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Demonstration of Optical Wireless Communications System using a Software Defined Ecosystem

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Abstract— In this paper, we experimentally demonstrate the implementation of an optical wireless communication system in a software defined radio platform using GNU radio ecosystem and verify the link performance in terms of the bandwidth and jitter by changing the interpolation parameters in the software domain. We show that, the software defined optical system provides high reconfigurability and can be easily implemented without the need to change the architecture of the hardware, providing a real-time signal based system, which is highly desirable.

Keywords—Optical Wireless Communications; Software-Defined Radio; USRP; GNU Radio.

I. INTRODUCTION

The number of wireless devices such as smartphones, laptops and tablets increases each year, while multimedia content becomes the main part of the overall mobile data transferred [1]. The optical spectrum has already played a significant role in the global expansion of the Internet due to the concerns about the capacity and availability of communication systems developing rapidly as wireless communication networking becomes ingrained in our daily lives [2]. As a result of the need to deliver high-speed data transfer to end users, new optical network access methods have been developed to address these issues [3]. Optical wireless communication (OWC) networks could be considered as a complementary technology to radio frequency (RF) based systems and also as a possible option to the spectrum management and easing of the spectrum congestion [1]. One of the main reasons is the capacity of OWC systems allowing the confined light wave to achieve strong physical layer security. Ease in installation, operating in an unlicensed band, providing security (reduced risk of interception), high data rate and portability are also the main advantages of OWC technology [3].

To achieve a high data flow over short distances, also known as ‘last mile’ or ‘last meter/kilometre’ access, OWC technology has shown significant and promising solutions, such as flexible traffic routing, fast deployment, and more secure channels, compared to RF [4]. OWC systems can also be implemented as part of the back- and front-haul traffic areas where cable fixed links are not economical and due to lengthy new fibre wiring [5]. Another economic reason for OWC technology is the availability of

components, which are extensively used in matured optical fibre technology [2]. In addition to the growing attention from both academia and industry to practical deployment, theoretical investigations and design aspects of OWC systems have been widely carried out [6]. However, most reported literature is purely based on hardware solutions involving the use of traditional optical sources, photodetectors and integrated circuit boards, which limit cross functionality and can only be modified through physical intervention. Even though there is reconfigurable hardware solution involving the use of field programmable gate arrays (FPGAs) or digital signal processing (DSP) boards, it requires highly skilled and specialized personnel [7].

In contrast to the hardware reconfiguration, software defined ecosystems provide a relatively easy, efficient, cost effective, and highly flexible approach to design dynamic, efficient, and highly secure wireless/wired communication network components. By doing so, most of the physical layer functionalities can be implemented through the modifiable software platform. This allows reducing the hardware cost by adding new wireless features without the requirement of new components, which is highly desirable by service providers and product developers through to end users [8]. Furthermore, software defined radio (SDR) enables easy implementation of a range of radio and optical systems by adopting a common platform architecture and using off-the-shelf components such as the wireless open-Access research platform boards, and universal software radio peripherals (USRPs). Comparably, there have been some reported literature on the implementation of software defined optical communications system.

For instance, in [9], the experimental demonstration of a visible light communication (VLC) system using light emitting diodes (LED) was proposed based on adaptive modulation with multistate pulse amplitude and pulse position modulation schemes using USRP. The selection of the appropriate modulation scheme depending on the noise, interference, and environmental conditions, was demonstrated in a bi-directional system. Also, the investigation on the parameters used for the implementation of an SDR-based VLC system such as transmit speed, bit error rate, and highest reachable distance was reported in [10]. This work was focused on testing the system with multi quadrature amplitude modulation (QAM) using LabVIEW on the software side and USRPs, and two

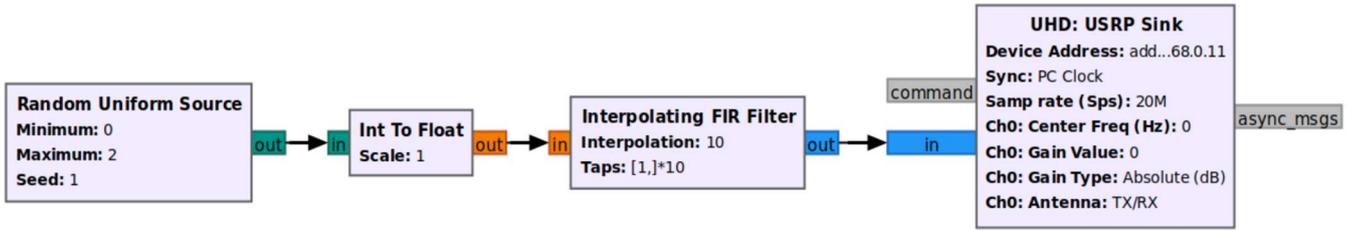


Fig. 1. Flow graph of OOK-NRZ generation.

