International Benchmarking Mission

FINAL REPORT

INDUSTRY
SCIENCE
TOURISM

THE Warren CENTRE
FOR ADVANCED ENGINEERING

MACQUARIE
BANK

Photonics in Australia

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Japan, UK
Sweden, USA

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Preface

Purpose of International Benchmarking Mission

The International Benchmarking Mission was undertaken at the request of the Steering Committee of the Photonics in Australia Industry Project. The primary purpose of the Mission was to: **1.** assess Australia's positioning in Photonics technology development and commercialisation; and **2.** to identify where opportunities for Australian Industry may arise.

This report provides a detailed account of the information obtained by the delegates, Ross Halgren and Phil Carmont, through visits to world leading companies and research organisations in Japan, UK, Sweden and the USA. The information sought and obtained from these visits is intended to provide informed input for the decision makers in Australian Industry, relevant Australian Government Departments, and Australian Research Institutions.

To benchmark Australia's technological and commercial position, the following issues were addressed where appropriate and agreed to by the Host Organisations:

- Research income or company R&D spending as percentage of gross sales;
- Source of research direction (Own control, Product Division, Customers; Government);
- Near term and long term product opportunities;
- Industries perceived to be driving demand (eg, Telecommunications, Medical etc);
- Emerging Photonics technology trends;
- Importance of vertical integration;
- Qualification requirements of R&D staff for institutional research or industry employment;
- Interaction between industry and educational or other research institutions;
- Degree of direct Government assistance;
- Existence and significance of entrepreneurial spin-off companies;
- Availability of private sector risk capital;
- Perception of Australia's Photonics technology research & product development; and
- Willingness to invest in and/or collaborate with overseas counterparts.

The Mission has been documentated and analysed in layers of increasing detail to meet the needs of different audiences. The focus of each of the documents is as follows:

Final Report - Executive Summary and analysis of Technical & Commercial Findings;
Visit Report - Detailed Technical and Commercial discussions with Host Organisations; &
Appendices - Delegate's presentations and handouts provided by Host Organisations.

Final Report Overview

This report summarises the technical and commercial findings of the visits (outlined in greater detail in the Visit Report) and presents the delegates' evaluation of Australia's position and opportunities in Photonics. It presents a number of recommendations for the management, technical direction and commercialisation of Australia's Photonics research, development and commercialisation activities.

About The Authors

Ross Halgren and Phil Carmont were selected for the International Benchmarking Mission by the Photonics in Australia Steering Committee of which the Department of Industry Science & Tourism, The Warren Centre for Advanced Engineering and the Macquarie Bank are members. They were chosen based upon their complimentary knowledge and experience in Photonics technology development, application, and investment strategies. A brief summary of each author's background is provided below.

Ross Halgren B.Sc., B.E., M.E., PG-Dip.Mgt, MIEEE

Ross brought to the International Benchmarking Mission over two decades of experience in optical fibre research, network and systems architectures and industrial product development.

In 1974, Ross authored his first report on laser communications for a 3rd year Physics project at the University of Sydney. In 1976, he produced the University's first undergraduate Electrical Engineering thesis on Optical Fibre Communications. From 1979-89, his research continued as an engineer with, and eventually as manager of, AWA's Research Laboratory. In this role, Ross directed AWA's research into optical fibre Local Area Networks (LANs), coherent optical communications, and acoustic sensors for fixed and towed arrays. Ross's optical fibre LAN research also formed the basis of his Masters of Engineering thesis at the University of NSW.

In 1983, Ross worked with Dr John Limb from Bell Labs on a Warren Centre project called "Local Area Networks and Office Automation". Ross was seconded for 3 months to the Warren Centre as the Case Studies Group Leader for the project.

From 1987 – 1993, Ross and other AWA team members' participation and contribution at the Fibre Distributed Data Interface (FDDI) Standards Committee meetings in the USA, led to AWA becoming the world leading supplier of 100 Mbit/s FDDI-2 LANs for integrated video, voice, and data applications. As a result, these optical fibre LANs are now being locally supplied and exported as the backbone of: Australia's new TAAATS Air Traffic Control voice switching system; Singapore Technologies' new integrated shipborne and police communications systems; and for military airborne communications systems through Telephonics in New York.

Ross recently formed HALTEC ENTERPRISES Pty Limited and is consulting to the industry on Photonics applications and other Networking technologies. He also continues research into optical backplane technology in conjunction with Macquarie University.

Phil Carmont B.Com., ACA, ASIA

Phil is a Manager within Macquarie Bank's Technology Investment Banking (MTIB) business. He has a Bachelor of Commerce Degree with majors in Accounting and Finance from the University of New South Wales, is an Associate of the Institute of Chartered Accountants of Australia and an Associate of the Securities Institute of Australia.

In his role with MTIB, Phil provides general corporate advisory services as well as advice in relation to private equity raising for Australian technology companies. In 1997, Phil shared MTIB's experience in technology commercialisation when he presented to the 1997 conference of the Australasian Tertiary Institutions' Commercial Companies Association.

Previously, Phil was a Manager in the Corporate Financing and Leasing Division of Macquarie Bank, during which time he was engaged in Macquarie's R&D Syndication business. This involved arranging and marketing structured finance transactions for Australian research companies and corporate investors.

Phil brought to the Photonics delegation:

- A long standing relationship with the Australian Photonics CRC.
- Extensive experience with a diverse range of R&D based companies and financial institutions, both through R&D syndication and through his current role within MTIB.
- Experience in making regular presentations to the senior management and Boards of MTIB client companies on technology related investment issues.

Photonics in Australia Project

Objectives

The overall objectives of this project are to speed up the growth of firms which may beneficially use photonic technologies and facilitate the uptake by Australian industry of the sector's R&D outcomes.

Target outcomes for the project are:

1. The creation of an industry forum supported by industry which can become a platform for building cohesion amongst the developers and users of photonics technology based products and services.

2. Achieving a profile for the photonics based industry in Australia as a capable supplier of world class products.

3. Facilitating access for the Australian industry to photonics based technology through raising awareness of the existence, capabilities, developed applications available in Australia and the future potential of these photonic technologies.

A steering committee of interested members of industry was established in 1997 to guide the project. The steering committee members directly involved in sponsoring and organising the International Benchmarking Mission are discussed below.

Department of Industry, Science and Tourism

The Commonwealth Department of Industry, Science and Tourism (DIST) has sponsored the project and concurrently contracted the Warren Centre for Advanced Engineering to prepare a study on the Australian industry base and provide a networking agent to create the industry forum and identify and stimulate networking among interested companies. The project follows a model described in "Capturing Emerging Technologies" a pamphlet available from DIST at the web address: http://www.dist.gov.au/infoind/html/infoind.html.

The Warren Centre for Advanced Engineering

The Warren Centre is a non-profit organisation which has resident expertise in technology transfer, SME management and finance, project management, industry networking, and conference organisation.

The Warren Centre was selected by DIST as it was well placed to undertake the networking with interested industry. The Centre had completed a similar project on the embryonic Australian Smart Card Industry with the Department which had delivered the Asia-Pacific Smart Card Forum.

The Centre's objectives linked well with DIST's. The objectives are:

- Stimulating innovation in the advanced engineering technologies important to Australia's industrial development;
- Encouraging effective deployment and use of new engineering technologies;
- Promoting the integration of technology, management, design and enterprise among Australian businesses;
- Providing independent advice and comment on the above issues and their impact on national policies and industrial development and enterprise.

Macquarie Bank

Macquarie Bank is committed to assisting in the development of Australia's high technology sector. This commitment is through Macquarie Technology Investment Banking (MTIB), a dedicated group established three years ago to provide a full range of investment banking services to technology organisations.

MTIB takes a proactive approach to identifying technology opportunities and organisations and providing creative ideas and solutions to achieve wealth creation outcomes. As part of this proactive approach, MTIB has been developing long term relationships with the Australian Photonics CRC and the Warren Centre for Advanced Engineering, and has previously targeted Photonics as an emerging, high growth industry of strong interest.

It was therefore a natural extension of MTIB's activities to take an active role in the Photonics in Australia Industry Project. Through this involvement, MTIB aims to gain a strong understanding of the relevant issues and opportunities, build relationships with key players in Australia and offshore, and position itself as a leading provider of financial services to this emerging industry.

Acknowledgements

The delegates would like to thank the representatives of the following organisations for their support in preparing for and funding this International Benchmarking Mission:

- The Warren Centre for Advanced Engineering
- The Department of Industry, Science and Tourism
- Macquarie Bank Limited
- The Office of the Australian Government Counsellor, Industry Science and Tourism in Washington DC

In particular, the editorial advice from Greg Gurr (DIST- Canberra) was greatly appreciated.

The delegates would also like to thank all representatives associated with the Australian Photonics CRC and their Australian Industry Partners who took the time to organise visits or provide contact names for the delegates to follow-up.

Finally, the delegates would like to thank the representatives of the Host Organisations visited during the Mission, who helped coordinate the visits, prepared and attended presentations, and provided laboratory tours.

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Introduction

This report benchmarks Australia's Photonics technology and industry position relative to international activities and highlights emerging Photonics opportunities that may be addressed by Australian industry.

The information presented in this report is based on the International Benchmarking Mission undertaken in May 1998 to Japan, UK, Sweden and the USA, and on additional research before and after the Mission to extend the coverage of the study.

The benchmarking information and opportunities are presented in terms of Australia's underlying technology capabilities, venture capital investment initiatives, government infra-structure support and industry success stories in accessing appropriate distribution channels.

Key Observations

I. The Future is Bright

Australia has built-up a solid intellectual property base through its 25 year investment in the research and development of Photonics based technologies. As we approach the year 2000, the 2nd generation of Photonics technologies being developed in Australia and overseas, presents a range of new product and systems opportunities for Australian industry. Given the infra-structure support currently provided by Government and leading-edge Customers; the recent Venture Capital (VC) funding initiatives; and the role models of successful start-up companies; there is every reason to believe that Australian industry can break out of its mold as a provider of specialised Photonics technologies and components, and move up the food-chain into value-added Photonics products and systems for the mainstream IT&T market.

II. Australian Research Standing

Australian research organisations have excellent coverage of the range of 2nd generation Photonics technologies being developed overseas. The flip-side to this is that Australia's research investment is being spread too thinly in some areas, thus reducing its effectiveness. Where there is focus, such as in optical-fibre based technologies (couplers, in-fibre gratings, multiplexers, circulators, sensors, etc), start-ups have been successful in producing a range of internationally competitive components that have attracted overseas investment. An area of intense Photonics research where Australian technology is showing promise and international attention is in Planar Optical Waveguides. Given these successes, Australia is now recognised internationally as a leading player in these particular Photonics technologies. This recognition should not however, be construed as being a leader in Photonics generally. Technology areas where Australia falls short may need to be licensed rather than developed if Australia is to mature as an innovator of products rather than a developer of technologies.

III. Australian Industry Standing – IT&T Markets

Overall, Australia's industry standing in the more lucrative, mainstream IT&T markets is considered poor by international standards due to the lack of vertical integration into higher-value, locally developed Photonic products and systems. The challenge for Australian industry generally is for fast-moving SMEs who have already exhibited vertical integration capabilities for 1st generation Photonics technologies, to access VC funding; acquire 2nd generation technologies through licensing or acquisition; and network with 2nd generation Photonics and Broadband technology researchers and other SMEs, to move the industry up the food chain as a supplier of 2nd generation Photonics products to the world market. Access to this market can be via the systems integrators, such as resident Multi-National Corporations (MNCs). Indications are that it will take at least 10 years for Australian industry to mature in this way.

IV. Australian Industry Standing – Niche Markets

In contrast to the mainstream IT&T market, Australia's positioning in the niche industrial (including Defence) markets is already at the product and systems level for the 2nd generation Photonics technologies. However, it is not yet clear that Australian industry is leading in many areas. For example, in the case of laser ranging systems and optical-fibre based underwater surveillance systems, Australian industry at both the SME and MNC levels is developing what appears to be leading-edge products by 1st generation standards, but these are less advanced than other US-based industries who have greater funding and support from US Defence research organisations. Optical-fibre based transducers for measuring current in high voltage power systems appear to have the international attention of ABB, however, it is understood that ABB are also considering a number of alternative technologies in parallel. There is not yet a clear winner.

V. Market Trends

There are several market trends that indicate where future Australian research activities could be focused. For example, the Internet growth that is currently driving the commercialisation of Dense Wavelength Division Multiplexing (DWDM) technologies appears to need 100 Gbit/s all-optical packet switching over DWDM as a future technology in its evolution. It is likely that by the time this technology is developed and commercialised, it will have applications in Trunk Networks, Metropolitan Area Networks (MANs) and Fibre To The Curb (FTTC) Networks. Interfaces between optical and electrical media (RF, XDSL etc) will be required in all cases. Associated with the Broadband revolution will be the need for capacity upgrades at all levels of the technology food chain. These factors are driving the development of high speed optical interconnects for future computer & communications equipments and the world-wide interest in the integration of optical planar waveguides and electronic circuits in a single package. In niche market areas, local and remote sensing, measurement and spectral analysis applications appear to be the main drivers for future Photonics technology developments.

VI. Future Research Focus

Australian researchers should focus on technology areas that fit with the market trends and for which they have a leading position. An increased competitive position for Australian industry would be achieved by forming joint research projects with others at different levels in the technology food chain. For example, the Photonics and Broadband CRCs could achieve more together than in isolation. Examples of technology areas where Australian researchers appear to have a lead and could develop further include: Integrated Optical and Electronic Circuits (IOECs), 100 Gbit/s packet switched MANs and a range of Photonics based sensors, transducers and lasers for measurement, surveillance and spectral imaging applications. The technologies needed for acoustic underwater surveillance could be developed as part of this. To maintain the development and accelerate the commercialisation of these technologies, it is important that the government/industry funding cycles for successful CRCs overlap in future, and that key researchers move with their technology into industry, as the product champions.

VII. Australian Industry Opportunities

Photonics product opportunities are crying out for Australian industry to pick-up and run with. Short-term opportunities include: Wavelength Converters and optical Add/Drop Multiplexers for interfacing 1st generation analog (RF) & digital communications products to 2nd generation 16-40 channel DWDM networks; Optical Amplifiers for network installations (in contrast to laboratory instruments); DWDM MANs and Network Management Software for optical DWDM networks. Longer-term opportunities (once the technology has been developed), include: Optical Cross Connect Switches, Broadband Packet / DWDM Routers, application-specific IOEC components and a new generation of MANs, FTTC access products and niche industrial products based on IOEC components. In all these applications, the potential benefit of having local expertise in IOEC component design, simulation and pilot production facilities, is the ability to develop high-volume, low cost Photonic & Electronic components that differentiate and secure the intellectual property of Australian industry products. The Mission results highlighted that the world-leading MNCs are vertically integrated and rely heavily on their in-house component development and manufacturing to differentiate their products.

Background

Mission Scope

The primary purpose of the International Benchmarking Mission was to compare the technical direction, core competencies and commercialisation of Australia's Photonics technologies with that of international research and development activities. The technology and market focus of the Mission was to be broadly based. It was to investigate both telecommunications and non-telecommunications applications of Photonics and to identify where opportunities for Australian Industry may arise. A secondary purpose of the mission was to establish new contacts and identify new collaborative opportunities between Australian and overseas organisations for the purpose of accelerating Australia's Photonics developments.

In the 3 weeks that were allocated to the Mission, only a limited number of organisations could be visited (15 in total) and hence the sample size of the International activities that could be investigated was limited. To diminish the impact of this limitation, a mix of countries (Japan, European & the USA) and a wide mix of organisations were selected. These included:

- 4 Large Multinational Corporations;
- 2 Medium Enterprises;
- 2 Small Enterprises;
- 1 Telecommunications Carrier;
- 1 Engineering Consulting Company;
- 3 Universities;
- 1 Defence Research Organisation; and
- 1 Measurement Standards Organisation;

Additional research was undertaken by the delegates before, during and after the Mission to extend the coverage of the study. This included a conference call with CE Unterberg Towbin, a US Investment Bank in New York and local visits and discussions with two Multinational companies, four SMEs, three Universities, DSTO (Melbourne) and Telstra Research Labs.

The following is the list of countries/continents and organisations visited during the Mission:

JAPAN

1. NEC C&C Media Research Laboratories (Tokyo)

EUROPE

2. British Telecom Laboratories (Ipswich UK)
3. Cambridge University Engineering Department (UK)
4. Arthur D Little - Cambridge Consultants (UK)
5. Ericsson Components (Kista Sweden)

USA

6. US Navy Research Laboratory (Washington DC)
7. Ciena Corporation (Linthicum MD) – by Telephone & Brochure drop/pick-up only
8. Lucent Technologies (Murray Hill NJ)
9. Galileo (Sturbridge MA)
10. National Institute of Standards & Technology (Boulder CO)
11. University of Colorado at Boulder (Boulder CO)
12. New Focus – Milton Chang (Santa Clara CA)
13. CE Unterberg Towbin (New York NY) – by Telephone Conference Call
14. Atmosphere Networks - Rob Newman (Cupertino CA)
15. HP Communications & Optics Research Lab. (Palo Alto CA)
16. UCLA Electrical Engineering Department (Los Angeles CA)

Detailed technical and commercial information pertaining to the above organisations is included in the associated Visit Report for the Mission.

Overview of Photonics Applications and Technologies

A formal definition of Photonics is:

> ***The control, manipulation, transfer and storage of energy and information using photons, the fundamental particles of light.***

A non-exhaustive list of applications requiring the latest Photonics technologies include:

- **Broadband Telecommunications** needed to meet the increasing demand for interactive Internet services and future high definition video-on-demand, Hi-Fi audio, and graphics based data services for the mass consumer and business markets.
- **High Performance Computing** using photonics technologies to speed-up the transfer of massive amounts of data between distributed electronic processors and memory. Virtual reality (3D imaging & video) - initially important to Defence surveillance and mission planning, will also flow-down to the higher-volume consumer and business applications.
- **Industrial Measurement and Control** - especially in non-benign environments (high pressure, high temperature, high voltage, high stress, etc) is proving to be a niche but viable market for photonics technologies where existing technologies are costly or inferior.
- **Remote Sensing and Surveillance** such as measuring distances to "mm" accuracy, mapping terrain features or water depth, detecting movement of remote objects and characterising object features from a distance. Applications include mining, geodesy, agriculture, environmental monitoring and Defence.
- **Medical** imaging, diagnosis & surgery are one of the oldest and well known applications that will improve with time as new and improved photonics technologies are introduced.

