Crosstalk-free AWGR-based 2-D IR beam steered optical wireless communication system for high spatial resolution

Citation for published version (APA):

Zhang, X., Li, C., Jiao, Y., van den Boom, H. P. A., Tangdiongga, E., Cao, Z., & Koonen, A. M. J. (2019). Crosstalk-free AWGR-based 2-D IR beam steered optical wireless communication system for high spatial resolution. In *Crosstalk-free AWGR-based 2-D IR beam steered optical wireless communication system for high spatial resolution* [Th1F.5] Optical Society of America (OSA). <https://ieeexplore.ieee.org/document/8696650>

Document status and date:

Published: 03/03/2019

Document Version:

Accepted manuscript including changes made at the peer-review stage

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

[Link to publication](#)

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy

If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

Crosstalk-free AWGR-based 2-D IR beam steered optical wireless communication system for high spatial resolution

Xuebing Zhang, Chao Li, Yuqing Jiao, Henrie van den Boom, Eduward Tangdionga,
Zizheng Cao and Ton Koonen

Institute of Photonic Integration, Eindhoven University of Technology, NL 5600 MB Eindhoven, The Netherlands

Corresponding Author: z.cao@tue.nl

Abstract: By creating polarization orthogonality between the odd and even channels, crosstalk-free OWC link is realized with spectral overlap. This technique can tolerate the wavelength misalignment between AWGRs and lasers, which relaxes the design of high port-count AWGRs and wavelength stable lasers.

OCIS codes: (060.2330) Fiber optics communications; (060.2605) Free-space optical communication; (230.7408) Wavelength filtering devices.

1. Introduction

To satisfy the exponential bandwidth increase in indoor networks, beam-steered indoor infrared (IR) light optical wireless communication employing narrow pencil-beams is attracting increasing interest [1-4]. The IR spectrum is license-free and its wide frequency range offers a potentially large capacity. The steered free-space narrow IR beam brings the light only where and when needed, and offers non-shared connections [1]. Recently, the λ -controlled 2-dimensional (2-D) IR beam steering system using a high port-count arrayed waveguide grating router (AWGR) was proposed and experimentally demonstrated [2]. As the λ -routing component, the AWGR module determines the spatial resolution and spectral efficiency (optical bandwidth per channel) in the beam steering system. As shown in Fig. 1(a), the output fibers of the AWGR are arranged in 2-D fiber array and the fiber array is put in the focal plane of a lens. The position of a fiber in the focal plane determines the 2-D direction in which its corresponding beam is emitted after the lens. In other words, each output port of the AWGR covers a certain area. With the increase of spatial resolution and transport capacity, a higher port-count and larger port-bandwidth AWGR is urgently needed. Considering that the usable spectral range is limited (e.g. 35 nm for C band), the spatial resolution is compromised with spectral efficiency. Fig. 1(b) presents the normal AWGR response. It is obvious that the most direct way of adding port-count is to reduce the channel spacing. But, to avoid the inter-channel crosstalk, a spectral guard band is inserted between adjacent AWGR channels, which inevitably causes a waste of spectral resources. Thus the port-bandwidth is also shrunk. Currently, the available solution is to reduce the AWGR channel grid (e.g. from 50-GHz grid to 12.5-GHz grid) and at the same time, upgrade the channel shape from ‘Gaussian’ to ‘Flat-top’ as depicted in Fig. 1(c) [5-6]. The 1-dB bandwidth can be extended from 31% to >65% of channel spacing [5]. Nevertheless, this ‘Flat-top’ design leads to higher crosstalk which requires larger guard band between the channels, thus this improvement is weakened again.

In order to solve these problems, we propose a crosstalk-free transmission scheme in AWGR-based 2-D IR beam steering communication systems. By creating polarization orthogonality between the odd and even channels, a very high crosstalk tolerance between spectrally overlapping AWGR channels can be realized. Because two signals with orthogonal polarization states will not beat with each other in a photodiode. The signal with crosstalk on orthogonal polarization state will not generate a heterodyning beat note after the photodiode and thus no crosstalk exists in electrical domain. This spectral overlap also means higher spectral efficiencies. The technique can also resist the wavelength misalignment between AWGRs and lasers. Moreover, in terms of AWGR design, the higher port-count

Fig. 1. (a) AWGR-based 2-dimensional IR beam steering system; (b) the normal AWGR response; (c) the improved ‘Flat-top’ design.

