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Industry Canada Industrie Canada

APPLYING PHOTONICS

TO

TELECOMMUNICATIONS

Canada

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TO

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Prepared for

Industry Canada

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Photonics Sector Campaign

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EXECUTIVE SUMMARY

Vision:

In the course of this assignment, we have developed a vision of what is technically and commercially possible with respect to the application of photonics technology to Canadian designed telecommunications equipment. By building upon the world class applied research already underway in Canada, Canadian industry has the opportunity to remain world class in this field, apply its growing knowledge to equipment and services designs as a strong supplier to global markets.

Failure to build from the Canadian present position of technical and applications strength will lead to the gradual erosion of Canada's position as a globally competitive telecommunications equipment supplier and as a research and development powerhouse in that industry.

Background:

Under conservative assumptions, the worldwide telecommunications industry will triple in the decade of the 90's. Heavy purchases of manufactured telecommunications equipment are implied. If serious infrastructure investments are made in the developing world, the opportunities for telecommunications equipment manufacturers increases disproportionally.

Northern Telecom, Canada's flagship company in telecommunications equipment manufacturing, is now ranked fifth worldwide in sales. This company was built upon the application of custom silicon to telecommunications equipment coincident with the commercial restructuring of the telecommunications industry in the U.S.A. Northern Telecom's silicon applied research which started in a serious way in 1961 had significant payoffs in product designs one and two decades later. Products with significant sales volume enabled by that research reached market in 1972, 1975 and 1979. The competitive interval between applied research and product availability are much shorter today than they were then.

Many Canadian companies have been founded from the Northern Telecom base and many more are significant suppliers to Northern Telecom.

Again, a technology and commercial evolution is possible in the telecommunications equipment sector. This time, the technology is photonics rather than silicon and the commercial change is the combination of the worldwide liberation of telecommunications equipment trade and the possibility of large demands for equipment from the developing world.

Today, Canada has a competitive position in applied research in photonics applicable to telecommunications. While Bell-Northern Research is the only industrial laboratory conducting medium term applied research, a number of government and university-based laboratories are involved. There is an opportunity to encourage the movement of this technology toward commercial product quickly and to simultaneously introduce the technology efficiently to some of the smaller Canadian companies. The collective capability also exists in Canada for continued leading-edge photonics applied research which could position Canada well for several years for future photonics-based telecom products and services.

Rationale:

The prime interest in photonics for telecommunications comes from its potential to be the critical enabling technology for high bandwidth transport and switching. It is already abundantly clear that fibre-optic networks will dominate the future of the world communications transport infrastructure. It seems likely that photonics technologies, now at the applied research stage, will be employed commercially in the multiplexing and switching of this traffic.

The likely ability of photonics technologies to carry very large bandwidths and to cost effectively partition this bandwidth dynamically as the user may wish, will enable ubiquitous integrated voice, data, image and video communications capabilities. The resulting end user demand for highly intelligent personal communications devices and for a very responsive network delivering data and entertainment, will stimulate the use of photonics-based communications systems throughout the world. A competitive supplier of communications equipment will have to have excellent access to state-of-the-art photonics technology.

The long run average demand for bandwidth at the highest levels of the networks in the developed world is climbing at its traditional rate of about 8% to 12% annually. Photonics has already been applied to the transport function at the highest networking levels. A much wider application depends upon the end user market pull as described in the preceding paragraph. While the economics of this pull are speculative, it is widely believed that the pull will indeed develop.

The rate of development of a broadly based pull for photonics capabilities depends upon the development of applications and the price of delivered bandwidth. The price of bandwidth is largely a regulatory issue (See p. 26).

Canada should put its industry in a position to benefit when the major swing to ubiquitous photonics based telecommunication equipment starts. The applied research base must be maintained and expanded under the assumption that international competitors to Canadian companies will probably expand their efforts as more firm indications of market pull are seen. Incentives should also be provided now to promote the early movement of the results of applied research toward exploratory equipment design in the face of continued uncertainty as to end user requirements. To do otherwise will significantly increase the risk that Canadian industry is insufficiently prepared when the expected acceptance of photonics technology occurs.

The system designer is key to generating a viable vision for the end user. Incentives must thus go to the exploratory system designer in the current time frame.