The relevance of the various Photonics technologies and Australia's positioning may be better understood by expanding on the most common Photonics components and their applications:

- **Optical Fibres**, now no thicker than a human hair, were first developed in the 1930s to <u>transfer</u> images over short distances - the first fibre bundle being assembled for medical applications. However, it wasn't until 1970 that fused silica glass fibres were first developed by Corning with the low loss needed for practical telecommunications applications. In Australia, relatively low loss "liquid-core" optical fibres were first developed in 1973 by AWA and the CSIRO, followed by "solid-core" optical fibres in 1976. Today, there are two high-volume optical fibre production facilities in Australia, albeit now based on Corning and Sumitomo technologies, and one SME - Redfern Fibres Pty Ltd - providing special purpose optical fibres to local and overseas customers. Optical fibres have many variants and properties that can be <u>manipulated</u> to meet the requirements of different applications (communications, acoustic sensing, temperature sensing, current sensing, strain sensing, bend sensing, inertia sensing, etc). The delay incurred by light travelling through an optical fibre can also be used as a means of <u>storing</u> information for short periods (eg, as a data buffer for packet switching). Information can be stored for longer periods by using loops of fibre with in-fibre optical amplifiers to prevent the data from fading away (akin to Dynamic Random Access Memory).
- **Optical Splitters** are components for <u>broadcasting</u> a optical signal to multiple devices or users**.** **Optical Couplers** are components for <u>combining</u> two or more optical signals into one optical fibre for example. Australian Optical Fibre Research (AOFR) in Canberra has one of the world's leading research and manufacturing facilities for these components. This technology was developed in Australia, and is now owned by ADC of the USA.
- **Planar Optical Waveguides** are similar to optical fibres (ie, Circular Optical Waveguides) except that they are formed by depositing layers of doped glass materials onto a planar substrate using masks to define the waveguide structure – a manufacturing concept similar to that used for integrated electronic circuits. It is expected that these emerging Photonics components will eventually be integrated with electronic circuits and will replace most existing Photonics components for a wide range of applications (except

optical fibre for transmission). The development of low cost optical fibre pigtail and V-groove splicing technologies go hand-in-hand with this trend.

- **V-Groove Splices** are hairline grooves cut as a V-shape in silicon or some other material for the purpose of accurately aligning and connecting two-fibres together, or for connecting a fibre pigtail to another component (laser, electro-optic modulator, photodiode receiver, splitter, coupler, optical filter, planar optical waveguide, etc).
- **Lasers** – first developed in 1960, are now a common device for generating and manipulating[1] photons of light with a broad range of wavelength options. Laser technologies include solid state (eg, Ruby), gas (eg, Helium Neon), semi-conductor (eg, Gallium Arsenide) and more recently, optical fibre lasers (eg, Erbium doped). A laser has two optical mirrors – one at each end of a cavity – to stimulate a continuous emission of light. In the case of a Distributed Feed-Back (DFB) laser, one of the optical mirrors may be a Bragg grating or filter, which permits only one wavelength of operation. Fibre lasers with wavelength options ranging from blue to infra-red light have recently been developed through Photonics CRC research activities. Laser applications include communications, sensing, medical, forensic and defence missile counter-measures.
- **Electro-optic Modulators** (such as Lithium Niobate) and **Optical Switches** are devices developed to externally manipulate (modulate) or control (block or switch) the photons of light generated by another device (eg, a laser). Australia has traditionally been weak in this area in terms of product development, however, indications are that this situation may be turned-around due to recent Australian developments in planar optical waveguides and associated electro-optic materials technologies.
- **Photodiode Receivers** are components which convert photons of light over a broad spectral range to electrons of current, and then amplify the current to produce a usable output voltage. Various photodiode options are available to match the wavelength windows required – 850nm, 1310nm, 1550nm etc. Various receiver amplifier options are available to meet the gain, bandwidth and noise requirements of the application.
- **Circulators** are components that provide a non-reciprocal coupling of light between two fibre paths. Applications include bi-directional optical multiplexing systems in communications, sensing and instrumentation (eg, OTDRs). Photonics Technologies in Sydney is a leading Australian developer and manufacturer of these components.
- **Optical Filters** are components that can for example, selectively manipulate (attenuate or pass) a single wavelength while letting all other wavelengths pass through with low loss (or be attenuated with high loss). Bulk optical filter components with broad filter characteristics have been available for some time. Dual-window optical fibre networks which operate at 1310nm and 1550nm can be built with components such as these.
- **Bragg Gratings** are components which provide better wavelength selectivity compared to bulk optical filters. Their applications include **Wavelength Division Multiplexers** (WDM) and **Sensors** (temperature, strain and acoustic signals). The more recent development of temperature compensated, in-fibre Bragg grating filters, for which the Australian Photonics start-up INDX is a success story, provides low-cost, Dense WDM, enabling 40 wavelengths onto a single optical fibre. INDX manufactures these components in Sydney for the world-market, and is now owned by Uniphase Corporation of the USA. These same Bragg gratings are being used for strain sensing applications, and without the temperature compensation feature, can be used for temperature sensing applications.
- **Optical Amplifiers** are components or products which can amplifier a broad spectrum of wavelengths simultaneously. These products can be built using semi-conductor, fibre laser or planar optical waveguide technologies. The term “laser” is in fact an acronym for “Light Amplification by Stimulated Emission of Radiation”. The main difference between a laser and an optical amplifier is that a laser has two optical mirrors – one at each end of a cavity – to stimulate a continuous emission of light. An optical amplifier on the other hand, relies on an input signal rather than mirrors to stimulate the emission of light. Both lasers and optical amplifiers require some form of external energy to raise the energy levels prior to emission. Optical Amplifier applications include telecommunications, distributed sensing systems and optical storage and processing systems.

[1] In communications applications, the term “manipulation” may include the “modulation” of laser light with audio/ video signals or data bits associated with millions of telephone conversations, television channels or PCs.

Photonics Opportunities

Benchmarking Framework

The results of the International Benchmarking Mission upheld the importance of Photonics to mainstream Information Technology & Telecommunications (IT&T) applications and niche applications, such as medical, remote sensing and industrial measurement and control systems. This was reflected in the words of Ericsson Components' researchers: "Photonics is the next big opportunity after the mobile phone," and was quantitatively supported by the spectrum of Photonics technologies, components, products and systems identified and the number of organisations working in similar technology areas.

Australia's position in the Photonics industry is benchmarked in terms of its Photonics research standing, industry standing and in each case, the accessible opportunities. The main focus of this report has been on 2nd generation Photonics technologies (broadly defined as core technologies and capabilities developed after 1990). Comparison is made in terms of mainstream IT&T trends and niche Photonics applications. An overview of the industries studied, the need for a strong technology and component base, followed by trends in each of these application areas, is included first to provide a backdrop for these comparisons.

For the purpose of analyzing and presenting Australia's relative position in the Photonics industry, the Vertical Integration Food Chain is used as a reference model. This is illustrated in Figure 1, where the more mature building, manufacturing & mining industry is included for comparison with the younger Photonics industry.

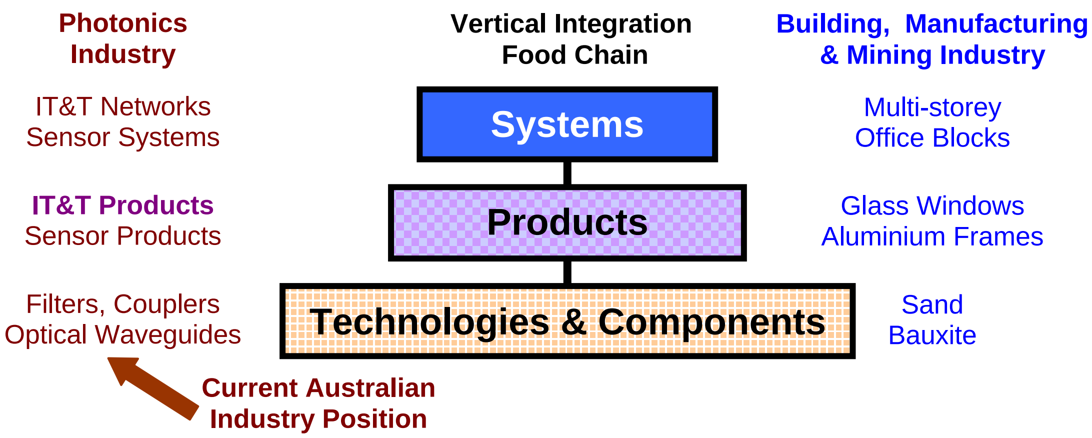


Figure 1 Vertical Integration Reference Model

Industries Studied

The Australian Photonics industry can be broadly classified as being focused on either mainstream IT&T markets, or niche industrial markets (including Defence). The mainstream IT&T players can be further categorised as: **A.** Multi-National Corporations (MNCs) that initially import 2nd generation Photonics products but invest in Australian Photonics research in the hope of developing some products locally; **B.** Start-up 2nd generation Photonic component companies – nearly all acquired by MNCs - who retain the local R&D and manufacturing operations in Australia, while providing distribution channels overseas; and **C.** Indigenous SMEs that have developed products and systems locally, have retained local Australian control, but have not progressed beyond the 1st generation Photonics technologies and have limited overseas distribution (compared to MNCs). Since 2nd generation Photonics has been the focus of this report, only category "**B**" industries has been studied in any detail.

The Need for Leading Edge Technologies and Components

Visits to Large Enterprises highlighted the importance of vertical integration in keeping ahead of the competition. From their perspective, developing new technologies and manufacturing leading-edge components before their competitors was essential to achieving product differentiation, improved features, lower costs and product protection.

For these same reasons, Australian SMEs and Large Enterprises cannot hope to compete in the Photonic product and systems arenas if they do not have early access to new components based on the latest Photonics technologies. If Australian industry has to rely on overseas suppliers for all of its Photonics components, then generally it's products will be technically behind its competitors.

A corollary to this is that if Australia continues to sell-off its Photonics technologies and components to overseas corporations as feeders to their overseas product development groups, it may never give its local industry the opportunity to develop world-leading products and systems, and will restrict industry moving up the vertical integration food chain.

Where there is a local technology shortfall, it is essential that Australian SMEs "network" (eg, as alpha-test sites) with overseas corporations making leading-edge components, so that they are not deprived of the technologies and components needed to be competitive.

Mainstream IT&T Trends

Mainstream IT&T trends are currently providing the greatest opportunities for Photonics technologies. These trends are aligned to high volume, non-specialised consumer and business applications where alternative technologies may already exist, but where Photonics provides significant performance improvements at lower cost. The following are examples:

- **Internet Growth**

  The Internet growth has been so great in recent years that it will soon dominate the incumbent telephony network. Long-haul optical fibre networks now need much more capacity than was forecast for telephony applications. To overcome this problem, Dense Wavelength Division Multiplexing (DWDM) is being introduced into service by fast-moving start-ups such as Ciena, with established industry giants such as NEC, Ericsson and Lucent following their lead.

- **IP over WDM**

  As the market is now Internet rather than Telephony-driven, the need for SDH and ATM networks and products is being questioned. The focus is now on sending Internet Protocol (IP) packets directly over WDM to reduce the number of processing layers, improve performance and to reduce cost. Lucent has developed a broadband IP packet switch that can be used in these applications and new Telcos such as Quest are understood to be using IP Switches for their new telephone and Internet services.

- **DWDM MANs and WDM / Plastic Fibre LANs**

  DWDM based Metropolitan Area Networks (MANs), plastic-fibre and WDM based Local Area Networks (LANs) are emerging as "mainstream" opportunities. In the case of the DWDM MAN applications, the initial focus is on format-transparent multiplexing of many different vendor's SDH, FDDI and IP switching products on the same fibre backbone. The benefit of this approach is that high capacity private networks can now be formed and reconfigured, where previously this might not have been possible due to insufficient fibre and cost issues.

- **100 Gbit/s All-Optical Packet Switching**

  In the future, 100 Gbit/s all optical packet switching networks are forecast by some researchers. These are claimed to be superior to format-transparent multiplexing on separate DWDM channels, due to the greater flexibility of packet switching compared to circuit switching, and due to the trend to IP packet switching of all services.

- **Mixed Media Fibre To The Curb**

  For Access Network applications, Fibre To The Curb (FTTC) was identified as a more likely trend than Fibre To The Home (FTTH) due to non-technical reasons, such as the high installation costs of fibre into homes. Customers want high performance (eg, high bandwidth) and low cost, they don't specifically or consciously want "Photonics". In some cases, Photonics technologies are the only way of meeting the customer's requirements. More often than not, however, the most pragmatic (and optimum) solution uses a mix of Photonics and Electronics with Fibre (eg, DWDM), Radio (eg, CDMA) and Copper (eg, XDSL) as a mix of transmission media options.

- **Optical Interconnects**

  For high performance computing applications, especially in Defence, technology is advancing towards optical interconnects to reduce bus and inter-processor traffic congestion, and the associated software complexity needed to manage the congestion. Applications include virtual reality and digital signal processing for radar, sonar and optronic video, where very fast tracking, spectral analysis and "needle-in-a-haystack" pattern matching are required. The same technology is also applicable to commercial high performance computing applications, such as medical imaging, geological surveys and weather analysis.

Niche Applications

Niche opportunities for Photonics include applications where alternative technologies may already exist, but where Photonics can provide performance improvements or lower cost under specialised conditions. Niche opportunities also include new but specialised applications where there are no practical alternative to Photonics.

Examples of niche applications are:

- **Local Sensing and Measurement**

  Localised sensing and measurement in harsh environments or where greater sensitivity or performance than existing electrical sensors or transducers can achieve. Emerging applications include current sensing in high voltage environments, temperature/strain sensing in high temperature and pressure environments.

- **Remote Sensing and Measurement**

  Remote sensing and measurement where low cost distributed sensors are required, or where high sensitivity and positional accuracy are required. Applications include multi-point strain measurement on bridges, military smart structures (ships/aircraft), gas leak detection on long pipelines, acoustic surveillance arrays, satellite laser ranging, terrain height / water depth measurement and terrain spectral reflectance mapping.

- **Medical Imaging and Spectral Analysis**

  Three dimensional medical imaging and diagnosis using optical probes and spectral analysis of tissue layers, for applications such as cancer cell detection.

Australian Industry Position and Opportunities

Australian Photonics Research Standing

Discussions with overseas organisations familiar with Australia's Photonics research activities revealed that Australia does have a high reputation in terms of Photonics research and technology development. The International Benchmarking Data presented in Figure 4 (p.28), also supports these views, as highlighted by the number of Photonics technology areas in which Australia is working. The following summarises Australia's core capabilities:

- **Fibre-based Technologies**

  As outlined in the Technical Findings section, an analysis of Australia's core Photonics capabilities highlighted optical fibre and more recently, precision UV writing technologies, as a common theme – a heritage based on over 25 years of research and development in Australia. Applications of this technology include: optical fibre cable, fibre pigtails, couplers and splitters, in-fibre Bragg gratings, circulators, filters, Erbium Doped Fibre Amplifiers (EDFA), Wavelength Division Multiplexers (WDM) and sensors (transducers).

- **Specialised Lasers**

  For niche applications, Australia's development and application of lasers is also a core capability, although US Defence research organisations clearly had advanced further in this area due to their level of funding and military need. Applications of this technology include: laser ranging, spectral analysis, local and remote sensing, scanning and cutting.

- **Fibre-Lasers**

  The Photonics CRC's development of fibre-lasers with wavelengths ranging from blue to infra-red combines the above two capabilities. The benefit of fibre laser technologies are that they have both mainstream IT&T and niche applications. As substitute products for semi-conductor DFB lasers, fibre-lasers offer an opportunity for Australia to access a market for which Australia has previously had a low standing by international standards.

- **Simulation Software**

  Whist not actually a Photonics technology, simulation software developed through the knowledge and experience of our Photonics researchers, is another key capability that can be applied to the development of mainstream WDM Network Management Systems.

- **Planar Optical Waveguides**

  Planar optical waveguides is a new technology area where Australia is recognised overseas as having important capabilities and strengths. The core capabilities behind this technology area has similar roots to that of Australia's optical fibre technologies. Specifically, pure science skills in optical and plasma physics, materials science and chemistry, with applied science skills in Chemical Vapour Deposition (CVD) and doping processes are at the root of many of Australia's core Photonics technologies, and in fact are at the root of semiconductor manufacturing processes.

  Applications for planar optical waveguide technologies include just about every application listed above that is currently implemented with optical fibre based components (except for the fibre-cable itself). As such, planar optical waveguides may be a low-cost threat to our existing fibre-based technologies and associated components. Following the lead of large corporations such as Microsoft and Kodak, it is commendable that Australia is a leader in the development of a potential substitute technology for its product base.

Technology areas where Australian research is behind its overseas counterparts include: micro-machining, semi-conductor lasers and associated bonding to silicon substrates, external (Lithium Niobate) optical modulators, optical (space division) switching, optical interconnects, and >40 Gbit/s optical time division multiplexing and packet switching. In the case of the US, many of these technologies are still supported by large Defence and Defence-industry funded research and development programs. It is likely that all these areas can be addressed through the new technology developments outlined in the following section.

Photonics Research Areas of Potential for Australia

Based on Australia's technology positioning and core capabilities, the following were identified as Photonics research areas that are both accessible and offer potential for Australia:

- **Packet Switching Elements and Protocols for MANs and LANs**

  Building on the MAWSON project being undertaken within the Photonics CRC, and prior research undertaken by PRL on optical packet buffers, Australian researchers could develop all-optical packet switching elements in support of efficient ring-based protocols (such as the buffer-insertion ring protocol) for broadband MAN and LAN applications. Such a project would need an industry sponsor having core expertise in these applications. The involvement of the Broadband CRC as part of a joint-project would benefit both CRCs due to their complementary experience and capabilities.

- **Optical Acoustic Sensors for Fixed and Towed Array Applications**

  In conjunction with DSTO and a Defence industry sponsor, there is an opportunity to develop distributed, all optical, highly sensitive, acoustic sensor arrays having a broad range of Defence and Commercial applications. Examples include:

  – Detection of vessels, such illegal fishing boats and submarines;
  – Detection of induced seismic waves for petroleum exploration; and
  – Perimeter surveillance networks (Defence establishments, prisons etc).

- **Integrated Optical and Electronic Circuits (IOECs)**

  Planar optical waveguides manufactured from silica or polymer materials at relatively low temperatures would appear to be Australia's next leading Photonics technology. The technical benefit of low temperature manufacturing is the ability to integrate high-speed or low-power CMOS electronic circuits with planar optical waveguides to produce integrated "system on a chip" devices which enable the development of more competitive "system-level" products.

  In contrast to the Australian Photonics "PE-CVD" planar optical waveguide processes, overseas competition use a "Flame Hydrolysis Deposition" process at (1200°C) temperatures which are too high to allow the integration of electronic circuits.