Fig. 2. The principle of the AWGR-based 2-D IR beam steering no-crosstalk transmission scheme; a-g: The spectra at the relative points. Tun. LD: tunable laser; PBC: polarization beam combiner; PD: photodiode

can be implemented simply by reducing the gap between output waveguides on a chip, which allows us to keep the small AWGR footprint. The constrain on high stability tunable lasers is also relieved.

2. Operation principle

In the traditional system, the signal that is fed into the AWGR module has arbitrary polarization and non-overlapped to avoid the inter-channel crosstalk through the AWGR. In order to further improve the spectral efficiency, especially facing the requirement of high port-count/large port-bandwidth AWGRs, the new crosstalk-free transmission method is proposed. Fig. 2 shows the principle of the system. Usually, the intensity-modulation/direct-detection (IM-DD) method is utilized [2]. In the scheme, the input signal is split into two groups: even and odd channels according to the spectral response of the AWGR as shown in Fig. 2 (a) and (b). The adjacent channels are set to be overlapped in spectrum to realize a high spectral efficiency. The polarization states of even and odd groups are shifted to orthogonal polarizations respectively, and then combined by a polarization beam combiner (PBC). Fig. 2 (a-c) present the spectra before and after the PBC. Due to the filtering function of the AWGR, the signal is λ -split and steered to different directions. For the channels of λ_n and λ_{n+1} , they contain the target signal (including the carrier and the signal) and the so-called ‘crosstalk’ (signal without carriers) from adjacent channels with the orthogonal polarization as shown in Fig. 2 (d-e). Then the received signal is detected by a photodiode and the detected photo current can be presented as

$$I_n = |E_{c,n,x} + E_{s,n,x} + E_{s,n+1,y} + E_{s,n-1,y}|^2 = |E_{c,n,x} + E_{s,n,x}|^2 + |E_{s,n+1,y} + E_{s,n-1,y}|^2 + 2\text{Re}(E_{s,n,x}E_{c,n,x}^*) \quad (1)$$

$$I_{n+1} = |E_{c,n+1,y} + E_{s,n+1,y} + E_{s,n+2,x} + E_{s,n,x}|^2 = |E_{c,n+1,y} + E_{s,n+1,y}|^2 + |E_{s,n+2,x} + E_{s,n,x}|^2 + 2\text{Re}(E_{s,n+1,y}E_{c,n+1,y}^*) \quad (2)$$

where, $E_{c,n,x}$ and $E_{s,n,x}$, $E_{c,n+1,y}$ and $E_{s,n+1,y}$ are the carriers and signals in n (with x -polarization) and $n+1$ (with y -polarization) channels, respectively. $E_{s,n+1,y}$ and $E_{s,n-1,y}$, $E_{s,n+2,x}$ and $E_{s,n,x}$ are the crosstalk signals in n and $n+1$ channels due to the spectral overlap. It is known that two signals with orthogonal polarization states will not beat with each other in a photodiode, so will not generate a heterodyning beat note. From the final expressions of each photo current, the first term is direct current (DC) that does not affect signal. The second term is signal-to-signal beat interference (SSBI) generated by target signal and the third term is the SSBI caused by inter-channel crosstalk, which can be neglected [7]. The last term is the recovered signal. It is obvious that, compared to the traditional IM-DD 2-D beam steering system, no electrical crosstalk is brought given that the third SSBI term is negligible [7].