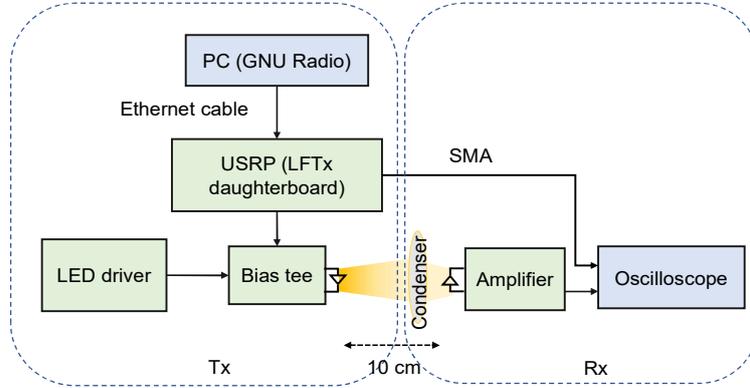


Fig. 2. System block diagram.

types of transmitters, i.e., Skoda Octavia III tail-light and Phillips indoor light. In [11], an optical front end for USRP radios using infrared LEDs was reported with the achieved bandwidth of 10 MHz.

In this paper, we experimentally demonstrate a SDR-based OWC system and verify its flexibility and investigate its performance in terms of the bandwidth and the jitter of the received signal by changing the interpolation parameters in the software domain. The proposed system can be also used for infrared light communication systems.

The rest of the paper is organized as follows: Section II characterises the system implementation in GNU Radio and experimental setup. Section III describes the results and provides discussions and finally, Section IV concludes the paper.

II. SYSTEM MODELLING

A. GNU Radio

To implement the on-off keying non-return to zero (OOK-NRZ) signal generator in GNU Radio, we used the built-in modules as seen in Fig. 1 and as described in the following:

- i. **Random uniform source:** This generates pseudo random binary numbers included in $[\min, \max)$.
- ii. **Int to float:** In this block, the conversion of a stream of integers into a float data type is implemented. The interpolation filter only takes float and complex data type, which necessitates the completion of this step.
- iii. **Interpolation filter:** This is a finite impulse response filter, which up-samples the input to a higher rate by inserting $(L-1)$ zeros between samples and uses the method of the zero-order hold [12]. The number of taps is given by:

$$N = sps \times L \quad (1)$$

where sps is the samples per symbol, and L represents the interpolation rate.

- iv. **UHD (USRP Hardware Driver), USRP sink:** This is the main connection between the GNU Radio environment and the USRP. The unique Internet protocol address of USRP in the experimental setup is required in this module.

B. Experimental setup

The schematic block diagram of the proposed experimental set up is shown in Fig. 2. Note, all the key system parameters are given in Table 1. The transmitter (Tx) unit consists of the PC in which the GNU Radio ecosystem is used to generate the OOK-NRZ signal. The PC is connected to the N200/210 USRP with Xilinx® Spartan® 3A-DSP XC3SD1800A and a low frequency transmitter daughterboard. The output of the USRP is connected to the bias tee, which is also connected to the LED driver and the LED. The intensity modulated light

Table 1. Key system parameters in experimental set up.

Parameter	Value
LED type	Rebel star – NW100
Transmit optical power P_{Tx}	17.7 dBm
Optical wavelength λ	430 nm
Link length l	10 cm
Rx optics	Lens diameter D_{Rx} - 50 mm Effective f_l - 44 mm
Optical Rx	PDA100A2 – Si Switchable gain detector
Photodetector active region	75.4 mm ²
Responsivity of PD at 960 nm	0.72 A/W
Rx operating wavelength range	320-1100 nm
Rx bandwidth	11 MHz
Noise equivalent power	2.67 – 71.7 pW/ $\sqrt{\text{Hz}}$