  It is possible that many existing fibre-based products (Bragg gratings, fibre-lasers, couplers, splitters, etc) will migrate with time to planar optical waveguide implementations (thus becoming functional elements or standard cells in ASIC terminology terms). To address emerging Photonics opportunities in mainstream IT&T and niche applications, it is likely that new functional elements requiring significant initial research (or acquisition through licensing) may be implemented as shown in Figure 2. Examples include:

  – Electro-optic modulator elements based on new technologies being developed;
  – Add/Drop DWDM multiplexer elements;
  – Adjustable lenses, reflectors, switches, modulators and sensing elements using micro-machining techniques;
  – RF Microwave multiplexing and transmission at frequencies up to 40 GHz for mobile and multi-point distribution applications;
  – Erbium-doped planar waveguide lasers and pixel arrays for high performance computer interconnect and Digital Signal Processing applications;
  – High-density, optical space-division switching elements;
  – Optical Signal Processing elements, including regenerative optical amplifiers and radar pulse stretchers for later integration with high-speed Digital Signal Processors;
  – Integration of soliton-type optical pulse generators, pulse multiplexers / demultiplexers and opto-electronic detectors for future 100 Gbit/s IP networks; and
  – Optical Packet Address detection elements for future 100 Gbit/s IP networks.

  In most applications, fibre-pigtail connections will be required for the IOECs. Also, in some cases, the circular symmetry of fibre-based components offers improved performance over asymmetric planar optical waveguides. A mix of circular/planar technologies is therefore required, and a low-cost interconnection technique will be important (such as the Optical Fibre Clip technology developed by Cambridge Consultants Limited).

In contrast to optical fibre based Photonic components, the long-term benefit of planar optical waveguides in general and IOECs in particular is the potential for high-volume, low cost manufacture using proven techniques developed for the semi-conductor industry.

Based on discussions with researchers at BT Labs, it would appear that a capital outlay totaling approximately A$10 million over 5-years is required to build and maintain a state-of-the-art IOEC development and pilot production facility.

It was also evident from discussions with overseas and Australian researchers knowledgeable of our technology position, that while our existing skill-base is of the right calibre, a larger number of Ph.D qualified personnel will need to be employed and/or focused on this area of applied research[2] if Australia is to capitalise on its current position in this technology.

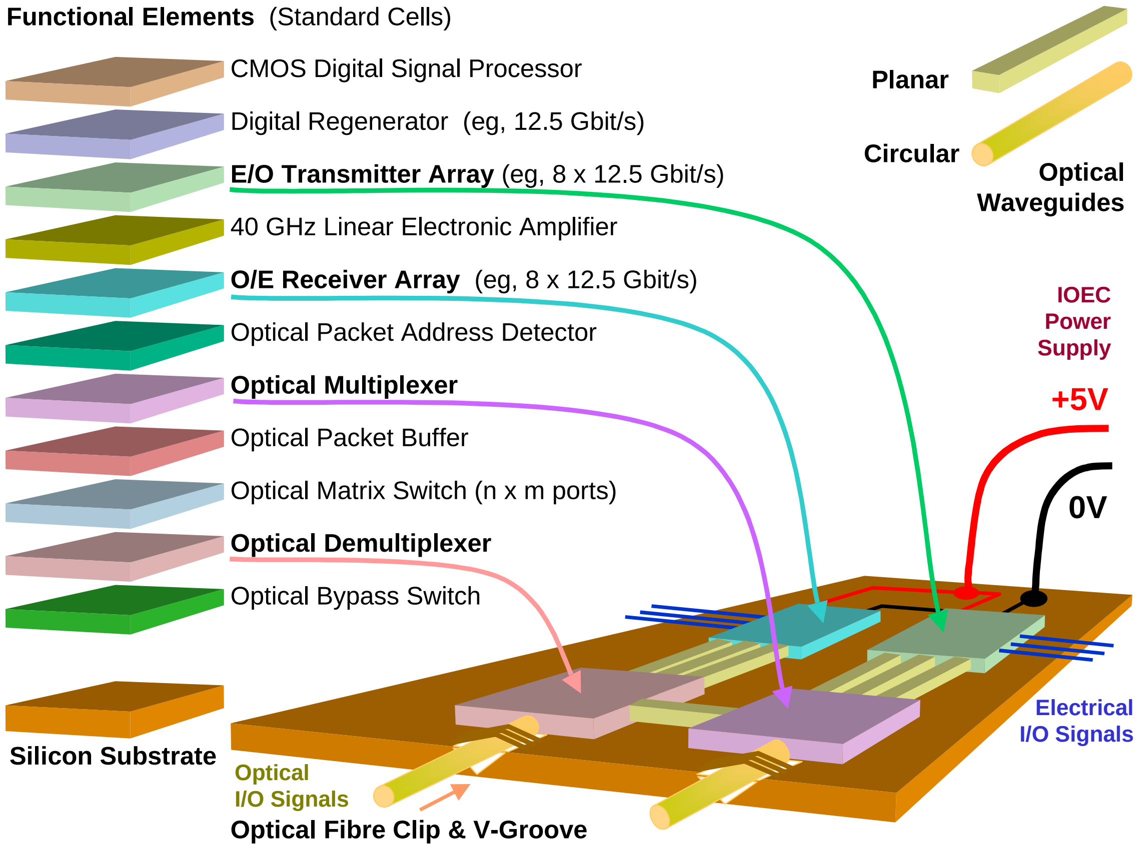


Figure 2 **IOEC Functional Elements**

Prospective customers for IOEC components based on “standard” and “application-specific” combinations of the above (and more) functional elements include:

- Australian and overseas companies in the business of developing state-of-the-art Photonics products with improved performance, smaller size and lower cost;
- Other IOEC manufacturers through licensing arrangements.

2 “rather than on highly theoretical research activities that are unlikely to be commercialised by Australian industry”, was a comment made by one researcher in the UK.

Australian Photonics Industry Standing

Mainstream IT&T Products

Whilst Australia's high research standing in Photonics has provided the underlying technologies and components on which Large Enterprises depend to remain competitive, there are as yet no corporate champions in Australia – like Uniphase or Ciena, that are able to invest in building a portfolio of mainstream IT&T system-level products based on these components. Australia appears to have been relegated to being a component supplier only.

The purchase of the Australian INDX fibre-grating technology by Uniphase (USA) reflected the increasing worldwide demand for high quality Photonics devices for the IT&T market, and the high calibre of Australia's Photonics technologies. The same can be said for the purchase of AOFR's coupler, splitter and DWDM technologies by ADC (USA), and the 30% equity taken by Nortel in Photonics Technologies for their circulator, filter and EDFA amplifier technologies.

Unfortunately, since Australia did not and still does not have a Uniphase or Ciena sized Photonics company of its own, the sale of INDX and AOFR was the best possible outcome under the circumstances. In both cases, the ongoing technology development and the manufacturing has stayed in Australia and greater global market access has been provided by the US owners. However, Australian industry access to these technologies is now under US rather than Australian control. In the new "global economy" this may not be an issue.

The Mission identified the following (non-exhaustive) list of reasons why Australian technology companies (such as start-ups and SMEs) have in the past, failed to commercialise their mainstream IT&T products, leading to their acquisition by overseas corporations:

- No venture capital funding to support the growth of a single component or product company, or to fund the acquisition of technologies and components needed to build a product portfolio;
- No symbiotic relationship with an established corporate partner or market player through which Australian developed components or products can be sold in volume;
- No overseas sales and marketing teams comprising overseas nationals who know their market and the contacts needed to make a sale;
- No successful role models to which Australian companies can seek advice regarding high technology product commercialisation;
- Inexperienced management team;
- Insufficiently differentiated technology;
- Attempting to undertake costly product development over several years, rather than introducing product variants early, followed by incremental improvements; and/or
- Inadequate involvement by the technology champions in product commercialisation (generally only applies to Australian SMEs that license technologies).

Due to the above deficiencies, the Australian Photonics industry is still at the lowest level of the vertical integration food chain for the more lucrative IT&T market. Additionally, nearly all the start-ups and SMEs that have survived at this level, have done so by being acquired by an overseas corporation (generally US based) for the purpose of creating their own product portfolios. Nevertheless, there are still advantages of retaining the development and manufacturing operations in Australia, irrespective of who owns them. For example:

- The Australian operations provide a foundation for further growth of the industry, spurring the formation of spin-off companies as an inevitable outcome of this growth;
- Increased management skills formed within the companies serve as role models for start-ups / indigenous SMEs or can be transferred to start-ups and SMEs at a later stage;
- Multi-National Corporations that are linked tightly to Australia's technology base are potential corporate partners or market players for which symbiotic relationships can occur.

Mainstream IT&T Systems

These are supplied in Australia to the Telcos (Telstra, Optus, Vodafone, AAPT, etc) via Multi-National Corporations who are selected as Strategic Partners of the Telcos. Systems integration is developed and supplied as a local (Australian) capability, however, the Photonics products which form the systems are often imported or manufactured in Australia under license. SMEs must generally go through the Strategic Partners to access the Telcos. Fortunately, many of the Strategic Partners are members of the Photonics CRC, which increases the likelihood that these partners will develop leading Photonics products and systems in Australia. Notably, the Strategic Partners provide a ready distribution channel for Australian Photonics technologies, products and systems to the world, thus achieving the desired vertical integration in the more lucrative IT&T market.

Niche Products and Systems

If we assume that a Photonics product does not require all the functions to be present that form the definition of "Photonics" (viz, *control, manipulation, transfer and storage of photons*), then a list several pages long could be formed for the number of niche Photonics products and systems developed by Australian industry (start-ups, SMEs and Large Enterprises).

For the purpose of this report, only those niche Photonics products and systems which employ 2nd generation Photonics technologies are studied (the definition of 2nd generation is necessarily vague, but it would generally involve core technologies developed after 1990).

Examples of such products and systems developed by Australian industry include:

- Current sensors (transducers) for high voltage power systems;
- Satellite Laser Ranging systems with "mm" accuracy;
- Confocal imaging systems for tissue scanning in 3D;
- Hyper-spectral imaging systems for remote sensing applications; and
- Towed acoustic arrays (using optical fibre for communications only at this stage);
- Laser Airborne Depth Sounding system (LADS);
- Photonics simulation software programs;
- Vibration/noise sensors for detecting leaks in gas pipelines or for movement detection around the perimeter of a prison;
- Distributed strain sensing systems for bridges
- Special in-fibre gratings for other company's niche products;
- Special optical filters for other company's niche products;
- Special fibres and fibre-lasers for other company's niche products;
- Light curtains for failsafe machine access control.

It is evident that Australian industry can address the above markets at all levels – including Photonic components, products and complete systems. For niche Photonics applications, Australian SMEs have achieved the benefits of being vertically integrated, thus resulting in a pool of engineering capability being embedded within the industry.

In terms of Australian industry's standing compared to international competition in niche markets, there are few of the above products and systems that could be considered "outstanding". It would not however, be appropriate to judge which are the best (or worst).

Often a niche market is accessible due to reasons other than having the best technology. Reasons for apparent technology success may include: geographical co-location; better promotion; lower margins; corporate partners with market access; "buy Australian" customer preferences; and willingness to manufacture at a customer's location.

Australian Photonics Industry Opportunities

Mainstream IT&T Products

In contrast to the niche Photonics products and systems discussed previously, mainstream IT&T products must “stand on their own” against world-class competition. This is because the high-volume nature and demand for IT&T products results in few barriers to entry (especially in Australia).

The flip-side to this for Australian industry, is the opportunity to export high-margin IT&T products in volume to a world market that is 50x the size of the Australian market. However, to successfully address the lucrative IT&T market opportunities with vertically integrated products and systems, Australian industry will need the best Photonics technologies available.

As a new global player on the block with access to venture capital funding, Australian industry will need to follow the lead of US corporations. Access to the best Photonics technologies will require a mix of local technology development (where Australian core capabilities permit) and overseas technology licensing (where Australian capabilities fall short of world-class or cannot be developed within the window of opportunity).

With access to the required Photonics technologies, an Australian start-up company or SME will need to develop products that offer a short time-to-market. The company should have a strategic vision of its future products, with a incremental product evolution towards that end. Following each product launch, the profits from sales must be fed back in their entirety to fund the growth of the business and the R&D necessary for the next product variant.

At some point in the company’s growth, there may be a need for further investment by a Large Enterprise having complementary products, or for a merger with other SMEs to grow the company into a Large Australian Enterprise in its own right. This is often the point at which the venture capitalists will make an exit.

Given that all the necessary commercial criteria are met, the following product opportunities exist in the IT&T market, and should be accessible by Australian industry. The products are ordered in accordance with the evolutionary product strategy described above.

- **Fibre Lasers**

  There is an opportunity made possible by the Photonics CRC’s development of fibre laser technologies, for a Photonics start-up company to develop and market a range of DFB fibre-laser products of various wavelengths. These products can substitute for existing DFB semi-conductor lasers where external modulation is used.

- **Wavelength Converters for DWDM**

  This is a product opportunity that involves the integration of a range of Photonics components, including fibre lasers, Lithium Niobate modulators and electro-optic receivers. Such a product would permit the connection of off-the-shelf SDH and FDDI products for example, to a multi-channel DWDM backbone for point-point applications.

- **DWDM Add/Drop Multiplexers and Wavelength Converters**

  Through the integration of DWDM Add/Drop multiplexer components with the Wavelength Converter products, a new product variant is formed which permits distributed access of SDH and FDDI products at multiple nodes, to a DWDM backbone network (trunk or ring). Such a product is at the level of vertical integration that it needs to be managed. Consequently, a processor, OA&M software and a out-of-band management channel will need to be added to complete the product. As part of the management channel development, a packet switching protocol is required. For ring applications, a FDDI protocol could be used. For trunk applications, a polling protocol is the simplest.

- **Optical Amplifiers for Outside Plant Installations**

  This is another product opportunity that involves the integration and packaging of a range of Photonic and electronic components, including fibre lasers, add/drop DWDM components for out-of-band management, electro-optic receivers, a processor, a packet switching protocol and software for network management purposes.

- **Network Management Station Software Drivers**

  Software drivers specific to the DWDM Add/Drop Multiplexer (ADM) and Optical Amplifier (OA) products will need to be developed to run on a industry standard Network Management platform such as HP OpenView. The graphical user interface can then be used to manage a trunk or ring network comprising multiple ADM and OA products. The NMS can interface to the DWDM network via a Ethernet or FDDI LAN.

- **Optical Cross Connect Switches**

  As for all the above products, this is a product that can be sold by itself, or integrated into a trunk or ring network. Once again, it will require the integration of several components, including space-division optical switching and network management.

- **Broadband Packet Routers**

  This is the first step away from circuit-switched DWDM towards very high bit-rate IP-based packet switching. A joint development with a packet router product supplier is recommended. For example, Ciena have joint ventured with Cisco for this purpose. The long-term target is 100 Gbit/s, however, an initial product release at 10 Gbit/s is more achievable in the medium-term. As research backing to the data networking industry, the MAWSON Photonics research project could be directed towards this requirement. Acceleration of the MAWSON project could be achieved through collaboration with the Broadband CRC.

- **IOEC Components**

  Due to the Photonics CRC's strength in low-temperature planar optical waveguide manufacture, Australia is in a prime position to develop the mixed Photonic and Electronic technologies and IOEC components (as per Figure 2) needed to meet a range of system requirements. Australia will need to coordinate and integrate its technologies and management skills at all levels to achieve and commercialise this opportunity of strategic importance.

  A scenario for the development and commercialisation of IOEC components and associated products could involve:

  – Photonics research & technology development activities – including the development of ASIC design libraries having Photonics components as standard cells;

  – Formation of a start-up company to design and manufacture Application Specific IOECs to enable Australian Industry to develop new products and systems. Ideally, the semiconductor manufacturer – Quality Semiconductor Australia who until recently, specialised in electronic ASIC design and manufacture, would be involved with the start-up company;

  – Volume production of IOECs for the mass market may require licensing or off-shore manufacture, with the Australian start-up providing pilot production facilities; and

  – Development by Australian industry (SMEs and MNCs) of world-competitive products based on the IOECs (as shown in Figure 3 and outlined below).

- **IOEC Based Products**

  IOECs provide the benefits of higher performance and lower cost for products comprising mixed Electronic and Photonic technologies. As illustrated in Figure 3, mainstream IT&T and niche product applications include:

  – Fibre To The Curb Access Units (with XDSL on copper or CDMA radio to the home);
  – Fibre To The Home Wall Units (with wireless communications within the home);
  – Metropolitan Area Networks (DWDM Add/Drop Multiplexer & IP switching products);
  – Plastic-Fibre and Wireless (Radio or IR) Local Area Networks and Home Networks;
  – Optical Interconnect devices for communications within equipment racks, circuit cards and processing devices; and
  – Sensor sub-systems, specifically those products that interface optical sensor networks to electronic processing and measuring equipment.

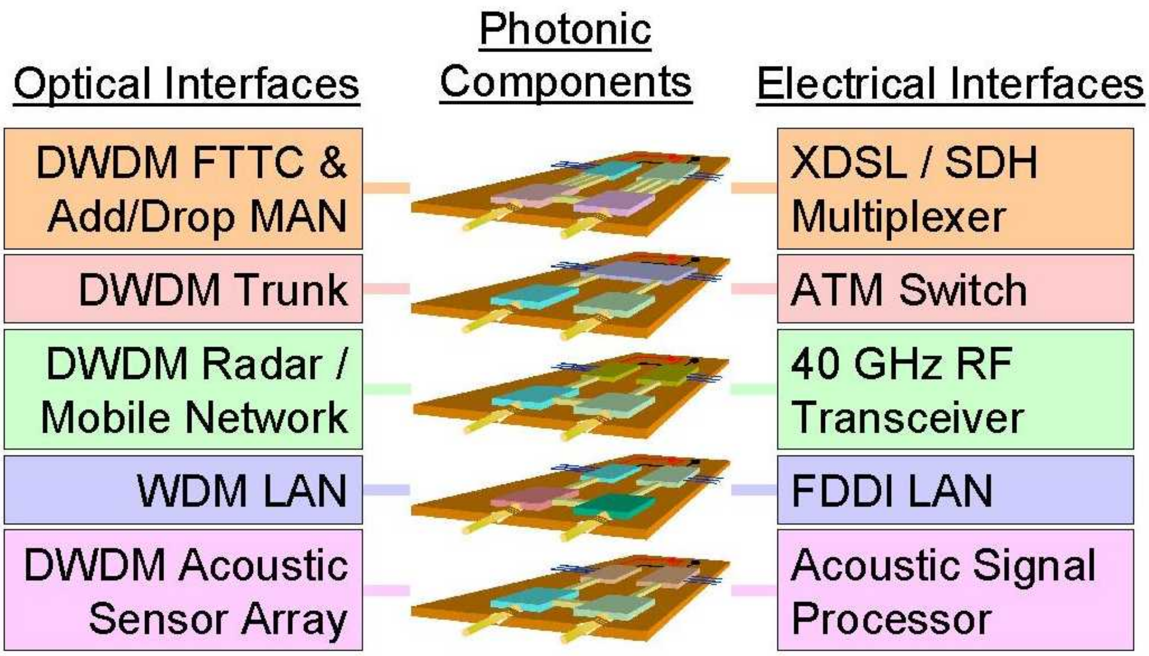


Figure 3 IOEC Based Products

Niche Products and Systems

Australian industry requires little external direction to address niche product and systems applications. This is an area where it appears to find its own way. Nevertheless, some opportunities to be considered are:

- All-optical acoustic arrays (fixed and towed) for Defence and Commercial applications;
- Radar pre-processor products using optical pulse stretching techniques;
- Smart Structures for military aircraft, mine hunter vessels, etc;
- Continued development of current and voltage sensors;
- Continued development of strain and temperature sensors;
- Continued development of surveillance systems;
- Continued development of laser-ranging systems;
- Multi-wavelength solid state laser systems for various spectral analysis applications (medical, forensic, remote geological, agricultural, environmental and Defence sensing).

