Research Assessment Exercise 2020
Impact Case Study

University: The Hong Kong Polytechnic University
Unit of Assessment (UoA): Electrical & Electronic Engineering (12)

Title of case study: Advanced signaling techniques and optical components for data centers and renewable energy systems

(1) Summary of the impact

Optical components and signal processing algorithms developed by UoA12 based on an interdisciplinary approach have played a key role in advancing optical fiber communications supporting data centers Worldwide and Light Detection and Ranging (LIDAR) systems for more efficient wind turbine operations. Since 2006, the impact of this research has been to:

- Develop signaling techniques and help Huawei define technology Standards for 100Gb/s optical transceivers for data center transmissions
- Develop 2 digital signal processing (DSP) algorithms for Huawei's 100Gb/s optical transceiver testing chipset
- Spin-off a startup company **PlugTech** which specialize in bias-voltage controllers for the optical modulators with customers Worldwide
- Developed fibre laser for Lidar solutions for **Amonics**, a local HK company founded by UoA12 PhD graduates in optical fiber amplifiers and associated equipment

(2) Underpinning research

The underpinning research has been focused on **digital signal processing (DSP) algorithms** to compensate fiber transmission impairments and optical devices imperfections as well as the development of **fiber lasers** for LiDAR applications since 2008.

Digital signal processing (DSP) algorithms for short-reach and long-haul systems

- As global Internet traffic is increasingly concentrated in data centers with short distance optical links, low-cost transceiver technologies supporting > 100 Gb/s per channel is a pivotal area of research in recent years. Appropriate signalling techniques that take into account the hardware limitations is a key issue in enabling low-cost high speed solutions. Prof. C. Lu and Prof. A.P.T. Lau's research in 2014 investigated different signalling schemes including Pulse Amplitude Modulation (PAM), Carrierless Phase and Amplitude (CAP) and discrete multi-tone (DMT) and concluded that PAM outperforms others in DSP and hardware complexity [3.1] and is therefore a more favourable choice of technology for commercialization. Another key bottleneck for short-reach systems is bandwidth limitations of low-cost devices which creates significant distortions. Prof. C. Lu and Prof. A.P.T. Lau developed a computationally simple decision-directed Faster-Than-Nyquist(DD-FTN) algorithm [3.2,3.3] in 2014/15 that combines the flexibility of adaptive signal processing and low-complexity maximum likelihood sequence estimation (MLSE) technique that does not enhance noise effects so that the overall algorithm has high detection performance and is low-cost and practically feasible.
- For long-distance systems, knowledge of transmission impairments such as chromatic dispersion (CD) is vital when initializing a link where the transmission impairments are compensated by DSP. Estimating CD quickly with minimum amount of transmitted signals to reduce the communication overhead becomes imperative especially for future dynamic network

connections. Prof. C. Lu and Prof. A.P.T. Lau developed the then-fastest CD estimation algorithm which make use of the autocorrelation properties of the received signal power waveforms [3.4]. The technique can accurately estimate CD in about 1us and is robust to other transmission impairments in practice, thus enabling a key step in realizing transceivers for future dynamic optical networks.

- Automatic bias control (ABC) algorithms and circuitry is a core component for stable operation of optical modulators in generating high quality optical signals. Recognizing a lack of suitable controller in the market, a few undergraduate students led by B. Fang built their own ABC as a research project, "Laser and Optical Modulator Control System", in the Department of Electronic and Information Engineering under the supervision of Prof. C. Lu in 2013. He later co-founded a spin-off company **PlugTech** and is selling such ABCs Worldwide with an annual sale of about HK$2.5 million.

Development of fiber laser for Light Detection and Ranging (LiDAR)