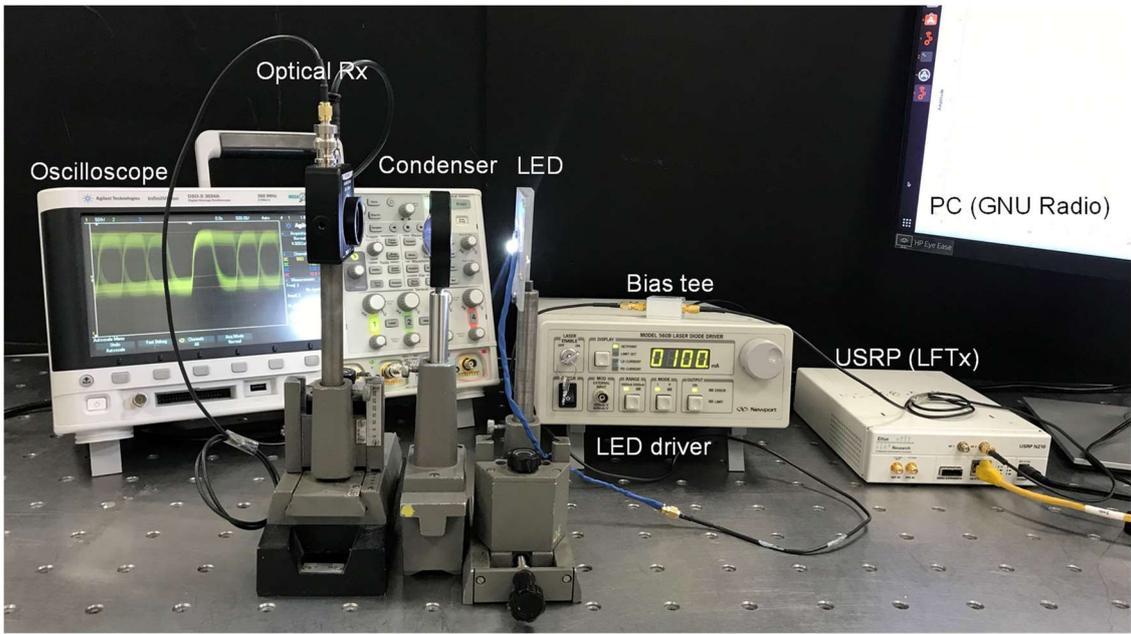


Fig. 3. Experimental setup.

beam is then launched over the free space channel, which is of length 10 cm (for the proof of concept; obviously, longer length can be used in practice). On the receiver (Rx) unit, the incoming light signal is focused on a photodetector (PD) of an optical Rx using an optical condenser. The regenerated electrical signal is then captured using an oscilloscope for the real time assessment.

III. RESULTS AND DISCUSSION

In this section, we demonstrate the OWC system in the GNU Radio platform and investigate the corresponding relationship between the interpolation filter, bandwidth, and jitter of the received signals. We show the flexibility and capability of controlling the system shown in Fig. 2 by simply changing the parameters in the software domain. We carried out a number of tests and measurements by increasing the taps of interpolation rate while maintaining the PC sample rate at 20 MHz (the sampling rate limit of the

Table 2. Bandwidth and jitter of the received signal corresponding to the interpolation rate and taps.

Interpolation rate (L)	Interpolation taps (N)	Bandwidth (MHz)	Eye jitter (ns)
10	$[1] \times 10$	4.0	12.4
12	$[1] \times 12$	3.1	13.4
14	$[1] \times 14$	2.6	14.7
16	$[1] \times 16$	2.4	15.2
18	$[1] \times 18$	2.1	16.0
20	$[1] \times 20$	2.0	17.4