Technical Findings

This section includes a summary and analysis of the International Benchmarking Data derived from information presented in the Mission Visit Report. An overview is then provided of the main Photonics application areas for which Australian industry is or can be involved. Further details regarding application opportunities for Australia are included in Annexes A and B. Finally, based on discussions with the organisations visited, cyclic R&D processes are presented for career advancement and technology & product development success in fast-moving markets.

Vertical Integration Reference Model

The level of technical maturity and commercialisation of the Photonics industry in Australia compared to the rest of the world, is represented by its current position or level in the vertical integration "food chain". As illustrated in Figure 1, this technology based food chain is used as a reference model for this report.

Observation 1

Through both general observation and analysis of the following International Benchmarking Data, it was found that Australia is still at the lowest level of the vertical integration food chain for the more lucrative Information Technology & Telecommunications applications of Photonics. Only in niche applications, such as sensing and medical, are Australian developed Photonics technologies being commercialised by Australian Industry at all levels.

Presentation of International Benchmarking Data

The technical maturity of the Photonics technologies, products & systems identified and discussed during the Mission are tabulated in Figure 4 and cross referenced to the organisations involved in these activities. Figure 4 therefore summarises the International Benchmarking data used to compare Australia's relative position in the Photonics industry.

To assist in identifying industry positioning and technology trends, the organisations visited are grouped into: Universities/Standards Bodies; Small to Medium Enterprises (SMEs); Large Enterprises; and Customer Research organisations. Similarly, technologies are grouped into: Generic Capabilities and Photonics Components and Communications & Industrial applications (including sensing and medical).

Colour coding is included as an additional dimension to Figure 4 to correlate industry positioning and technology trends to the vertical integration model. For example;

Orange is used for Technologies being researched or integrated into products.

Purple is used for Products that can be sold separately or integrated into systems.

Blue is used for Systems that are being trialled or installed.

Category	Technology / Application	Univ. of California - Los Angeles (USA)	Univ. of Colorado - Boulder (USA)	Nat. Inst. Standards & Tech. (NIST) (USA)	Cambridge University (UK)	Cambridge Consultants Ltd (UK)	Atmosphere Networks (USA)	New Focus (USA)	Galileo (USA)	Ciena (USA)	Lucent Technologies (USA)	Ericsson (Sweden)	NEC (Japan)	Hewlett Packard (USA)	British Telecom Labs (UK)	US Navy Research Labs (USA)	All the above Organisations (World)	University & Gov't Research Organisations (Australia)	Industry and Customer Research & Development (Australia)
Type of Organisation		Universities Standards Bodies				Small to Medium Enterprises					Large Enterprises				Customer Research				
Industrial	Power (Voltage / Current) Sensing Systems																		
Industrial	Surveillance Systems (Land & Underwater)															1	1		
Industrial	Smart Structures & Systems (Civil/Defence)															1	1		
Industrial	High Power Laser Systems					1										1	2		
Industrial	High Power Lasers (Medical, Defence etc)			1							1					1	3		
Communications	Integrated FTTC / MAN and XDSL						1				1	1	1		1		5		
Communications	FTTH Networks										1	1	1		1		4		
Communications	IP over WDM "Internet-2" Protocols									1	1	1	1	1	1		6		
Communications	DWDM MAN/LAN Networks									1	1	1		1			4		
Communications	DWDM Trunk & Oceanic Networks									1	1	1	1				4		
Communications	OA&M Management of DWDM									1	1	1	1	1			5		
Communications	Infra-Red Networks (LAN & Home)												1	1			2		
Communications	Plastic Fibre Networks (LAN & Home)												1	1			2		
Generic Capabilities and Photonic Components	Optical Amplifiers for Network Installations			1					1	1	1	1	1	1	1	1	9		
Generic Capabilities and Photonic Components	In/GaAs/P Laser / VCSEL Devices		1	1				1			1	1	1	1	1		8		
Generic Capabilities and Photonic Components	Photodiodes and Integrated Receivers	1	1	1				1			1	1	1	1	1	1	10		
Generic Capabilities and Photonic Components	Special Purpose Optical Fibres								1		1				1		3		
Generic Capabilities and Photonic Components	V-Groove Optical Interconnects to POWs			1	1	1		1	1		1	1	1	1	1		10		
Generic Capabilities and Photonic Components	External Optical Modulators ($LiNbO_3$, Abs.)	1		1				1			1	1	1	1		1	8		
Generic Capabilities and Photonic Components	DWDM Muxes, Filters, Splitters, Circulators, etc	1		1				1		1	1	1	1	1		1	9		
Generic Capabilities and Photonic Components	Optical Switching Devices	1	1								1	1	1	1	1		7		
Generic Capabilities and Photonic Components	Optical Sensor Devices (current, strain)			1												1	2		
Generic Capabilities and Photonic Components	Solitons (Fempto-sec Pulses)										1			1		1	3		
Generic Capabilities and Photonic Components	Optical CDMA Devices & Networking	1															1		
Generic Capabilities and Photonic Components	Optical Signal Processing	1	1										1		1	1	5		
Generic Capabilities and Photonic Components	RF Microwave and CATV on Fibre	1		1						1	1	1			1		6		
Generic Capabilities and Photonic Components	1310nm Fibre Lasers								1						1		2		
Generic Capabilities and Photonic Components	1550nm Fibre Lasers			1							1	1		1		1	5		
Generic Capabilities and Photonic Components	Integrated Optical & Electronic Circuits (IOECs)	1	1	1							1		1	1	1	1	8		
Generic Capabilities and Photonic Components	Optical Interconnects & Pixel Arrays	1	1								1	1		1			5		
Generic Capabilities and Photonic Components	Terabit/s DWDM & OTDM									1	1	1	1			1	5		
Generic Capabilities and Photonic Components	>40 Gbit/s OTDM	1		1									1	1	1	1	6		
Generic Capabilities and Photonic Components	Flip-Chip InGaAs/InGaP Bonding	1	1												1		3		
Generic Capabilities and Photonic Components	Micro-Machining	1	1		1	1					1				1		6		
Generic Capabilities and Photonic Components	Planar Optical Waveguides (POWs)	1	1	1	1	1					1	1	1		1		9		

Technologies, Products & Systems

Type of Organisation

Organisation Visited

Figure 4 International Benchmarking Data

The total number of organisations visited that are involved in each technology is shown in the 3rd last column of Figure 4, labeled "World". The figures in this column indicate the level of commonality between each organisation's technical activities. It would be misleading to suggest that these figures are representative of the market potential of a given technology, especially given the small sample size of the study. However, based on the premise that the most important technologies will be investigated by more organisations, it is possible to draw some conclusions from this information.

For comparison, two columns labeled "Australia" and grouped under University/Government and Industry/Customer Research, are included in Figure 4 to indicate Australia's involvement in each technology area and hence its current level in the vertical integration food chain.

General Analysis of International Benchmarking Data

Observation 2

There are currently many areas in Photonics which are at an immature stage in their development. This gives Australia the opportunity to invest in the development and commercialisation of these technologies and applications while the window of opportunity is still open.

The level of immaturity generally in Photonics technologies is reflected by the small number of purple and blue squares in Figure 4. Australia has relatively more orange squares than the combination of organisations visited, indicating that Australia has well developed technology and component capabilities – the essential requirements for vertical integration, but insufficient emphasis on developing the products needed to achieve this integration. Mainstream communications applications are an area where Australia is especially weak in commercialising its Photonics technologies. This highlights a lack of focus by Australian industry on Photonics product and systems development for the lucrative telecommunications market. Some reasons for this are presented here and in the Commercial Findings section.

The following sections summarise the vertical positioning and technology focus of each of the organisational groups and technology groups listed in Figure 4. Interactions between organisational groups are discussed to highlight the mechanisms for technology development into products & systems. Comparisons are made with the equivalent organisations in Australia. Interactions between technologies are discussed to highlight trends that Australian industry can lever off. The analysis is based on a synthesis of the International Benchmarking Data (Figure 4) and qualitative information drawn from the detailed Visit Reports.

Analysis by Organisational Grouping

Universities/Standards Bodies

Observation 3

Australian Universities are as good as overseas Universities in most Photonics technology areas. However, US-based Universities still benefit by strong Defense funding support and close development relationships with Defense Industries. Dual-use programs now enable technology to diffuse into commercial applications with short-term returns. Overall, the University and commercial environments overseas are more conducive to forming spin-off companies that move the Photonics technologies up the food chain into the products and systems needed to sustain the industry.

As for Australian Universities and Government Research Organisations, the three overseas Universities visited, and the US National Institute of Standards & Technology (NIST), were primarily focused on research rather than product or systems development. Like Australia, the overseas research organisations also had close links with their local Industries. Unlike Australia, the Universities visited in the USA were still heavily funded by and directed to meet the application requirements of the US Department of Defense and associated Defense Industries. Dual-use programs now allow the technologies developed to be spun-off into commercial products and systems which offer repeat sales with short-term returns.

In terms of technology focus, there were few technologies for which overseas University research organisations were well ahead of Australia's Universities. The exceptions were in semiconductor lasers, optical interconnects, optical signal processing, micro-machining and high bit rate (>40 Gbit/s) optical transmission. In some areas, such as long-distance soliton transmission, Australian Universities were ahead of their overseas counterparts. However, as pointed out during the visits to BT Labs and NRL, long-distance soliton transmission is no longer considered a practical technology for the near-term. It does however, have application to the generation of short (fempto-second) pulses for future 100 Gbit/s packet networks.

Like the Australian INDX and Virtual Photonics start-up scenarios, the overseas Universities have also spun-off start-up companies (SMEs). However, the difference to Australia is the rate at which start-up companies are spun-off. For example, the Optoelectronic Computing Systems Centre at the University of Colorado in Boulder has spun-off 14 start-up companies in recent years. This indicates that Australian Universities are either less willing to spin-off start-up companies, or find it difficult to do so due to the Australian commercial environment.

Small to Medium Enterprises

Observation 4

Overseas countries are well ahead of Australia in terms of new or established SMEs commercialising the latest generation of Photonics technologies into products & sub-systems. Overseas SMEs achieve this through collaboration with Universities, technology licensing, focused or niche technology development and through networking with other SMEs.

Referring to Figure 4, the high proportion of purple squares associated with the SME grouping highlights the overseas SME focus on product, rather than technology development. In comparison, the small number of Australian Photonics products (purple squares) is in stark contrast to the level of Photonics research undertaken in Australia (orange squares). Only in niche Photonics areas such as sensing systems (eg, smart structures) and high-power lasers is there any evidence of vertical integration and commercialisation by Australian SMEs.

The overseas SMEs visited were focused on the development of component products that could be sold in volume to larger product developers, systems integrators and telecommunications carriers (telcos). There were however, wide variations on the products offered. For example, Cambridge Consultants' "product" is really a low-cost fibre connection technology that can be licensed. At the other extreme, Ciena's DWDM add/drop multiplexer and optical amplifier products are configured and sold as sub-systems. Ciena's sub-systems are marketed as "products", perhaps to give the appearance of being low-down in the vertical integration food chain, thus appearing to be less of a threat to the larger enterprises.

Since the overseas SME's were focused on products, they either: relied on their ties with Universities to access new technologies (eg, Atmosphere Networks and the Australian Broadband CRC); or networked with other SMEs who could provide the technologies they needed (eg, Ciena with Uniphase); or licensed technologies and undertook further technology development, but in a very focused or niche area (eg, Galileo with BT technology). The latter scenario also applied to Ciena during its formative years (General Instruments' technology).

Observation 5

In principle, the commercialisation approaches adopted by overseas SMEs could be used by Australian SMEs to exploit the wide base of Photonics capabilities and technologies available. The SME networking approach may however, be thwarted by the spate of Australian SME acquisitions by large overseas corporations. It is often not in the interest of large corporations to help create an industry (whether in Australia or their home country) that may eventually compete against them.

In benchmarking Australia with the overseas organisations visited, one of the most notable deficiencies is the lack of Australian industry-developed products based on the latest Photonics technologies available. Furthermore, the Photonic products that have been developed (eg, fibre-based gratings and splitters from INDX and AOFR) now belong to US Corporations (Uniphase and ADC respectively).

In comparison to the latest Photonics technologies, the 1st generation of optical fibre-based technologies developed in Australia and overseas 20 years ago, have resulted in a gamut of indigenous and multi-national Australian industry developed products that are now sold locally and exported. Examples include: Fibre-optic 1 GHz Analog CATV networks sold into China, FDDI-2 LANs sold to Singapore for ships and to the USA for military aircraft, fibre-optic CCTV surveillance and SCADA data networks. Note that only 2nd generation and the most recent of the 1st generation Photonics technologies & products have been included in Figure 4.

As for the latest generation Photonics companies and products, many of the Australian SME's and their 1st generation fibre-optic products have similarly fallen into overseas corporate hands (eg, Fibernet takeover by AMP, AWA Transport & Communications takeover by Plessey S.A., JNA takeover by Lucent). These overseas acquisitions have both benefits and drawbacks. The benefits include access to a broader market base and corporate R&D funds. The drawbacks include loss of Australian control and hence, the ability or desire to network with other Australian SMEs. As for the latest generation Photonics technologies, the 1st generation technologies were often developed through Australian Government grants, Telstra R&D contracts and Defence-Industry funding.

Large Enterprises

Observation 6

Outside Australia, Large Enterprises depend on their own core Photonics research and technology development to differentiate their computer and communications products and systems. In contrast, there are no indigenous Australian companies that have achieved the same depth of technology and vertical integration. Only through access to a pool of Photonics technologies, business networks and VC funds can Australian SMEs hope to create virtual Large Enterprises that can develop and successfully market world-class Photonics products and systems.

Three of the four Large Enterprises visited exhibited total vertical integration from computer and communications technologies to associated products and systems. The only exception was HP who tended to stop at the product level, although like Ciena's products, some HP products are verging on sub-systems due to the number of components involved.

Unfortunately, Australia no longer has any indigenous Enterprises involved in the mainstream computing and communications industry, that could be considered “large”. All Large Enterprises in Australia that are involved in the development of Photonics products and systems for the mainstream markets, are multi-national corporations. Possible candidates could have evolved from Telstra or BHP, however, Testra is becoming more of a service provider than a technology developer, and BHP are again focused on their core businesses (as evidenced by their sale of AOFR to ADC).

The results presented in the last two columns of Figure 4, are consistent with the fact that many Large Enterprises based in Australia rely on the Australian Photonics CRC and/or their overseas Research Laboratories for most of their Photonics technologies. The exceptions are where a multi-national corporation has taken over an Australian SME and has retained the Australian Photonics technology base (eg, Uniphase/INDX and ADC/AOFR). It is not yet clear whether future Photonics products and systems developed in Australia by Large Enterprises will be based on technologies developed in Australia or by their Photonics Research Laboratories outside Australia.

Irrespective of what the Large Enterprises do with the Photonics technologies developed in Australia, there is scope for Australia’s SMEs to exploit this technology base to develop world-class products and systems. A broad technology and product base equivalent to that of a Large Enterprise can be achieved through the networking of fast-moving SMEs with access to Venture Capital (VC) funding. As evident from several local and international papers presented at the World Innovation & Strategy Conference in Sydney in August 1998, business networking is becoming a world-wide trend. This trend reflects the needs of SMEs who hope to unite and compete against the Large Enterprises who continue to get larger (and possibly slower) through mergers and acquisitions. It is also feasible that a successful Australian SME network could grow to become a Large Enterprise through a merger of the SMEs involved.

Customer Research Organisations

Observation 7

Like overseas Customer Research Organisations, Australian organisations such as Telstra and DSTO are a key resource for developing “customer-focused” technologies and systems that can be licensed to Australian industry for local sale and export. Similar organisations with lesser research facilities (eg, Optus, Energy Australia, Transgrid, State Rail & RTA) can achieve the same result by providing market guidance and infra-structure projects to Universities/CSIRO, SMEs and Large Enterprises.

Customer Research Organisations, such as British Telecom (BT) Research Labs and US Navy Research Labs were generally focused on technology and systems development, but not on product development. This is evident from the lack of purple squares against this grouping in Figure 4. Product development was generally undertaken by their industry partners.

The reason for undertaking research and the nature of the research varies with each type of customer organisation. As one might expect, the technology areas addressed by these two organisations were almost mutually exclusive. The only areas of common research were: >40 Gbit/s OTDM; Integrated Optical & Electronic Circuits; Optical Signal Processing; Photodiodes & Integrated Receivers; and Optical Amplifiers. These areas are therefore ideal candidates for dual-use (commercial & defence) development programs.

The reasons for customer organisations undertaking research, technology and systems development were as follows:

Like Telstra, BT need to undertake technology evaluation to be an “informed purchaser”. Beyond this basic need, BT also supports fundamental research and technology & systems development to give them a competitive edge against other emerging carriers. BT’s technologies are now being commercialised through licensing arrangements (eg, Galileo’s 1310mn fluoride fibre amplifiers) and through start-up companies that spin-off from BT (a revived initiative that previously failed). Systems, such as Fibre To The Home (FTTH) and Curb (FTTC) are also being developed and trialed to offer new services and thus maintain BT’s competitive edge.

Like DSTO, US Navy Research Labs also need to undertake technology evaluation to be an “informed purchaser”. However, in contrast to commercial organisations such as Telstra and BT, Defence research, technology and systems development are driven by a fundamental need (and a lot more funding) to provide the best technologies and systems needed to win a conflict or war. Once developed, these are licensed to local Defence industries to develop products and systems for local use and export (with limitations).