3. Experimental setup and parameters

The signal can be of single-carrier or multi-carrier type. For the proof-of-concept demonstration of our scheme, the signal used is the orthogonal frequency-division multiplexing (OFDM) format. Two AWGR channels (central wavelength 1550.02nm and 1550.12nm) are utilized. The optical carriers are offered by two tunable lasers (Tun. LDs) and then are fed into two separate Mach-Zehnder modulators (MZMs) driven by OFDM-16QAM signals. The OFDM signal uses 512-point FFT size, in which 212 subcarriers have data and 8 subcarriers no data in order to avoid the low-frequency interference. The signal is transmitted by an arbitrary waveform generator (AWG) running at 10GSa/s. The double-sideband bandwidth and net bit rate are 8.59GHz and 15.4Gbit/s, respectively. The modulated signal is λ -switched to two input ports of a PBC, which carry the odd and even channels of the AWGR. A polarization controller

Fig. 3 Experimental setup. Tun. LD: tunable laser; MZM: Mach-Zehnder modulator; AWG: arbitrary waveform generator; PBC: polarization beam combiner; X/Y-Pol.: X/Y-polarization; PC: polarization controller; VOA: variable optical attenuator.

(PC) is used before the PBC to align the polarization state. After the amplification by an EDFA, this specially designed signal is split into different channels and transmitted to a 1.1m free-space link (~ 2.5 dB loss) via a lens collimator. The receiver consists of a lens collimator followed by an avalanche photodiode (APD). The variable optical attenuator (VOA) is only for measuring performance, which can be removed. The detected signal is sampled by a digital phosphor oscilloscope (DPO) at 25GSa/s rate. The inset shows the optical spectra before and after the AWGR. The minimum carrier-spacing is set as 3.5GHz with 5.1GHz spectral overlap.

4. Experimental results and discussion

Fig. 4 (a) The AWGR response; (b) the measured SNR performance curves; PBC: polarization beam combiner; OC: optical coupler.

A commercial AWGR is used to prove the effectiveness of our crosstalk-free transmission scheme as shown in Fig. 4(a). Due to the large spectral guard band (hence low spectral efficiency), here, we shift the central wavelength of the signal closer to the passband edge to emulate the inter-channel crosstalk. First, we put the 8.59-GHz target signal-band at 1550.06nm (the central wavelength 1550.02nm). Then we move the adjacent 8.59-GHz signal-band close to the target signal. Fig. 4(b) illustrates the performance comparison after AWGR between our method using PBC and the traditional way using an optical coupler (OC). With the decrease of the two signal-bands' spacing, more spectral overlap introducing crosstalk is generated. This overlap will cause a large drop in SNR (>5 dB in Fig. 4 (b)), but our method maintains the SNR performance which shows no crosstalk interference occurs. Actually, as long as the spacing is <8.59 GHz, the overlap always exists. Just because of the strong filtering of this large-guard-band AWGR, the crossed power is at very low level when the spacing is not small enough, causing very limited interference (e.g. spacing 5.5-7.5GHz). The proposed scheme will present greater advantages than the conventional scheme for the case when the 'specially-designed' flat-top and small-guard-band AWGR is employed.

5. Conclusion

We propose a cross-talk-free transmission scheme in AWGR-based 2-D IR beam steering communication system. By creating polarization orthogonality between the odd and even channels, the spectrally overlapping AWGR channels can mitigate the impact of crosstalk on performance, achieving higher spectral efficiency. The proposed technique can tolerate the wavelength misalignment between AWGRs and lasers, which relaxes the design of high port-count AWGRs and wavelength stable lasers.

Acknowledgement. This work is supported by the ERC FP-7 Proof of Concept grant BROWSE-PLUS and the NWO Zwaartekracht program on Integrated Nanophotonics. National Natural Science Foundation of China (NSFC) (61575186, 61635001); Open Fund from State Key Laboratory of Advanced Optical Communication Systems Networks, China; NWO China Exchange Programme (530-5CDP06).

7. References

- [1] T. Koonen, *Journal of Lightw. Technol.* 36, no. 8, 1459-1467 (2018).
- [2] T. Koonen et al., *Journal of Lightw. Technol.* (2018).
- [3] Z. Cao et al., *Proc. OFC*, pp. Th5A-6, Los Angeles, Mar. (2017).
- [4] T. Koonen et al., *Journal of Light. Tech.* 32, no. 4, 591-604 (2014).
- [5] M. K. Smit et al., *IEEE Journal of selected topics in quantum electronics* 2, no. 2, 236-250 (1996).
- [6] Madsen et al., *Optical filter design and analysis*, (1999).
- [7] W. Shieh et al., *OFDM for optical communications*. (2009).