- LiDAR has seen increasing applications in wind detection, autonomous driving among others. Lidar requires accurate reception of both the amplitude and phase of the light signal. An important component for optical phase stability is a laser with accurate lasing frequency and extremely narrow linewidth. Another important component is the high-power optical fibre amplifier capable to amplify nanosecond laser pulses with high output power for wind detection and ranging LiDAR systems over several 10's km. The underpinning research is in the areas of optical fibre amplifier which was conducted at UoA12 by Prof. Tam and Dr. W.S. Man for over 20 years. In 2001, Dr. W.S. Man, Prof. Tam and D. Y. Tang demonstrated a passively mode-locked fiber ring laser[3.5] which laid down the ground work for subsequent research on stable single-frequency single-polarization fiber ring laser at 1053 nm with high power by using Yb^{3+} doped fibers and cascaded fiber Bragg gratings (FBG) to reduce the linewidth performance to less than 10 kHz, which is suitable for LiDAR applications [3.6]. The results were presented at the OptoElectronics and Communications Conference and the Australian Conference on Optical Fibre Technology in Australia in 2008. Dr. W.S. Man and Dr. K.S. Tsang are the CEO and Senior Engineer of Amonics Limited. Dr. Tsang obtained his PhD from UoA12 in 2017. Amonics is now a major fibre laser module provider to top LiDAR manufacturers in the world. The annual revenue of Amonics is about HK$40 million. Amonics has about 50 employees, including five PhD graduates, all graduated from UoA12. Amonics is based in Hong Kong and is the only advanced photonic equipment manufacturer in Hong Kong.

(3) References to the research

[3.1] K. Zhong, X. Zhou, T. Gui, L. Tao, Y. Gao, W. Chen, J. Man, L. Zeng, A.P.T. Lau and C. Lu, "Experimental study of PAM-4, CAP-16, and DMT for 100 Gb/s short reach optical transmission systems," *Optics Express*, 23(2), 1176-1189, 2015.

[3.2] K.P. Zhong, X. Zhou, Y. Wang, Y. Wang, W. Zhou, W. Chen, L. Zeng, L. Wang, A.P.T. Lau and C. Lu, "Transmission of a 120-GBd PM-NRZ signal using a monolithic double-side EML," *IEEE Photonics Technology Letters*, 28(20), 2176-2179, 2016.

[3.3] K.P. Zhong, X. Zhou, Y. Gao, W. Chen, J. Man, L. Zeng, A.P.T. Lau and C. Lu, "140-Gb/s 20-km Transmission of PAM-4 Signal at 1.3um for Short Reach Communications," *IEEE Photonics Technology Letters*, 27(16), 1757-1760, 2015.

[3.4] Q. Sui, A.P.T. Lau and C. Lu, "Fast and robust blind chromatic dispersion estimation using auto-correlation of signal power waveform for digital coherent systems," *Journal of Lightwave Technology*, *31*(2), 306-312, 2013.

[3.5] W. S. Man, H. Y. Tam, M. S. Demokan, and D. Y. Tang., "Soliton shaping of dispersive waves in a passively mode-locked fiber ring laser," *Optical and Quantum Electronics*, Vol.33, No. 11, Nov 2001, pp.1139-1147

[3.6] K.S. Tsang, R. Man, L.-Y. Shao, H.Y. Tam, C. Lu and P.K.A. Wai, "Single-Frequency Single-

Polarization Fiber Ring Laser at 1053 nm," Proceedings, *OptoElectronics and Communications Conference and the Australian Conference on Optical Fibre Technology* (OECC/ACOFT'2008), paper P-24, July 2008, Sydney, Australia.

(4) Details of the impact

[Emerging social media, data center, cloud computing, AR/VR, 5G wireless and Internet of Things (IoT) applications dominate global Internet traffic growth demands. For optical communications that form the core of telecommunications Worldwide, coherent detection and DSP algorithms opens up new dimensions to encode information, allow complete and adaptive compensation of transmission impairments and became the defining technology for this generation of optical transceiver technology. Other optical systems such as Lidar has also been benefitted by such advances in optical communications technology. UoA12 has worked in DSP algorithm developments over the past 10 years and collaborate extensively with industry, most notably with Huawei with funding over 20M HKD. We also formed a joint collaboration lab on PolyU main campus.

Our research in PAM4 signalling [3.1] suggested that PAM4 is a good technology choice and became the basis for Huawei's participation and position in the standardization process of 400Gb/s transceivers(100Gb/s per channel) for short-reach systems with distance up to 2 km. The PAM4 technology has been accepted to the IEEE 802.3 400GB Ethernet standard in Dec. 2017. With Worldwide shipment of 400G transceivers beginning to ramp up in 2019, the underpinning technology has helped advance transmission speeds of data centers worldwide, which in turn enable various high-speed cloud computing, IoT, AR/VR applications that shape the way we interact with each other in the workplace and personal lives. Such new interconnectedness and interactions are known to lead impact in the **quality of life and health** of individuals as witness recently by the proliferation of cloud-based health monitoring devices. As stated in the testimonial by Huawei, PolyU's contribution to their business was significant because the research outcomes from PolyU "**have sped up the underlying technology and production cycle of our optical transceivers tremendously**" [5.1]