Examples of Defence Photonic systems developed by US Navy Research Labs include: high-power lasers (eg, counter-measures and weapons); smart-structures (eg, mine-hunter ships and fighter aircraft); and surveillance systems (eg, underwater fixed and towed arrays).

In Australia, 1st and 2nd generation Photonics technologies and systems developed by DSTO and Australian Industry for Defence and Industrial applications include: Infra-red sensing technologies, fibre-optic LAN/PBX networks (eg, FDDI-2 / MILNET); laser ranging systems (eg, LADS - Laser Airborne Depth Sounder); acoustic fibre sensors; and smart structures for fighter-aircraft, high temperature pressure vessels and bridges.
Commercial 1st and 2nd generation Photonics technologies and systems developed in Australia by Telstra Research Labs (TRL) and Telstra’s strategic (multi-national) partners include: FTTH (eg, Alcatel MACNET); FTTC/ADSL (NEC Trials); and fibre-optic MAN networks (eg, Alcatel / QPSX Fastpac).

Other customer organisations that would fall within this grouping include: competing Telcos; Electricity Companies; Rail and Road Authorities. Not all these customers have research facilities of their own. In such cases, relationships with Photonics Research Organisations and industry are essential to the development of Photonics technologies, products and systems which address real customer needs. Furthermore these customer organisations can provide the necessary infra-structure to trial the Photonics products and systems that are developed by industry partners. The development of current sensing products for high-voltage power systems is an example for which Transgrid, ABB and the Photonics CRC are involved.

Analysis by Technology Grouping

The technologies listed in Figure 4 are loosely grouped into Generic Capabilities and Photonics Components towards the bottom and Applications towards the top. The Applications group is further sub-divided into Communications and Industrial applications. The former applies mainly to Telecommunications customers, however, both sub-groups may apply to Defence customers. The following analysis looks at technology relationships and trends within and between these groupings, with a focus on the core-strengths and relevance of Australia's Photonics Research and Development.

Generic Capabilities and Photonic Components

Observation 8

Australia's core Photonics technology capabilities were developed into products over a 25-year cycle of Basic Research & Development. These capabilities include: Pure Science skills in Optical & Plasma Physics, Materials Science and Chemistry with Applied Science skills in Chemical Vapour Deposition and doping processes, specialised Optical Fibre drawing and manufacturing processes and UV writing of Gratings into Optical Fibres. Resultant component products include splitters, filters and sensors. Future products that could be readily developed and marketed by Australian start-ups or SMEs, include Fibre-Lasers and Optical Amplifiers.

The generic capabilities and component technologies listed in Figure 4 were grouped with those producing saleable component products at the top and capabilities towards the bottom. The technology areas where component products are maturing (whether sold separately or as part of a integrated product) often showed a high-count in the column labelled "World". These products can be summarised as follows:

- Photodiodes and Integrated Receivers;
- V-Groove based Optical Fibre Interconnects for Planar Optical Waveguides;
- **DWDM Muxes / Filters**, **Splitters (Couplers)** and **Circulators**;
- Optical Amplifiers for Network Installations;
- Semi-conductor (In/GaAs/P) Lasers and VCSEL Devices;
- External Optical Modulators ($LiNbO_3$, Absorption);
- Optical Switching Devices;
- **Special Purpose Optical Fibres**; and
- **Optical Sensor Devices (current, strain)**.

Of the above technology areas, Australia currently supplies only five component-level products to the market. These are highlighted in the above list.

If we look more deeply into the core-capabilities and technology areas that led to these products, it is in pure science skills in optical & plasma physics, materials science and chemistry, plus applied science skills in the development, manufacture, manipulation and assembly of standard and specialised **optical-fibre** based components.

Looking deeper again, Chemical Vapour Deposition (CVD) and doping processes are at the root of Australia's Photonics component technologies. UV writing of Gratings into Optical Fibres was a more recent development. These core Photonics capabilities were developed in Australia over a 25-year period of basic Research and Development. Australia has not applied the same level of R&D investment to any of the other technology areas listed above, and the resultant lack of Australian Photonics products reflects this fact.

Given the above optical-fibre technology-base, there are two product areas that Australia could quickly move into and expect to capture a reasonable market share:

- **Fibre Lasers**; and
- **Optical Amplifiers** (fiber-based).

Since these products are just components in large, distributed sensing systems and communications systems, they are non-threatening to the Large Enterprises addressing these markets. Furthermore, since these are generic products that have a broad range of commercial, industrial and Defence applications, it would not make economic sense to license the product designs to any one multi-national corporation. Instead, they are the kind of products that may be readily developed and marketed by Australian start-ups or existing SMEs, and purchased by the multi-national corporations in Australia or overseas, for local use and export as part of their own products and systems. Start-ups and SMEs aiming to develop and market these products should be ideal candidates for VC funding.

Observation 9

Australia is well positioned to develop integrated Photonics products based on its new Planar Optical Waveguide technologies and established Optical Fibre technologies & capabilities. Furthermore, Australia's Planar Optical Waveguides employ unique, low temperature manufacturing processes which enable the development of fully integrated Electronic, Electro-Optic and Optical Waveguide products . These are the technology areas exhibiting greatest collective focus by the organisations visited.

If we focus on trends in Photonics technology development, it can be seen from Figure 4, that the areas of greatest collective development of new or improved technologies by the organisations visited are (represented by the number of orange squares):

- **Planar Optical Waveguides (9);**
- **Integrated Optical and Electronic Circuits (8);**
- **V-Groove based Optical Fibre Interconnects for Planar Optical Waveguides (7);**
- **Micromachining (6);**
- RF Microwave and CATV on Fibre (6);
- >40 Gbit/s OTDM (6);
- Terabit/s DWDM & OTDM (5);
- Optical Signal Processing (5);
- Optical Interconnects & Pixel Arrays (5);
- Optical Switching Devices (5);
- Photodiodes & Integrated Receivers (5);
- 1550nm Fibre Lasers (5) and Optical Amplifiers (4);
- DWDM Filters, Splitters & Circulators (4); and
- External Optical Modulators (4).

Product Improvements

Areas of either high product maturity, low priority or niche research included:

- Semiconductor Lasers (3);
- Flip-Chip Bonding of Semiconductor Lasers to Planar Optical Waveguides (3);
- Solitons (3);
- 1310nm Fibre Lasers (2);
- Optical Sensor Devices (1); and
- Optical CDMA Devices & Networking (1).

It is noteworthy that the top four technology areas listed above are important to all the technologies that follow. As the density of wavelengths and bit-rates increase, the need to manipulate and process signals in the optical-domain increases. Whilst optical fibre as a signal processing medium has served us well to-date, it will be Planar Optical Waveguides which perform this function in the future. This is because they are more readily integrated and manufactured in volume compared to Circular Optical Waveguides (ie, optical fibres).

The need to connect Planar Optical Waveguide components to Electro-Optic components via low-cost fibre-pigtails, is currently being resolved through new V-Groove coupling techniques, such as the "Optical Fibre Clip" technology developed by Cambridge Consultants. Such coupling devices require very accurate alignment of the fibre-pigtail "core" which is proving difficult with standard telecommunications fibre. Again, an opportunity exists for Australian industry to leverage its core-capabilities by developing high-quality optical fibre-pigtail products for the emerging Planar Optical Waveguide market. It is likely that this development will be undertaken by the Photonics CRC.

In the longer term, increased performance and reduced cost of components requires the integration of Electronic, Electro-Optic and Planar Optical Waveguide components. This is one of the most important areas of research being undertaken by the organisations visited.

To Australia's benefit and credit, the Photonics CRC is recognised by several overseas research organisations as having a low temperature Planar Optical Waveguide manufacturing process that is superior to other high-temperature processes. Only through a relatively low temperature process can the Electronic and Electro-Optic components be integrated in the future. The Photonics CRC have already demonstrated this capability by integrating a silicon PIN Photodiode Detector with a Planar Optical Waveguide. In the future, it is feasible to have a common silicon substrate with CMOS VLSI electronics, electro-optic devices, external optical modulators, optical waveguides, filters, splitters, V-grooves, optical fibre clips and special optical fibre pigtails, all integrated into a single packaged product (system on a chip).

If we seek out the roots of Australia's technology capabilities that brought us to this point, we will again identify the same pure science skills in optical & plasma physics, materials science and chemistry, plus applied science skills involving Plasma Enhanced Chemical Vapour Deposition (PE-CVD) and doping processes and UV writing of Gratings in Silicon substrates.

If we go back even further, we will find that Australia's first CVD capabilities were developed more than 25 years ago in the manufacture of electronic integrated circuit components. These core capabilities have been fostered through Quality Semiconductor Australia at Homebush and through Australia's Photonics research activities. These capabilities will go "full-circle" with the integration of Electronic, Electro-Optic and Planar Optical Waveguide components.

Communications Applications

Observation 10

Australian Photonics research is focused more on component-level products than system-level products for Telecommunications applications. Given the disciplines and capabilities required, it may be unrealistic to expect more than this. If system-level products are to embody the best of Australia's Photonics and Broadband Switching technologies, then inter-CRC collaboration in the form of joint projects is essential to creating a vertically integrated industry in Australia. In terms of market focus, products for FTTC, MAN and LAN applications would utilise Australia's Photonics and Broadband capabilities to the fullest.

In the communications area, the most mature Photonics technologies have been integrated into systems and applied to Dense Wavelength Division Multiplexed (DWDM) Trunk and Oceanic Networks. Operations Administration & Maintenance (OA&M) Management of DWDM is an essential sub-system requirement. This market has been driven by the need for greater capacity to service the growing Internet traffic. This traffic-level was not allowed for in the 1st generation fibre-optic trunk networks.

The next most important areas of communications system development are for Fibre-To-The-Curb (FTTC) and Metropolitan Area Network (MAN) applications. Fibre-To-The-Home (FTTH) is still on the agenda, but is more research-oriented at this time. In fact, FTTH may not be commercialised for at least 10-15 years due to installation rather than technology issues.

Plastic fibre and Infra-red technologies for bit-rates up to 2.5 Gbit/s are under development for Local Area Network (LAN) applications. Networks and products based on these technologies may eventually displace existing category-5 twisted-pair networks and products. In the transition phase, there will be an opportunity for protocol converter boxes between them.

The transmission of Internet Protocol (IP) traffic directly over WDM (or DWDM) is an area of considerable research focus. The aim of this research is to reduce traffic congestion and cost by eliminating unnecessary protocol layers and framing. This could result in the elimination of SDH/SONET as a multiplexing protocol for the backbone networks. IP switching products are also emerging and these could eliminate the need for ATM and PBX switching in the future.

Unfortunately, Australia is not as actively involved in the research and development of the above application areas. There have been some FTTH, FTTC and MAN trials but very little real product and systems development. The only products that have come close, are the QPSX MAN product (originally marketed as Fastpac by Telstra), and a 622 Mbit/s ATM Ring product recently developed by Atmosphere Networks – a spin-off from the Broadband CRC.

In contrast to the above, Australian Photonics' projects are more focused on component-level research and associated product development. The MAWSON project funded by the Photonics CRC was intended to rise above this component focus, however, closer examination reveals very little industry direction for the project. This situation could be overcome by providing real applications to drive the project direction and joint research with the Broadband CRC to bring valuable protocol and switching experience to the project.

Further details on communications technology trends and Australian industry opportunities in FTTC, MAN, LAN and Micro-LAN (Optical Interconnect) applications is included in Annex A.

Industrial Applications

Observation 11

In-line with Australia's traditional leaning towards "niche" markets, Industrial applications are an area where Australian SMEs are achieving vertical integration, from Photonics technologies to products & systems. These technologies can be further exploited by SMEs for Defence applications with support from Defence sponsors, Large Enterprises and through closer collaboration with DSTO in Photonics R&D activities.

The industrial applications listed in Figure 4 did not form a large enough sample size to allow any serious conclusions to be drawn from the table itself. Most conclusions will therefore be drawn from the visit reports and other studies undertaken before and after the Mission.

The most notable observation is that this is a “niche” application area where Australia is achieving vertical integration of several Photonics technologies. Strain sensor systems for example, are being developed by an Australian SME for bridge monitoring applications. These sensors use similar in-fibre Bragg gratings to that developed in Australia for the mainstream DWDM communications market.

An area of technology and product development where Australia appears to be ahead is in current sensing for high-voltage applications. Unfortunately, a visit to ABB in Sweden could not be organised for this particular Mission, so there was no overseas input into this analysis. Whilst ABB are working with the Photonics CRC, it is understood that they are also tracking other technologies, such as those being developed through their subsidiary companies in Canada and the USA. It is not yet clear which of these technologies will be adopted as ABB products and marketed internationally.

Laser ranging, optical scanning and spectral analysis systems are another technology area where Australian SMEs are providing vertically integrated solutions. Applications include:

- Satellite Laser Ranging: (eg, WESTPAC-1 used to measure movements in the earth’s surface to an accuracy of millimetres)
- Water Depth mapping: (eg, LADS - Laser Airborne Depth Sounding System)
- Surface Spectroscopy: (eg, HYMAP Airborne Hyperspectral Imaging System for mining, forestry, environmental and Defence applications)

In contrast to the communications applications, only two of the overseas organisations visited (Cambridge Consultants and US Navy Research Labs) were involved in industrial applications. Notwithstanding this, the visit to NRL indicated that their research and development was more advanced than any similar R&D being undertaken in Australia for applications such as Surveillance Systems, Smart Structures and Very High Power Laser Systems.

Optical fibre towed arrays for example, are known to exist for both submarine detection and petroleum exploration, however, such arrays generally use fibre-optics for communications purposes only. NRL have taken their research further to develop all-optical fixed and towed-arrays that employ fibre as both an acoustic sensor and as a transmission medium for the acoustic signals. They have licensed the towed-array technology to Litton Corporation for petroleum exploration applications.

Unfortunately history continues to repeat itself, since the fibre-based acoustic sensing technology developed by NRL was previously demonstrated 10 years ago by both AWA Research Laboratory and AOFR, but was not commercialised due to inadequate co-operation in this area, between DSTO and industry researchers.

Based on recent discussions with NRL and DSTO, and through knowledge of current Defence industry activities in Australia, there is again, a strong case for the development of Photonics based surveillance systems in Australia. Optical fibre arrays can be developed for both towed and fixed sensing, for Defence, Industrial and Mining applications. With the support of Australian Defence sponsors and DSTO, vertical integration could be achieved by Australian SME’s supplying specialised Photonics sensor components and products to Large Enterprises that are experienced in Defence systems integration and project management.

Further details on optical sensing technologies, products and systems, and opportunities for Australian industry in Defence applications, are included in Annex B.

Technology & Product Development Cycles

New Career Cycle for R&D Professionals

Discussions with Hewlett Packard Labs amplified the trends to shorter product life cycles and the hence the importance of reducing the time-to-market, from basic research through to technology and product development. This need translates to a new career cycle for R&D.

Observation 12

It is no longer possible for researchers to simply throw their technologies "over the wall" to the development group and hope that a product champion will pick them up and produce a product. Instead, it is now important that the researchers take "ownership" of the development tasks and follow their technologies through into the product stage. When this R&D process is complete, the researchers can either move up the career ladder into management, or if they still have a technical bent, they can cycle back to the laboratories to work on the next research project.

The above cycle of technology and product development is illustrated in Figure 5.

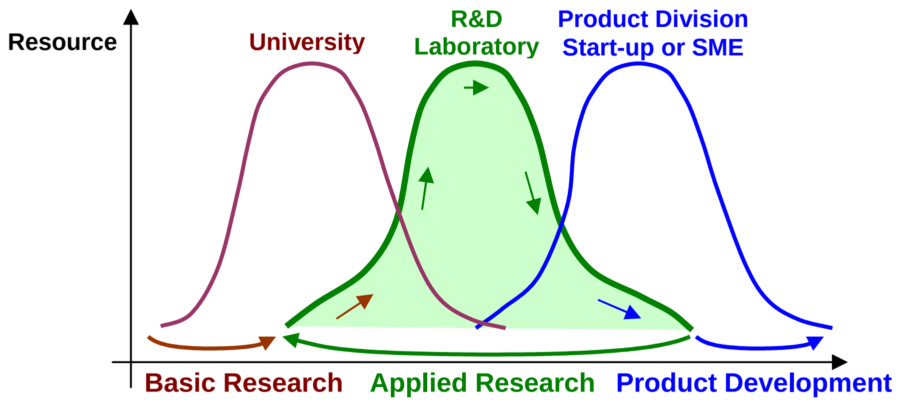


Figure 5 The New Career Cycle for R&D Professionals

In the case of Australia, where there are currently no corporate champions similar to Uniphase or Ciena, there is a greater need for start-up companies to form, comprising researchers and technologies emerging from the Photonics CRC and other similar research activities. These start-ups need to develop the Photonics technologies into products, thus moving Australia up into more profitable areas of the vertical integration food-chain. The financial and management models for such start-ups are outlined under Commercial Findings.

As an alternative to start-up companies, existing Australian SMEs can acquire the technologies developed under the Photonics CRC and similar projects. Such SMEs would normally have complementary products, capabilities and a business growth strategy that underpins the need for the new Photonics technologies.

Based on the above commercialisation "ownership" issues identified by HP, it is important that both the technologies and the researchers are acquired by SMEs (this is generally a-given for start-ups). In contrast to the US, the importance of "human capital" has in recent years, been under-valued by Australian companies, a situation that must be turned-around if we are to stop losing our best Australian researchers and technologies to overseas corporations.

Improved CRC Funding Cycle

Observation 13

Early guarantee of next-round funding for successful CRCs provides further recognition and motivation to the key researchers to stay in Australia and follow their R&D career cycle through to technology commercialisation with a profitable outcome for Australia. Retention of the key researchers, whether in start-ups, SMEs, local multi-nationals or in the Photonics research facilities, also provides a source of training and role models for new researchers being introduced into the CRC program.

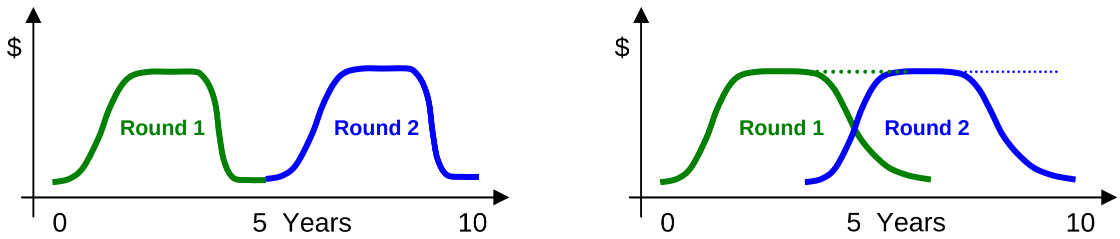
Discussions with Photonics researchers who have left or are leaving Australia to work for US corporations, highlighted a deficiency in the Photonics CRC funding process that, along with the lack of local investment and industry funding, is contributing to the "brain-drain" of good researchers to corporations overseas.

