultra Wideband Signals and Systems in Communication Engineering*,” West Sussex, U.K.: Wiley, 2004.

[3] D. Porcine, P. Research and W. Hirt, “Ultra-wideband radio technology: Potential and challenges ahead,” *IEEE Commun. Mag.*, vol. 41, no. 7, pp. 66-74, Jul. 2003.

[4] Fed. Commun. Commission, Revision of Part 15 of the Commission’s Rules Regarding Ultra-Wideband Transmission Systems, Apr. 2002. Tech. Rep., ET-Docket 98-153, FCC02-48.

[5] T. Kawanishi, T. Sakamoto, M. Izutsu, “Ultra-wide-band radio signal generation using optical frequency-shift-keying technique” *IEEE Microwave and Wireless Components Lett.*, vol. 15, no. 3, pp.153-155, 2005.

[6] F. Zeng, J. Yao, “An approach to ultrawideband pulse generation and distribution over optical fiber,” *IEEE Photon. Technol. Lett.,* vol. 18, no. 7, pp: 823-825, 2006.

[7] W. P. Lin, J. Y. Chen, “Implementation of a new ultrawide-band impulse system,” *IEEE Photon. Technol. Lett.,* vol. 17, no. 11, pp. 2418- 2420, 2005.

[8] A. Kaszubowska, *et al*. 'Multiple RF carrier distribution in a hybrid radio/fiber system employing a self-pulsating laser diode transmitter,' *IEEE Photon. Technol. Lett.,* vol. 14, pp. 1599-1601, 2002.

[9] A. Kaszubowska, *et al*. “Development of Highly Flexible Broadband Networks Incorporating Wavelength Division Multiplexing and Sub-carrier Division Multiplexing in a Hybrid Radio/Fiber Distribution System,” Invited paper Th.B.4, *International Conference on Transparent Optical Networks,* Warsaw, Poland, 30 June - 3 July, 2003.

[10] W. Hu, *et al*. “50 GHz WDM Sources and is Uplink System Using Two-Mode Injection-Locked Fabry-Perot Lasers and Electro-Absorption Modulator for Millimeter-Wave Radio-on-Fiber Communications,” *Optical Fiber Communication Conference 2003,*vol. 1, pp. 145-146.

[11] P. Anandarajah, *et al*. “Self Seeding of a Gain Switched Integrated Dual Laser Source for the Generation of Highly Wavelength Tunable Picosecond Optical Pulses”, *IEEE Photon. Technol. Lett*., pp. 629-631, 2004

[12] L.P. Barry, *et al*. “Optical pulse generation at frequencies up to 20 GHz using external-injection seeding of a gain-switched commercial Fabry-Perot laser” *IEEE Photon. Technol. Lett.*, vol. 13, pp. 1014-1016, 2001.

Authorized licensed use limited to: DUBLIN CITY UNIVERSITY. Downloaded on January 12, 2009 at 06:00 from IEEE Xplore. Restrictions apply.