The DD-FTN and CD estimation algorithms developed in [3.2-3.4] are outcomes of research collaboration projects with Huawei. The algorithms were further refined by the product development team of Huawei and sample chips containing the algorithms has been fabricated and tested before commercial launch of their optical transceivers. The algorithms helped Huawei to finalize the transceiver design that strives a technical and economic advantage which in turn help their products secure a sizeable market share globally. Furthermore, the DD-FTN algorithm also helped set a world record in fastest optical transmissions over 2-km fiber for data centres in 2016 and is reported worldwide [5.2-5.4]. These benchmarks provide important guidelines for public services as they are incorporated into the regulatory decisions that are shaped by public policy makers.

Spin-off company in automatic bias controllers for optical modulators: Upon completion of a research project, students from UoA12 founded Shenzhen Plug-Tech Precision System Ltd. in 2014 and focused on automatic bias controllers for optical modulators. At present, the annual revenue is around 300,000 USD/year and they provide controllers and full solutions to customers worldwide including NASA, Bell Labs, Microsoft Research in UK, Huawei Tech. Co and other universities worldwide. Serving as the technical advisor, Prof. Chao Lu "**provided essential guidance and assistance during the establishment of the company and R&D of products. His help was critical as the company sought to enter the market of the bias-voltage controllers for optical modulators**" [5.5]. The skill involved to fabricate such sophisticated bias controllers is significant in that supports one of the key public policy objectives of the Greater Bay Area mission to develop

industries that are at the forefront of technology. Plug-Tech provides employment and economic support in the region, but importantly, by focusing on high-value technology and low-skill manufacturing with minimal pollution or emissions in the way that the traditional industries would in the past, there are tremendous **environmental benefits** as the quality of life is improved for millions of people in the Shenzhen and Greater Bay Area region. This transition is essential to the long term sustainability of southern China and mitigating the environmental damage caused in the past by heavy industries and manufacturing.

Lidar systems: Our UoA12 colleagues Prof. HY Tam and Prof. Alex Wai serve as technical advisors to Amonics. The fiber laser developed in PolyU provided the know how and experience for Amonics to advance their Lidar business leading to significant economic impact for the company and HK, where they are based. Most of their Lidar customers use fiber lasers as the light source for their Lidar devices and it is important for them to understand the fiber laser properties so that they can design the amplifiers and other associated components appropriately to meet customers' demands. As stated in the testimonial by Amonics, PolyU's contribution to their business was significant because "the research is significant to our LiDAR business …" [5.6]. Recently, **Amonics' Lidar products** were recognized for their global leadership and this earned them the **2017 Hong Kong Awards for Industries: Technological Achievement Award** [5.7]. Such awards bring about significant **impact to the local culture** as they reinforce HK's technological capabilities in the minds of young and old tech-savvy enthusiasts in HK. In fact, such notoriety are important for public policy in HK as they showcase the strengths and areas of talent in HK for appropriate prioritization in forming public policy objectives.

Finally, our established track record on optical communications research has also enabled our staff in UoA12 to **contribute to policy developments in China**. In particular, Prof. Chao Lu has been invited in the panel of experts for Ministry of Science and Technology (MoST) to provide input to the National plan for 2035 in the areas of optical communications. MoST develops policies and plays a major role in China's technology strategy and resource allocations to R&D in the long- and medium-term. As China embarks on the next phase of national development to improve the quality of life in remote and urban regions, optical communications are essential to enabling more connectivity, efficiency and opportunities in new economic developments. Therefore, the impact on society is profound.

(5) Sources to corroborate the impact

[5.1] Testimonial by Huawei
[5.2]https://www.scmp.com/news/hong-kong/education-community/article/1934202/sharper-virtual-reality-soon-hongkongers-develop
[5.3] https://phys.org/news/2016-04-team-world-fastest-optical-centers.html
[5.4] http://www.ecnmag.com/team-breaks-world-record-of-fastest-optical-communications-for-data-centers/
[5.5] Testimonial by PlugTech
[5.6] Testimonial by Amonics
[5.7] https://www.tid.gov.hk/hkindustryaward/mobile/english/winners/2017_ta.html