Under the current CRC funding scheme, the key researchers are enthusiastic and accomplished in producing valuable technologies during the first 3-4 years of CRC funding. For the successful CRCs, such as the Photonics CRC, this results in a number of researchers moving-on (as they should) to form start-up companies (eg, INDX).

The flip-side to this success is that researchers who have not yet completed their technology developments are put under increased work-load and pressure due to the loss of skilled Photonics resources (personnel and materials). Insufficient confidence in accessing future round(s) of CRC funding and associated industry funding prevents the successful researchers from being replaced with new Ph.D qualified talent. This current CRC funding cycle is shown in Figure 6a.

In the absence of any Photonics CRC or industry commitment to funding, remaining key researchers often leave prematurely to accept more secure and well paid jobs with a multinational's overseas research laboratories, product development facilities or overseas research institutions. This brain-drain process reduces the number of technologies that are full-developed and commercialised in Australia.

To help reduce the brain-drain process, the Australian Government could allow early submissions and approvals for the next round of funding for CRCs that have demonstrated successful research outcomes during the first 3-4 years of the current round. This overlapping cycle of CRC funding is illustrated in Figure 6b. Of course, Government support alone is not enough to reduce the loss of experienced researchers. As outlined in the following Commercial Findings section, venture capital and industry investment play an even more important part in building a sustainable Photonics industry that would attract our own as well as overseas researchers.



a. Current CRC Funding Cycle **b. Successful CRC Funding Cycle**

Figure 6 CRC Funding Cycles

Incremental Technology & Product Improvements

Observation 14

For the fast-moving communications technologies & products discussed, it is important that an incremental approach to technology & product development be employed. For example, only through incremental product developments by fast-moving start-ups or SMEs can rapid market changes be tracked and accommodated into the next product. This is in fact, one of the processes by which product life cycles are being shortened.

Discussions with Rob Newman at Atmosphere Networks highlighted that the QPSX MAN technology for which Australia is renowned had a 2.5 year product development cycle, which was far too long. Consequently, when the product was complete, the original market requirements on which it was based were no longer valid. Rob stated that these days, 50% of the original market requirements for any high-tech communications product are invalid after only 12 months.

In terms of technology development, Australia has a tradition of losing opportunities due to lack of commercialisation. The response to this is often to “leap-frog” the competition in the hope that we may get it right next time. This cycle of “technology leap-frog” and “commercial failure” is partly an outcome of the issues discussed above. Often the outcome is a one-off technology sale to an overseas corporation – a process that (as discussed in the Commercial Findings section), offers little more than a linear return on investment.

In contrast to the “leap-frog” approach, an incremental technology and product development approach with local commercialisation, offers the reward of early product sales, re-investment in upgraded technologies and products, and hence a compounded return on investment.

To stop the cycle of technology “leap-frog” and “commercial-failure”, it is important that Australian researchers and product developers commercialise what exists now and grow more rapidly through profits from sales and reinvestment of profits in incremental technology and product improvements. As highlighted from discussions with HP Labs, the involvement of the Photonics researchers in the product development process is key to a successful outcome.

Commercial Findings

Use of the INDX Case Study

In order to encourage a free flow of dialogue on the important issue of commercialisation, a case study was presented by Phil Carmont which focussed on the recent fund raising and commercialisation experiences of an Australian Photonics start-up company, INDX Pty Limited ("INDX"). The case study highlighted the challenges which faced INDX after it was spun off from the Australian Photonics CRC and the mixed reaction which its eventual sale to a US multinational had caused in Australia. Our host organisations were then encouraged to give their opinion on the INDX story and to share some of their own experiences and insights with regard to technology commercialisation.

The slide presentation which was used as an aid in presenting the INDX case study is included in Vol.3 of this report, however, an abridged version is as follows. INDX, the first of three companies to be spun-off from the Australian Photonics CRC, manufactured Photonics components based on in-fibre processing, primarily for Wavelength Division Multiplexing (WDM) applications in long-haul, optical fibre telecommunications networks. The CRC had recognised that the rapidly growing WDM components market created an opportunity for companies such as INDX to fill technology gaps which traditional telecommunications equipment suppliers no longer had the resources or inclination to address. This situation was a reflection of a general state of flux in the telecommunications industry where the traditional roles of telecommunications carriers, equipment suppliers, and components manufacturers were (and still are) being redefined.

Observation 15

Whereas once the telecommunications carriers would maintain their own systems and networks, they have now become more focussed on value added services, such the provision of internet services and pay television. This trend has seen equipment suppliers increasingly take on the role of maintaining telecommunications systems and network equipment. This upwards migration in the telecommunications food chain created a role for companies such as INDX to be niche providers of Photonics components formerly manufactured by the equipment suppliers.

INDX performed the role of a niche components supplier very successfully. After commencing operations in October 1995 with a staff of ten (primarily Ph.Ds from the CRC and Masters graduates from Macquarie University); seed funding from the CRC of around A$900,000 (which included the value of manufacturing equipment and salary support); and licenses from the CRC, INDX had achieved a roughly break-even operating result in less than two years, sales growth of 260% per annum, and a projected annual rate of sales growth in excess of 100% for the next four years. This growth led to an inevitable working capital crisis. The CRC could not justify playing the role of a venture capitalist to INDX, however the company desperately needed funds to enable it to grow and meet market demand.

The CRC made the decision to seek a trade buyer for 49% of INDX. The purchase price of A$2.5 million (which was to be left available to fund INDX's growth and not returned to the CRC), implied a value of approximately A$5 million for 100% of the company. A trade buyer was seen as preferable to a venture capital investor(s) because of: INDX's pre-existing knowledge of likely bidders; the urgency of its funding requirement; and for market access - local venture capital funds consulted by INDX and the CRC were unfamiliar with the industry and could not move quickly enough.

Four trade buyers indicated an interest in INDX. This was later narrowed down to two serious bidders. A medium sized US multinational, Uniphase Inc., was ultimately chosen because of its good strategic fit, historical relationships between the personnel from both companies, and the preparedness of Uniphase to build its South East Asian manufacturing base in Australia. Significantly, there was no Australian company capable of buying and successfully integrating INDX into its operations. The other short-listed bidder was a company owned by UK interests.

In the process of bedding down the purchase, it was realised that INDX would require significantly more than A$2.5 million in new funding over the subsequent two years to be successful. Uniphase eventually negotiated to buy 100% of the company (for approximately A$8 million) so that it could fully integrate INDX into the newly established operations of Uniphase Australia Pty Limited.

The discussion points drawn out of the case study included the following:

- Should it be seen as a negative development that a CRC spin-off company, developed with Australian public funding and Australian intellectual property and know-how, was now owned 100% by foreign interests?
- In the circumstances, was there a better course of action available to the CRC?
- Because INDX established an early technological advantage in WDM components, equipment suppliers were prepared to buy from it despite the fact that it was a one product company with an uncertain future due to its lack of access to capital. Once INDX's competition caught up in technological terms, was it doomed to be a victim of its small size and limited product offering?
- Uniphase, which grew its sales by 55% to US$107 million in 1997 and has been a stellar performer on the NASDAQ stock exchange, has successfully employed a strategy of growth through acquisitions - with INDX being one of its smaller purchases. Was it possible to grow an Australian Photonics company of similar stature or are we inherently limited to trade sales to foreigners?

In reviewing the insights of our hosts, as well as our own reactions to what we observed over the course of the Mission, it became apparent that it was most appropriate to analyse our experiences in Japan and Europe separately to those in the US - such was the contrast in the approach of each group to the issue of technology commercialisation.

Japan and Europe

Our visit to NEC offered little in terms of commercialisation insights relevant to Australian Photonics companies. This was not entirely unexpected, given that the Central Research Laboratories are responsible for developing NEC's "day after tomorrow" technologies and not for developing strategies aimed at getting products to market. The highly structured "big corporation" approach of NEC also had little in common with the fragmented Australian Photonics industry, characterised as it is by a lack of large corporate players.

Observation 16

In visiting British Telecom's Networks Research Laboratories in the UK, it was apparent that they too were grappling with many of the same issues facing Australian institutions like Telstra, the CSIRO and our Universities. Notwithstanding that BT continues to undertake significant levels of R&D with the stated intention of remaining an "informed purchaser", there is growing pressure for this publicly listed company to earn a commercial rate of return on these outlays.

Commercialisation of BT's technologies was already happening on a small scale through royalties on technology licenses. New ideas being contemplated by BT included the formation of spin-off companies, the seeding of BT developed technology within established companies (in return for equity), and the secondment of BT staff to established technology companies so as to build their entrepreneurial skills.

BT's senior research staff could provide no insight as to how small Photonics start-ups in Australia could overcome the problems associated with being cash strapped, single product companies, particularly when no medium to large sized Australian company was capable of picking up smaller Photonics enterprises, funding their growth, and successfully managing their ongoing operations. Selling INDX or companies like it for a profit seemed an acceptable result to BT.

Advantages and Disadvantages of Australian Technology Sales

Our visit to Cambridge University saw a continuation of the same line of argument with regard to INDX. Dr David Moore argued strongly that there was nothing wrong with selling our technology to foreign interests, or alternatively, buying their technology: after all, technology is just another commodity and if a profit is made on the sale, then it is a good deal for Australia. After some reflection, we remained of the review that although the CRC had acted prudently and sensibly with regard to INDX, the result can be sub-optimal for the following reasons:

First, whereas the benefit of repeated re-investment of capital from start-up companies sold for a profit is roughly linear (eg. invest $5M, sell for $20M, re-invest $10M and so on), …

Observation 17

if ownership and manufacturing operations are retained locally, the company's expertise can build upon itself in a compounding way as sales grow and operations expand, producing balance of trade benefits for Australia and a much larger capital gain over time.

In support of the CRC decision, this sales growth scenario continues to apply due to the retention of INDX's manufacturing operations in Australia.

Secondly, …

Observation 18

when an Australian technology company is sold to a foreign controller, access to that company's know-how and intellectual property can be lost to other local industry participants. This can result in expensive new technology acquisition and redesign costs for Australian industry.

The sale of a semiconductor plant at Homebush in Sydney (formerly owned by AWA), demonstrated how limiting this can be. The new owner, US company Quality Semiconductor International, was initially prepared to perform new chip design and manufacturing on a contract basis for Australian companies. Importantly, this was the only such resource available in Australia. However, as AWA and others were to learn to their detriment, when Quality Semiconductor's US management changed the business strategy for the Australian subsidiary, contract manufacturing services were withdrawn. In a larger country with an established IT industry, this would not have been a problem. In Australia, however, it meant that the local industry now had a reduced capability to develop sophisticated products for export markets and for import replacement. Additionally, local industry incurred the added expense of having the integrated circuits on which their export products depended, redesigned for offshore manufacture, or alternatively had to make last-buy purchases.

Thirdly, …

Observation 19

access to valuable human capital can be lost when a local technology company is sold to a foreign acquirer. This human capital may be transferred overseas and employed furthering the growth aspirations of the foreign acquirer, rather than growing an Australian company capable of earning export income or replacing high tech imports.

The greater the number of quality people that leave in this way, the more diluted the pool of local commercial and scientific talent becomes. This in turn makes it increasingly difficult to create the next generation of start-up ventures. Ultimately, good people may return to Australia to establish new technology ventures, but this is a long term scenario and not the fast-tracked growth strategy which many argue Australia needs.

Figure 7 Ross Halgren, Phil Carmont & David Moore discuss INDX

Following our thought-provoking discussions with David Moore at Cambridge University (Figure 7) we were faced with a difficult question: how do we achieve critical mass in the Australian Photonics industry in the absence of a local corporate champion? One thought was to investigate the level of cooperation between the eight Australian CRCs in the IT&T cluster, with a view to potentially creating critical mass via the Australian Government's own contribution. This was thought was tempered, however, by a realisation that direct government intervention has been shown historically to be a poor substitute for private sector investment.

Comparisons between Australia and Scandinavian Countries

Like NEC in Japan, Ericsson in Sweden is a very large company (accounting for 15% of Sweden's export income) and consequently the senior researchers from Ericsson's Photonics Research Laboratories did not have a great appreciation of the issues facing start-up companies such as INDX.

We posed a question to Ericsson that we had often heard asked by average Australians. Why was it that Australia, with a population roughly twice as large as Sweden's or Finland's, had not produced a company of the stature of Ericsson or a Nokia? In reply, Ericsson pointed out that:

- Both Ericsson and Nokia were companies with over 110 years of operating history and their current success had not been achieved overnight; and
- Both companies collaborated with their respective government owned tele-communications utilities, and with each other, to develop Scandinavia's world leading mobile telecommunications capability. Not only was a substantial amount of R&D and project risk directly subsidised by the governments of both countries, but there was also a ready made and financially dependable consumer in the form of each of the government owned telecommunications carriers.

This reply reinforced two difficulties for Australia:

First,…

Observation 20

it is a relatively young country which is trying (as it must) to keep up with or outperform nations who have had a significantly longer period of time to understand their markets and grow mature companies to critical mass.

Secondly,…

Observation 21

in a country with a small population, it is very rare for a company to succeed on a global scale without significant local support in some form.

Ericsson's reply also reminded us of an earlier thought we had had after visiting BT. Since Telstra is no longer a government owned entity, the fundamental research once performed by Telstra Research Laboratories (TRL) may no longer be undertaken by them. Consequently,....

Observation 22

the public sector's direct contribution to R&D in telecommunications now takes place primarily through the CRCs in the IT&T cluster. It is therefore essential that these CRCs act in a coordinated way to achieve maximum critical mass. Fortunately, the combined output of these CRCs should be even more valuable to Australia than the work formerly performed by TRL, since the technology can be made more accessible to Australia's SMEs.

Japan and Europe - Conclusions

Although our period of observation in Japan and Europe was very brief, we did not see any clear evidence of a developed skill in turning R&D and intellectual property into successful commercial products and spin-off ventures. Large and successful companies like NEC and Ericsson were demonstrative of a model which was not highly transferable to the Australian context because they had achieved critical mass through a combination of government subsidy and their close proximity to large consumer markets.

The researchers we met seemed to posses very little sense of an ability to grow a small, technology based enterprise into a large one. Trade sales to larger, more established companies seemed an inevitable and acceptable result. Our own instincts told us that there should be a better way - it just wasn't obvious yet.

United States of America

Two of the three weeks available for the Mission were spent in the US. Not all visits were of equal importance in terms of insights for commercialisation, so only the more significant sites have been highlighted below.

Our visit to Lucent's renowned Bell Laboratories in Murray Hill was well timed. The Director of Lucent's Photonics Laboratories, Alastair Glass, had just returned from a trip to Australia and was very enthusiastic about our Photonics capabilities. His personal view was that Australia was unwise to sell INDX because such companies were necessary to build a local Photonics industry. Having said this, Alastair did not have an answer for how we could fund the growth of such companies in the absence of a well developed venture capital market or a Uniphase style of company in Australia which was capable of successfully consolidating smaller Photonics companies and funding their growth. Note that the recent acquisition of JNA by Lucent indicates that the internal views of large corporations are not necessarily consistent.

Alastair's view of government assistance was that it shouldn't be directed at specific companies, but rather it should be focused on providing infrastructure and an economic/regulatory environment which is conducive to the growth of corporate activity generally. He claimed that this had been part of the success of Silicon Valley.

Alistair suggested we study the short (but very successful) history of Ciena to see how a start-up can grow to achieve critical mass very rapidly. He had been amazed by Ciena's success and recalled meeting with them (not all that long ago) when they only had fourteen employees. He did point out however, that the close relationship between Ciena and the large US telecommunications company, Sprint, was a significant contributor to their success.

Growth through Acquisition and Licensing Strategy

Alastair did not see any reason why Australia could not develop a Ciena style success story. He (like David Moore at Cambridge University) also highlighted the following strategy:

Observation 23

There is merit in the idea of Australia purchasing or licencing-in technology where it has knowledge gaps. It is common practice for companies like Ciena and Uniphase to purchase or licence technology rather than develop it in-house. An attractive aspect of having large local players grow in this way is that they tend to drag along many smaller companies with their momentum. These small companies then become medium sized companies over time. Again, the obvious missing link for Australia is such an Australian corporate champion in the Photonics field.

Galileo, a medium sized opto-electronics company which we visited in Massachusetts, held useful parallels for Australia, only on a smaller, corporate scale. The company had once been very tied to the idea of being a large, local community employer. Consequently, whenever Galileo acquired a new business it would be relocated to the company's Sturbridge facility.

This view has now been jettisoned, with newly acquired facilities owned in Montreal, Florida, Berlin, and New Hampshire. The trigger for Galileo's changed world view was the loss of a single contract (supplying high speed copier components to Xerox) which cut the company's revenues roughly in half overnight, from US$38 million to US$19 million, and saw its share price plummet from US$22 to US$4. Fortunately Galileo had zero debt and US$19 million in cash reserves which have allowed it to acquire multiple businesses over the last eighteen months, rebuilding its sales and lifting its share price back above $15.

It became important for Galileo not to be blinkered about where the company's head office was situated or how many jobs could be created for the residents of Sturbridge. Galileo's management saw a parallel for Australia,….

Observation 24

Australia should not be provincial with respect to foreign ownership. The single most important issue is to make sure the country remains (or becomes) a genuine participant in the communications revolution which is sweeping the world. The purchase of INDX should be seen as a positive sign of the growth of a world class Photonics capability in Australia and that the sale to a US company is not a backwards step.

Galileo also believed that a key ingredient for success in the Photonics industry lay in being an early entrant into markets created by new technologies. This made sense in terms of the INDX experience - because of its early entry into the WDM components market, INDX was able to succeed in spite of its limited product offering and its lack of financial backing. Galileo hoped to gain a similar early advantage in the market for their new fluoride optical amplifiers. They saw it as critical to be in the market first because, given a choice, companies would choose to deal with established names like Ciena, from whom they probably bought most of their other WDM components.

Whilst in the San Francisco Bay area, we were fortunate to catch up briefly with Milton Chang. Milton is a well known US Photonics industry entrepreneur. An engineer by training, he held senior management positions in industry before becoming involved in a series of start-up ventures (almost exclusively in the Photonics field), all of which have grown into successful enterprises. New Focus is one example, of which he is Chairman. Milton was also one of the founders of Uniphase and is therefore familiar with its recent acquisition of INDX.

Observation 25

Milton Chang believed INDX was a real success story for Australia in that it demonstrated the quality of our Photonics technologies and legitimised us on the world stage. Uniphase is currently one of the darlings of the Photonics industry and it was a big compliment that they were prepared to fund a new Australian operation on the strength of the INDX acquisition.