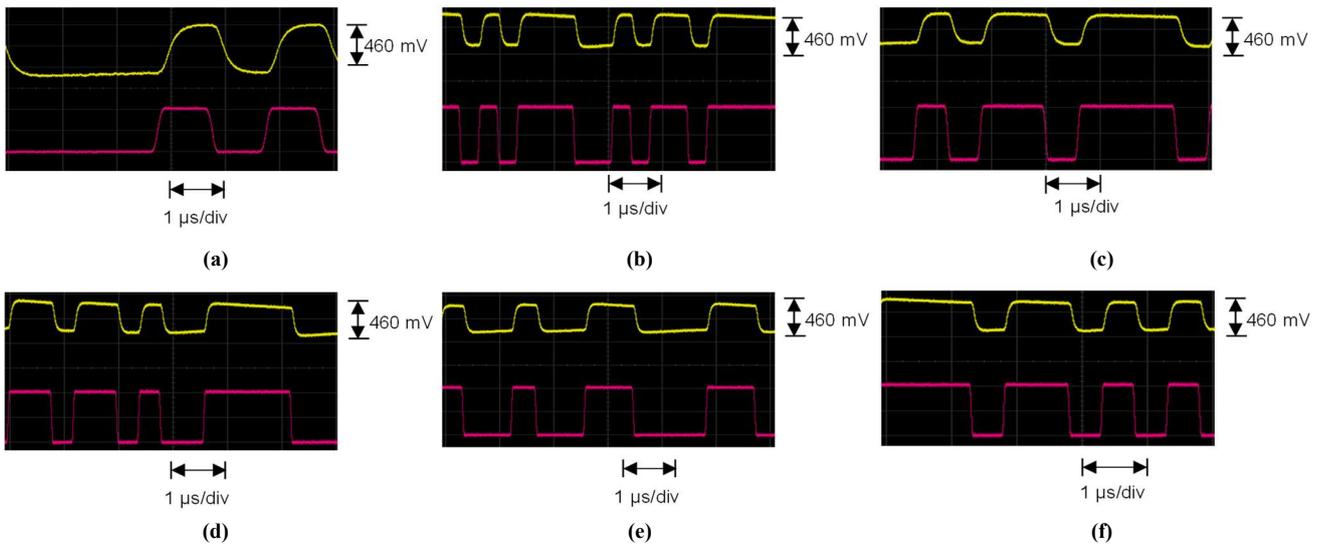


Fig. 4. Received OOK-NRZ signals via USRP (lower trace, in pink) and optical front end (upper trace, in yellow) with the interpolation filter length of: (a) 10, (b) 12, (c) 14, (d) 16, (e) 18, and (f) 20.

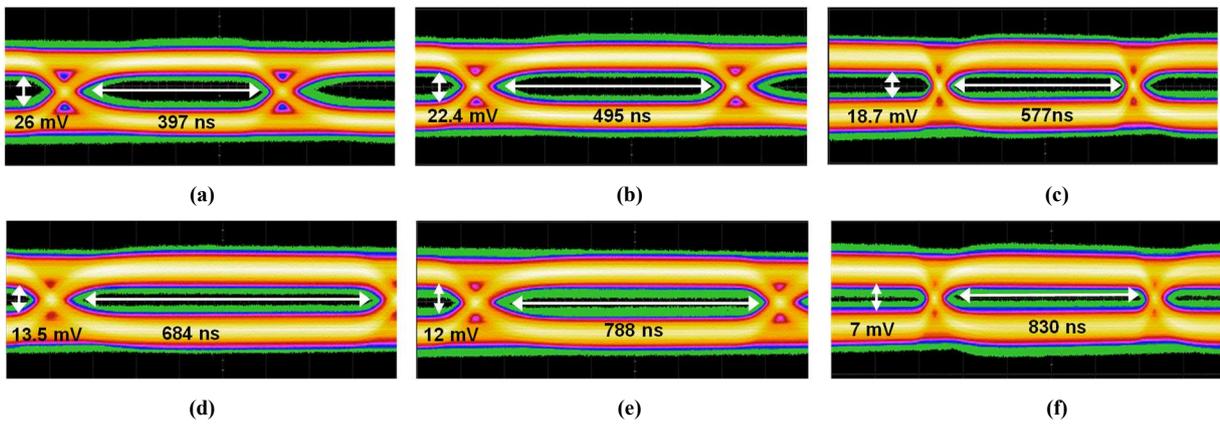


Fig. 5. Eye diagrams of received OOK-NRZ via optical frontend with the interpolation filter rates of: (a) 10, (b) 12, (c) 14, (d) 16, (e) 18, and (f) 20.

PC used). The system bandwidth was estimated by measuring the rise and fall time of the received signal, whereas the jitter was calculated by measuring the rise and fall time error of the eye diagram, see Table 2. Note, $sps = 1$ and is kept constant in this experiment. The lowest jitter of 12.4 ns is for L and N of 10, and for the bandwidth of 4 MHz. We have also shown examples of the received signal captured using an oscilloscope in Fig. 4, which illustrates the captured time domain signals via the USRP (lower trace) and optical front end (upper trace) for a range of interpolation rates of 10, 12, 14, 16, 18, and 20. It is noticed that the waveform of the signal becomes less distorted with the increased interpolation factor.

To assess the quality of received signal, we have presented the eye diagrams in Fig. 5. For instance, Fig. 5(a) shows the eye diagram for $L = 10$ with eye width and height of 397 ns and 26 mV, respectively, whereas Fig. 5(b) corresponds to $L = 12$ with eye width and height of 495 ns and 22.4 mV, respectively. Also, Figs. 5(c)-(f) show the eye diagram for L and N of 14, 16, 18, and 20, respectively. It is noticed that, the eye gradually closes as both L and N are increased; the widest eye opening is observed for the least L and N . This is due to the bias tee behaving as a high pass filter, distorting the signal.

IV. CONCLUSION

In this paper, we demonstrated the implementation of an OWC link using OOK-NRZ modulation scheme in an SDR platform using GNU radio ecosystem and investigated the effect of interpolation length and taps corresponding to the bandwidth and jitter of the received signal. We showed that, the software defined optical system provides high reconfigurability and can be easily implemented without the need to change the architecture of the hardware for real time signal processing. Future work will focus on the implementation of multi-level modulation schemes for an OWC link along with artificial neural network equalization using a more recent generation of USRPs and SDR ecosystem for online data processing.

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