Interestingly, Milton saw Ciena as a “false god” in terms of being the sort of model that Australian start-ups should be trying to emulate. To an extent, he believed that Ciena had been in the right place at the right time and it had benefited enormously from having Sprint as its development partner. These are not circumstances applicable to most start-ups.

Government Infrastructure Strategies

Milton thought that government intervention to foster the growth of Australia’s technology sector (eg. by limiting foreign ownership of CRC spin-off companies) would be a negative development. Milton expressed the following view,…

Observation 26

if assistance is to be provided by a government, it should come in the form of provision of infrastructure only. For example, Silicon Valley’s success was very much a result of the lack of regulatory intervention and the existence of a free flow of information and ideas. However, even if the economic environment was perfectly conducive, a real critical mass in the Australian Photonics industry would still probably take about ten years to develop. This same viewpoint was expressed by researchers at Ericsson.

Milton was of the view that a country’s R&D should be very industry focused and he liked the theory behind the CRC program. The difficult issue, he thought, was getting academics to switch onto product focussed R&D when their whole reward system was geared to the generation of technical papers.

Whilst in San Francisco, we also interviewed (by telephone link-up) John Dexheimer from the New York office of technology investment bank, CE Unterberg Towbin.

John has a long history of involvement with Photonics companies and was involved in taking Uniphase public in the US. Approximately 80% of John’s work in the Photonics field now relates to private equity investments, some quite early stage. John explained that he was presently involved in a spin-off company, backed by a Swedish consortium, which was developing tuneable lasers for WDM tests and back-up systems.

In terms of commercialisation insights, John pointed to the success of the so called “Israeli model”. A large number of communications and software companies, with strong technology but weak management, had successfully raised money in the US capital markets by installing resident US CEO’s and having an established US sales and marketing presence. Because the time zones are more conducive, European sales and marketing operations often stayed in Israel. Given that the US is the major market for software and communications products, it made sense for the company’s sales and marketing personnel to remain close to their major buyers.

Coincidentally, after we had returned to Australia, the Chairman of the Israeli Venture Capital Association, Eliezer Manor, spoke at Sydney venture capital conference. Eliezer verified the success of the Israeli model, explaining that in just 6-7 years, the number of venture capital funds in Israel had grown from 1 to 81. Like Australia, Israel's local market was too small to grow world class companies. Rather than being threatened by the prospect of US interests acquiring Israeli technology companies, this was part of the accepted corporate life cycle - be it though a trade sale to a US company or a NASDAQ listing. Listing on a local stock exchange was rarely contemplated. In summary, it seemed that….

Observation 27

the Israeli Government were comfortable with the view that technology is a commodity for sale to the highest bidder. Because the Israeli's had been able to sell their technology enterprises to US interests with such regularity, it had become part of a virtuous cycle for their domestic economy.

Venture Capital Funding Strategy

One of our last US visits was to Rob Newman, CEO of Atmosphere Networks Inc, a spin-off company of the CRC for Broadband Networking and Telecommunications in Perth. Atmosphere Networks is significant in that it employed the VC funding model to fund its growth and development, whereas INDX gave up on venture capital funding and sought a trade-buyer. Rob Newman's involvement in Atmosphere Networks had little to do with any direct role in the CRC, but rather was a result of a fortunate combination of circumstances.

Rob had returned to his home city of Perth for a one month sabbatical after leaving a senior position with the US networking company, Bay Networks. Tony Cantoni and Gary Pennefather, both from the Broadband CRC, had put together the basic business plan for Atmosphere Networks as a spin-off proposal and were using the services of John Poynten, a well-known Perth stock broking identity, to seek funds for commercialisation. They spent six months trying to drum up local VC interest, but the Australian market had considerable difficulty understanding the company's potential. Australian Mutual Providence were keen to play a role but the $1-2 million investment was too small for them.

Rob then introduced the business plan to a US VC firm where he was temporarily positioned as an entrepreneur in residence. The proposal was introduced in February 1997 and two VC funds, Benchmark Capital and Institutional Venture Partners, made their investment in June that year.

Observation 28

Atmosphere Networks was attractive to the VC investors for three reasons: it had a differentiated technology; a proven management team; and a rapid growth opportunity. Atmosphere Networks was incorporated in the US and this company purchased the Australian R&D operation.

After the first round of financing, the VC's held 40% equity (20% each), 10% equity was held by the CRC, and management and staff held the remaining 50%. The 10% equity allocation to the CRC proved difficult to negotiate with the VCs, but they were finally persuaded that this allocation was fair given that the CRC contributed valuable technology which Atmosphere Networks would have otherwise had to pay for. The 50% equity allocation to staff was seen as necessary to provide a reserve of employee stock options to attract top talent in the very competitive Silicon Valley employment market.

On the second round of financing, an additional 20% of equity was granted to new VC investors. This brought total VC funding to US$17million. The initial VC investors also topped up their investment in this round so as to maintain their respective 20% investment shares. This has left staff with roughly 40% equity and the CRC with an 8% interest.

Operationally, Atmosphere Networks is a US company with an Australian development group. The company employs 37 people, 18 in Australia and 19 in the US. The plan is to keep the Australian engineering operation basically intact and rapidly grow the US sales and marketing team.

Atmosphere Networks plans to take up a third round of private financing before seeking a public listing. At the next round, an additional 10-15% of equity will be sold and the investor is likely to be a corporate, both because of the higher valuation multiple obtainable from corporate investors and their importance in providing strategic partnering relationships. Strategic corporate investors provide important distribution channels for the company's products and also introduce the prospect of an exit by way of a trade sale, although this usually is at a discount to the potential public market valuation.

When discussing the INDX experience and getting Rob Newman's view of commercialisation models, he was of the opinion that,…

Observation 29

even in the telecommunications market, it was possible to be a one product company and be successful. For a company such as INDX to grow and succeed without being acquired by a larger company, it is necessary to have a symbiotic relationship with an established market player and to have access to venture capital funding in the early growth phase of the company.

One such example was a company MMC which has been VC funded by Institutional Venture Partners (Jeff Yang). This company has a very close relationship with Cisco, providing a single chip which is a vital part of a US$500 million product market for Cisco. MMC (NASDAQ symbol "MCN") commenced operations five years ago with a handful of people performing contract development work for larger companies. Today it is a successful NASDAQ listed company, still producing a single component. In retrospect, Uniphase may also have been able to provide this sort of partnering relationship for INDX but the missing link was the availability of venture capital funding at the critical moment in INDX's development.

An observation made by Rob with respect to growing viable companies in the telecommunications market, was that, ….

Observation 30

it is difficult to establish an appropriate sales and marketing team out of Australia. By hiring US locals (with the attraction of stock options) it was possible for Atmosphere Networks to employ people who already had valuable connections with most of the important buying groups in the US.

The US is by far the largest market for Atmosphere Networks' products, so a successful US sales and marketing team is vital. Rob did not believe that it was possible to succeed by having another company distribute your products in return for a royalty payment because the royalty stream was invariably never enough to fund the high product development costs of a start-up company.

United States - Conclusions

In reviewing our US experiences, there was one very obvious feature which differentiated this country and gave it the ability to produce "overnight" successes stories such as Ciena - the existence of a highly developed capital market. From the level of the venture capitalist through to the investment banks, executives with access to funds understand technology investment and there is a well understood formula for commercialising intellectual property and making money.

Observation 31

There are many factors which have contributed to the success of US technology companies, such as having an abundance of potential corporate partners and having access to a large domestic consumer market. However, with the general trend towards globalisation, and our proximity to Asian and China markets, these factors are becoming relatively less important for Australia. What Australian technology start-ups and SMEs need is venture capital money and good advice from people who have traveled the road to commercialisation many times before.

If we are looking for a benefit to Australia through Photonics, the Atmosphere Networks model has some attractions, but it too is not ideal. If the spin-off is a success, the CRC's equity stake will become very valuable, however the lions share of financial benefits will go to the US investors and US based senior management. Also, Atmosphere Networks' manufacturing function is being performed by another US company. In this respect, INDX is actually a better model because Uniphase Australia is building a manufacturing base in Australia.

Given the above, the optimum model for an Australian Photonics start-up would appear to include the following characteristics:

- VC funded (preferably from local institutions)
- Established corporate partner (not necessarily Australian)
- Australian R&D and manufacturing base
- US based sales, marketing and senior management

In INDX and Atmosphere Networks, we see some, but not all of these characteristics. If Milton Chang's prediction is correct, and provided that the Australian Government provides the necessary infra-structure and a conducive legal, regulatory, and tax framework, our relatively young technology industry should evolve over the next decade and gain critical mass. Ideally, more and more start-ups will posses more of the above characteristics. There is a clear model and precedent in the US for what we have to do to succeed in the commercialisation of technology. There would appear to be little downside in playing follow the leader.

Observation 32

In conclusion to the INDX story, there was no shortage of trade buyers, so arguably there was potential for a symbiotic relationship to be established with a large corporate partner (such as Uniphase or Galileo) once INDX had secured its ongoing financial viability. Such a partner would have provided INDX with access to the necessary distribution channels overseas. Unfortunately, due to lack of VC funding, this didn't happen, so the Uniphase acquisition was the best outcome under the circumstances.

Annex A

Communications Applications

Metropolitan and Local Area Network Technologies & Products

This is an area where Australia has a history of leadership in the development of technologies, products and systems. Photonics based Metropolitan Area Networks (MANs) and Local Area Networks (LANs) is the next logical step and both the Photonics CRC and the Broadband CRC have the necessary technology and product capabilities to develop and commercialise mixed DWDM and TDM / Packet based products for this market. Variants of these products can also be applied to FTTC and Home Network applications.

As shown in Figure 8, fast-moving companies such as Ciena are developing DWDM MANs for introduction to the market by the end of 1998. A spin-off company comprising researchers from Ericsson Telecom in Sweden is also believed to be focused on DWDM MAN applications. Similarly, the giants of the industry – Lucent and Hewlett Packard are working in these areas. The Australian Photonics CRC researchers thought they were focusing on MANs as a niche technology. The Mission proved that DWDM MANs are far from being "niche".

As indicated in Figure 4, Australia has a range of Photonics technologies that can be applied in the short-term to developing competitive products for these markets. These include:

- All-optical Packet Buffer-Insertion Technologies emerging from the MAWSON Project;
- Fibre-lasers (1550nm) and Optical Amplifiers;
- External Optical Modulators;
- DWDM Filters and Splitters/Couplers;
- Planar Optical Waveguides
- RF Microwave on Fibre

In addition to the above, there are two new technology developments needed for this market, being OA&M management of DWDM networks and IP over WDM (Internet-2) protocol developments. To this end, considerable benefit would be derived in having a joint product development project with the Broadband CRC and their spin-off company Atmosphere Networks. The Broadband CRC also has more experience then the Photonics CRC in the development of Media Access Control (MAC) protocols for Ring-based MANs and LANs.

In the longer term, Australia can provide "incremental improvements" to its Photonics MAN and LAN products through the development or acquisition of new technologies such as Integrated Optical and Electronic Circuits, Optical Switching Devices and higher bit-rate Optical TDM (OTDM) with all-optical packet address detection. For LAN applications, plastic (polymer) fibre is another technology to integrate for the final connection to the desktop.

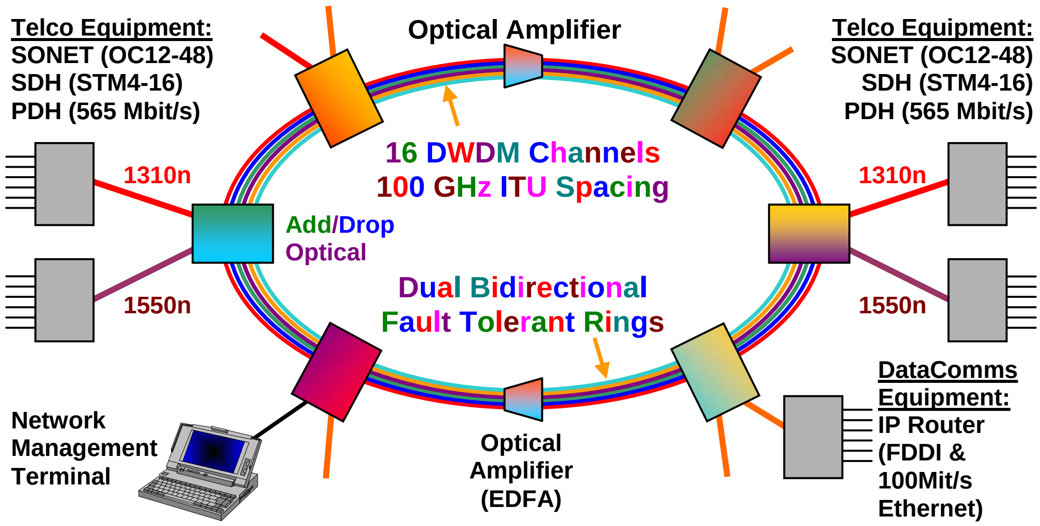


Figure 8 DWDM Based MAN and FTTC Networks

Optical Interconnect Technologies and Products

Optical Interconnects are optical micro-LAN networks used for connecting components within and between electronic equipment modules and racks. High speed optical backplanes for broadband switches, add/drop multiplexers, video servers, and multi-parallel computers are examples.

Currently, Australia is doing very little research in this area, even though it is likely to form the basis of many future broadband product implementations. The benefits of optical interconnects are increased bandwidth, reduced power consumption and reduced Electro Magnetic Interference (EMI) compared to existing electrical interconnect technologies.

As shown Figure 4, 30% of the organisations visited are working on these technologies. Much of the research in the USA is Defence funded for high performance computing and signal processing (needle-in-a-haystack) applications. With their new “dual-use” programs, these technologies can also be applied to medical applications, such as high performance image processors for the detection of cancer cells.

Hybrid FTTC, Copper and Radio Technologies & Products

The telecommunications carriers (Telcos) with an installed base of copper to the home (such as Telstra and British Telecom) have a more pragmatic approach to meeting end customer’s real needs. Customers basically want high quality services and in the case of telephony services, the existing copper and mobile phone network is adequate to met their needs.

However, the Telcos also realise that their customers now want high quality Internet services to the home, and that these services require increasingly greater bandwidth in all segments of the network, being the Core Network, the Access Network and the last segment to the Home. It is important to stress that customers basically want a higher quality service and this equates to “Bandwidth To The Home” (BTTH), but not necessarily “Fibre To The Home” (FTTH).

For example, the Telcos, can implement BTTH using Asymmetric Digital Subscriber Line (ADSL) technologies in the Customer Access Network using the existing copper-pairs. Up to 6 Mbit/s bandwidth can be provided in this way, which is 100x greater than customers already have. Alternatively, with the spread of Fibre To The Curb (FTTC), the Telcos can implement hybrid FTTC and high-speed XDSL technologies to deliver bandwidths of 50 Mbit/s to each home, again over existing copper-pairs. The same is true for the second and third carriers that are providing equivalent bandwidth services to the home over Hybrid Fibre Coax (HFC) networks and microwave radio distribution and mobile networks.

Figure 9 below illustrates the gradual erosion of the existing copper networks with optical fibre for increased bandwidth, and with radio for mobility. Two organisations visited considered the end-game to be FTTH and micro-cellular wireless (radio or infra-red) within the home. However, FTTH was not considered a high-priority for development and several of the organisations stated that commercial rollout of FTTH is not expected for 10-15 years. For the purpose of this report, it is even more important to realise that this timescale is driven by pragmatic cost issues associated with installing fibre to the home, and is not due to significant difficulties in implementing the FTTH technology itself.

Given the above, it is evident that for both the medium and long-term scenarios, that hybrid optical and electronic (copper or radio) technologies are needed to provide BTTH solutions. This highlights the importance of Integrated Optical and Electronic Circuits, which as indicated in Figure 4, is an area being researched by 50% of the organisations visited. Based on discussions with overseas organisations and with Australian researchers at UNSW and ANU, it was revealed that Australia has a leading capability in this area due to its relatively low temperature processes for producing planar optical waveguides. As a result, it feasible to integrate high speed CMOS electronic circuits with a range of optical waveguide circuits.
The benefits of this integration are increased performance and reduced cost. During the Mission, it was revealed by Cambridge Consultants that connecting optical pigtails to devices is a major cost component. This issue will be even more important for cost-sensitive FTTH, FTTC, MAN and LAN applications. By integrating the optical waveguide and electronic components onto a common substrate, this major cost element can be reduced significantly.

Examples of Integrated Optical and Electronic Circuit (IOEC) applications are:

- Add/Drop DWDM, Optical Packet Buffering, O/E Conversion, Packet MAC and IP Router;
- Add/Drop DWDM, O/E Conversion, SDH Framing and Add/Drop TDM Multiplexing; and
- Add/Drop DWDM, O/E Conversion, RF Frequency Tuning, RF Re-Transmission.

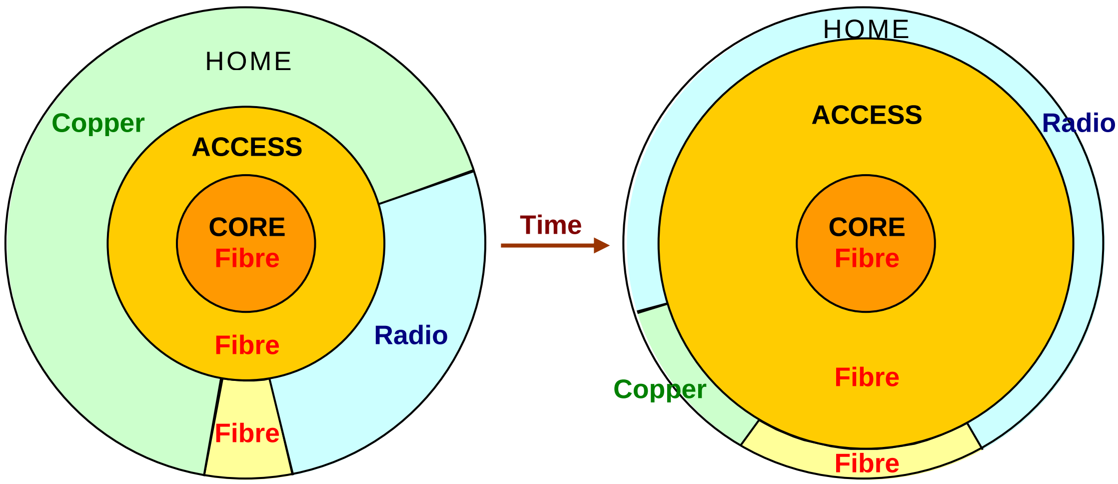


Figure 9 Fibre and Radio Migration to the Home

Annex B

Industrial Applications

Optical Sensing Technologies, Products & Systems

As seen from Figure 4, the only Photonics systems that Australian companies are currently involved in are sensing applications. These include optical fibre based smart structures and systems, such as for strain monitoring of bridges. This application is illustrated in Figure 10. In addition to being able to supply sensing systems, Australia is also supplying sensing products such as in-fibre Bragg Gratings. These products resulted from Australian technologies developed within the Photonics CRC.

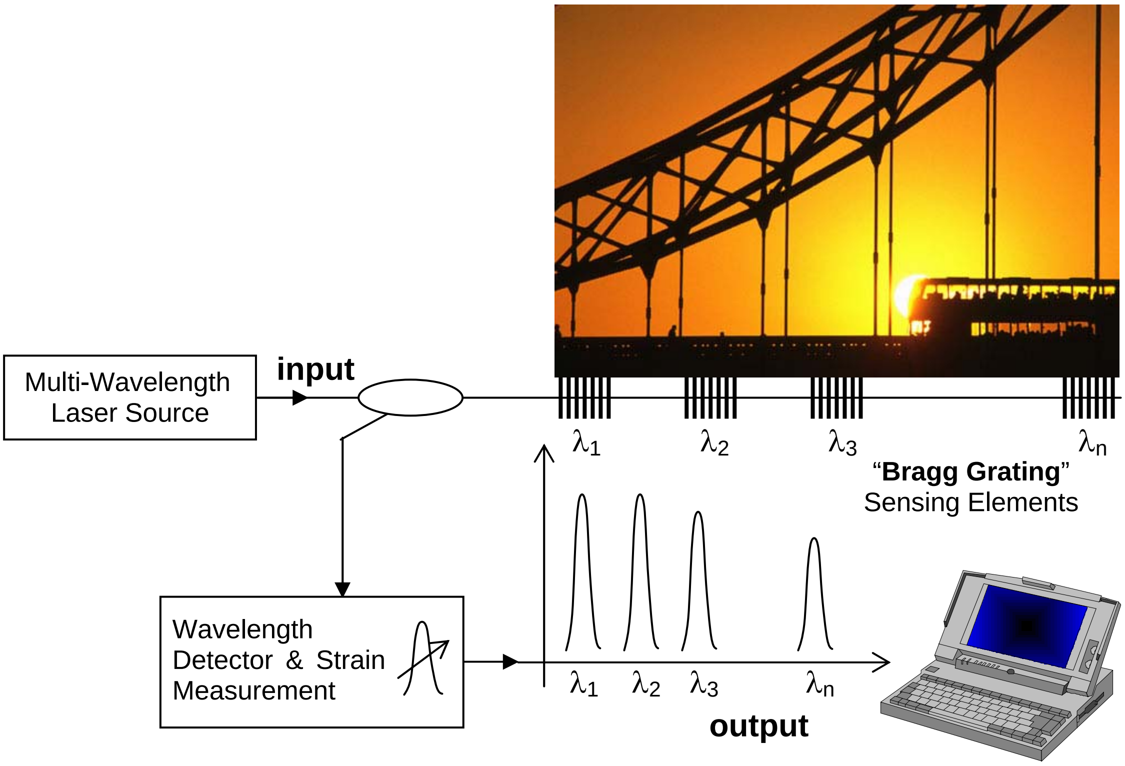


Figure 10 Distributed Optical Strain Sensors for Roads and Bridges

High voltage/current sensing is also included in the sensing systems category. This technology is still in the research and development phase in Australia, through a collaborative project with ABB in Sweden, with Transgrid as a potential local customer[3].

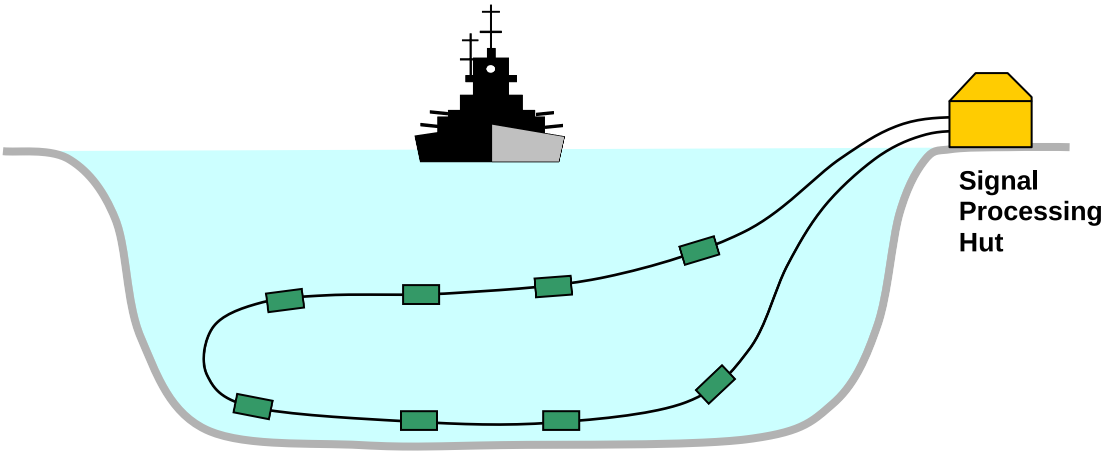
Australia has a lengthy history in the development of high power laser products for medical, industrial and sensing applications. This is reflected in Figure 4. Sensing applications including laser-ranging to a network of NASA satellites for detecting millimetre movements in the earth's crust and for measuring the depth of the ocean along a continental shelf.

As shown in Figure 4, Australia is also involved up to the systems level in fibre-optic surveillance applications. These may include Civil and Defence applications such as perimeter surveillance of prisons or military bases, and underwater acoustic surveillance for detecting illegal fishing boats or foreign navy vessels (ships and submarines). Both AWA Defence Industries (Research Laboratory) and AOFR developed extremely sensitive interferometer-based optical fibre sensors in the late 1980's, however, the technology was immature and hence was not commercialised into products at that time.

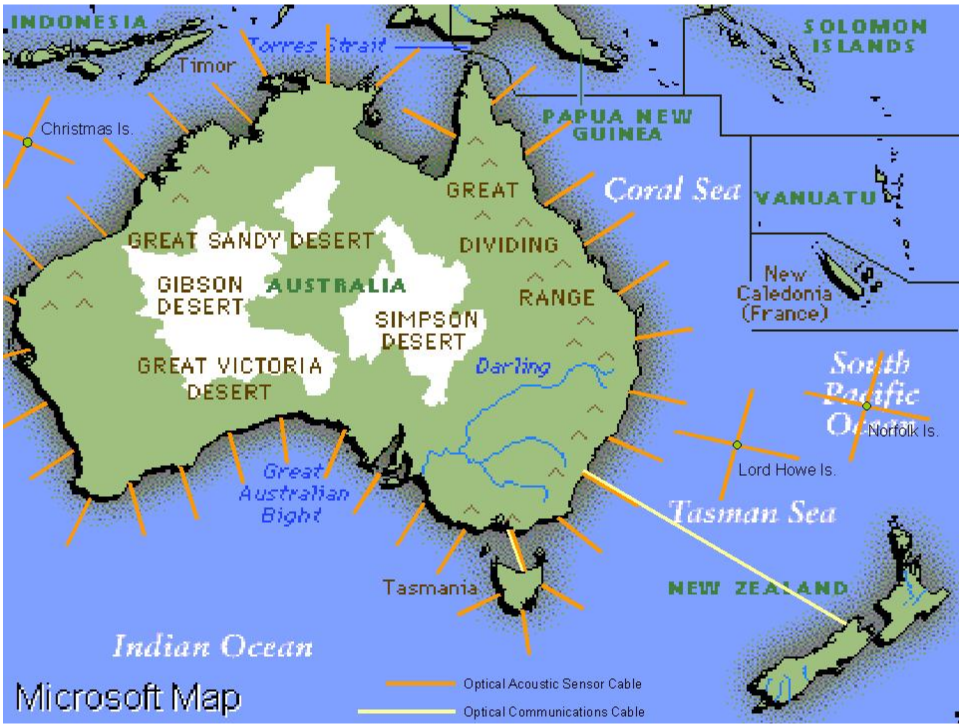
3 Unfortunately, there was no input from ABB to the table in Figure 4, since a visit to ABB in Sweden could not be organised given the timing of the Mission. It is therefore recommended that the table be upgraded in due course to reflect additional organisation's capabilities and the evolution of Photonics technologies in all organisations, including Australian organisations.

The visit to Navy Research Laboratories (NRL) in Washington DC highlighted that interferometer-based technologies have been developed to the systems level using both WDM and TDM multiplexing for distributed sensor applications. As illustrated in Figure 11a, NRL are now installing and testing interferometer-based products for fixed-array applications. NRL are also working with and licensing the technology to US companies to develop towed-array products as seismic activity detectors for oil exploration and Defence purposes. As illustrated in Figure 12, highly sensitive all-optical towed-arrays are ideal for the detection of submarines, surface combatants and illegal fishing vessels.

Clearly, Australian Photonics researchers have the capability and the technologies to work with DSTO and local Defence industries to develop both products and systems for underwater surveillance applications. In addition to the towed array applications, Figure 11b illustrates how the technology could be applied to protect Australia's coastline and its fishing resources.



a. Fibre-Optic Fixed Sensor Array - Installed by NRL in a Norwegian Fjord



b. Fibre-Optic Fixed Sensor Array – Potential Australian Application

Figure 11 Underwater Sensor Arrays for Defence Surveillance Applications

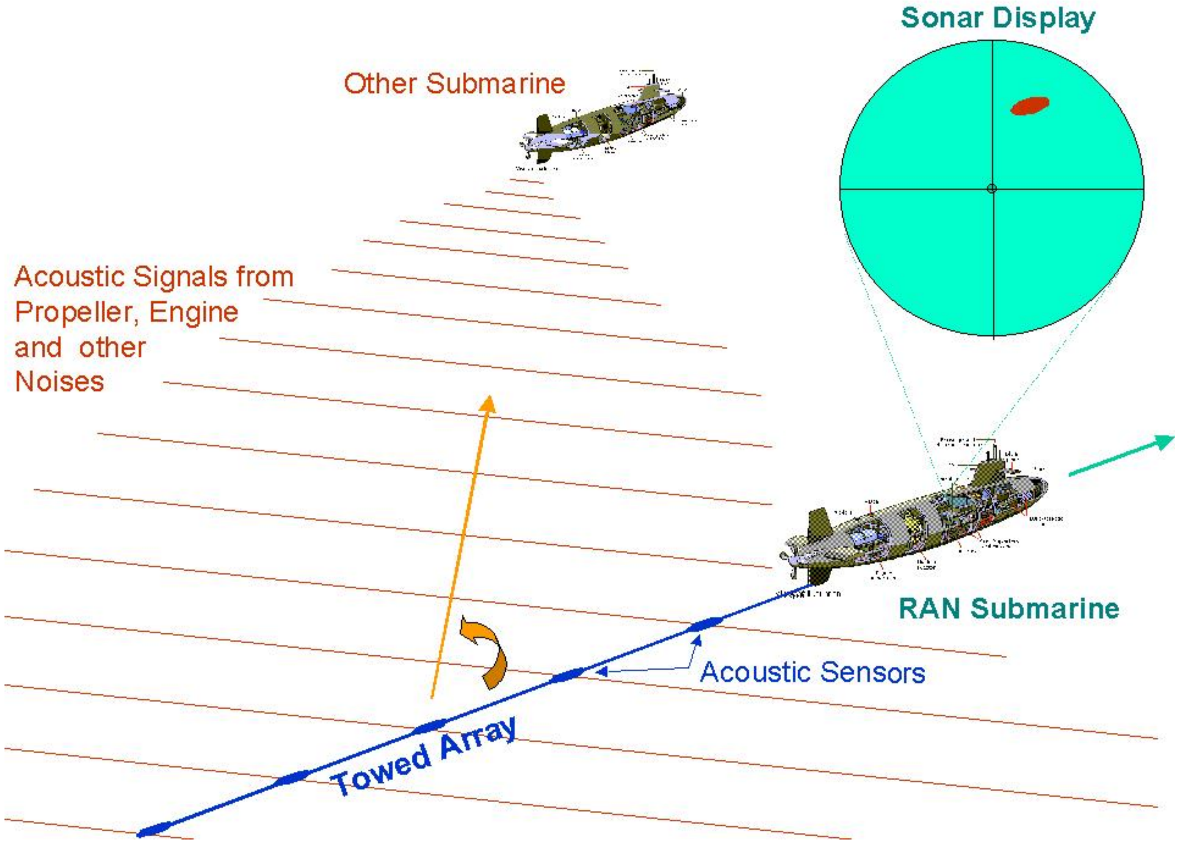


Figure 12 **All Optical Towed-Array for Defence & Commercial Applications**

Annex C

Glossary of Terms

Glossary of Terms

ADM **Add/Drop Multiplexer**

A component of a transmission system that can add or insert information into one of many channels and drop or receive information from one of many channels, each multiplexed onto a single optical waveguide (fibre or planar). Each channel may be a particular wavelength of light and/or a particular TDM slot in a SDH frame for example.

ADSL **Asymmetric Digital Subscriber Line**

This is a high speed modem technology that runs over the telephone lines between the telephone exchange and the home. Up to 6.144 Mbit/s downstream and 640 kbit/s upstream data rates are supported per twisted-pair line.

ASIC **Application Specific Integrated Circuit**

ATM **Asynchronous Transfer Mode**

A compromise of Channelised and Packetised TDM, aimed at meeting both time-continuous and bursty application requirements using a single cell-structure. Each ATM cell comprises a mini-packet of length 53 bytes which includes a mini-header of length 5 bytes. High priority and low priority cells can be allocated to continuous and bursty information respectively. The cell header contains a virtual channel number which is neither a destination or source address. There is no integrity checking of the cell information, only the cell header is checked.

ATM is well suited to providing virtual private networks that meet varying capacity requirements. ATM is still expensive compared to TDM for telephony applications and is proving inadequate for Internet applications due to its small header size and lack of information integrity checking. The separate Internet Protocol routers that must be associated with each ATM switch will in the future, negate the need for ATM switching if all telephony traffic is IP switched. Some MAN protocols, such as QPSX (also known as DQDB or SMDS), support both ATM cells and Channelised TDM on the same optical fibre and wavelength.

CATV **Cable TeleVision**

CDMA **Code Division Multiple Access**

CMOS **Complementary Metal Oxide Semiconductor**

CRC **Collaborative Research Centre**

CVD **Chemical Vapour Deposition**

DFB **Distributed Feed-Back** (as in laser)

DSTO **Defence Science and Technology Organisation** (Australia)

DQDB **Distributed Queue Dual Bus**

DWDM **Dense Wavelength Division Multiplexing**

A mature technology that now permits over 40 wavelengths of light to be sent down a single optical fibre. Each wavelength can independently transport multi-gigabit per second digital or microwave-frequency analog signals of any format.

EDFA **Erbium Doped Fibre Amplifier**

FDDI **Fibre Distributed Data Interface**

A dual-ring, Local Area Network protocol at 100 Mbit/s. Two options include FDDI-1 for packet-data only switching and FDDI-2 for packet-data switching and channelised TDM multiplexing and switching.

FTTC **Fibre To The Curb**

FTTH **Fibre To The Home**

IOEC **Integrated Optical and Electronic Circuit**

A future product based on the integration of planar optical waveguides and Silicon based semiconductors such as CMOS.

IP **Internet Protocol**

A TDM packet protocol for the multiplexing and switching of computer data, audio and compressed video between node on the world-wide Internet network (or web). IP packets can be easily switched to/from FDDI and Ethernet networks with minimum packet processing (eg, protocol conversion).

IR **Infra-Red**

IT&T **Information Technology and Telecommunications**

ITU **International Telecommunications Union** (previously CCITT)

LAN **Local Area Network**

LADS **Laser Airborne Depth Sounding**

LASER **Light Amplification by Stimulated Emission of Radiation**

MAN **Metropolitan Area Network**

MAWSON **Metropolitan Area Wavelength Switched Optical Network**

MNC **Multi National Corporation**

NMS **Network Management Station**

NRL **Navy Research Laboratories** (USA)

OA **Optical Amplifier**

OA&M **Operations Administration & Maintenance**

OFTC **Optical Fibre Technology Centre** (University of Sydney)

OTDM **Optical Time Division Multiplexing**

An all-optical packetised TDM network, generally targeted for 100 Gbit/s rates.

OTDR **Optical Time Domain Reflectometer**

PE-CVD **Plasma-Enhanced Chemical Vapour Deposition**

PRL **Photonics Research Laboratory** (University of Melbourne)

RADAR **RAdio Detection And Ranging**

RF **Radio Frequency**

REDCENTRE **Rapid Engineering Development Centre**

SDH **Synchronous Digital Hierarchy**

SDH is like SONET, a Channelised TDM multiplexing and transmission protocol specified by the International Telecommunications Union. A range of bit rates are supported, including: 155 Mbit/s, 622 Mbit/s and 2.4 Gbit/s.

SMDS **Switched Multi-megabit Data Service**

SME **Small to Medium Enterprise**

SONET **Synchronous Optical Network**

SONET is like SDH, a channelised TDM multiplexing and transmission protocol specified by the International Telecommunications Union. A range of bit rates are supported, including: 51 Mbit/s, 155 Mbit/s, 622 Mbit/s and 2.4 Gbit/s.

TDM **Time Division Multiplexing**

An old technology that permits multiple circuits or virtual circuits to be connected between nodes in a network and dynamically reconfigured at will to meet varying private network and traffic requirements.

Channelised TDM as used in SDH and SONET networks allocates integer multiples of 64 kbit/s to each circuit for the duration of the connection or call. Source and Destination address information is inferred by the channel numbers in a SDH/SONET frame. This multiplexing technique is well suited to time-continuous information.

Packetised TDM as used in FDDI and Ethernet networks, bundles a block of information (typically between 64 and 1500 bytes) into a packet and appends as a packet header, 48-bit source and destination addresses which are used to determine which node in a network receives the packet. Cyclic Redundancy Check bits are also added to the packet, thus adding a level of information integrity that Channelised TDM does not have. This multiplexing technique is well suited to bursty information.

The Internet network is based on the Packetised TDM approach. Some LAN protocols, such FDDI-2, support both Packetised and Channelised TDM on the same optical fibre and wavelength.

UV **Ultra Violet**

VC **Venture Capital**

VLSI **Very Large Scale Integration**

WDM **Wavelength Division Multiplexing**

A generic term meaning the simultaneous transmission of two or more wavelengths of light through an optical fibre.

XDSL **X - Digital Subscriber Line**

This is a generic term for any high speed modem technology that runs over the telephone lines between the telephone exchange and the home, or between a curb-side unit and the home. Up to 50 Mbit/s downstream and 4 Mbit/s upstream data rates are supported per twisted-pair line for the curb-side applications.

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