The study reported here looks for practical means of spurring the movement of photonics technology from the applied research environment into the exploratory equipment design arena and then on to the profitable production of product.

Opportunities and Barriers:

We have the opportunity now to accelerate the movement of five key components of photonics-based telecommunications equipment into serious exploratory systems development. These components are: photonic backplanes; components for an ATM switch; components for wavelength division multiplexing; a solid sate waveguide and the heterojunction bipolar transistor.

Northern Telecom has indicated its willingness to participate cooperatively with other Canadian companies in photonic applications.

The major barrier to serious private sector funded exploratory systems design work is the lack of well quantified technology/market research results which identifies specific applications, their bandwidth usage profiles and acceptable price points. The barrier to the serious involvement of the SME's in particular, is their need to invest now for a mid term product opportunity in an uncertain market. Their financial structures allow only for short term payback investments.

Recommendation: Achieving the Vision

Given the uncertainty in the timing of the market demand, the likelihood of a very rapid rate of product introduction once the vision of the practical capabilities of photonics-based product dawns on the end user and the Canadian opportunity to build quickly upon a strong commercial and technology base, we must foster private-public cooperation to:

- strengthen the ability of Canadian organizations to develop and market innovative photonics-based telecommunications products and services; and

- promote proactive supplier development, proactive technology standardization and human resource development.

The key to both the early development of a user vision of the practicality of photonics-based systems and to the early availability of cost effective product is to support the exploratory systems designer. We can initially focus on the five key components of photonics-based telecommunications equipment identified above. By encouraging the larger companies to involve some of the smaller companies in exploratory product decisions and subsystem supply, we can provide a widely available systems design capability for SMEs which they could not otherwise afford.

This enables the pull through of technologies to commercialization beyond the narrow product window of its first application within the SME and will significantly improve the prospects of the SMEs (See p. 30).

Although we have emphasized the need for exploratory development of product, we must also make provision for the increased support of Canadian photonics applied research because competitors are likely to increase their efforts as the market pull for product develops. Specifically, we should further coordinate the efforts of our existing applied research facilities to maintain a world class capability and encourage collaborative efforts.

User vision will be developed most quickly through marketing experiments and demonstrations of equipment capabilities. We therefore recommend that provision be made for some support of demonstrations/applications development in Canada. We note that CANARIE provides an important demonstrations/applications development vehicle, but it may be necessary to enhance this with specific support for photonics-based work.

We believe that all of the above recommendations can be best coordinated in practical application by forming a private-sector-led Photonics Consortium which:

- is initially based within SSOC;

- will eventually become an umbrella organization through which public support of photonics technology for all applications can be orchestrated;

- is made up of several well defined categories of membership and where these categories are representative of the phases of technology migration from research through to commercial product; and

- is cooperatively funded by the private and public sectors on a staged basis to manage Phase III of the Photonics Sector Campaign.

Details of this proposed Photonics Consortium will be found starting on page 40.

Over a two Stage Phase III Campaign, federal funds in the range of $110 million to $160 million will be needed within a five year program having a total estimated cost of $405 million (See page 50, 3).

We believe that this proposal initiates the action required and avoids the problems which have been associated with various foreign consortia which have had similar aims in other fields of endeavour. In particular, a private-public partnership is proposed to leverage Canada into a position of being a major world participant in photonics-based telecommunications products and services in the face of the inevitable international competitive market.

1.0 THIS ASSIGNMENT

1.1 The Scope of this Study

This study examines opportunities and barriers relevant to the application of photonics to telecommunications. Photonics, defined in this study as advanced light-based technologies, includes such products as lasers, optical fibres, optoelectronic devices, optical sensors, etc. Worldwide production of photonics components and subsystems was $29 billion in 1989 and is forecast to increase to over $230 billion by the year 2000.[1]

In the 1970s and 1980s, silicon semiconductor technology revolutionized the electronics industry. Canada had a reasonably integrated component/system capability in telecommunications silicon, and several Canadian telecommunications equipment suppliers were able to become world-class players. Now, photonics is emerging as one of the dominant technologies that will accelerate the transition to the new information economy.

In 1990, Industry, Science and Technology Canada (ISTC) commenced Phase I of a Photonics Sector Campaign, commissioning a study by Elliott Consulting[1] to make a preliminary assessment of the economic potential for the application of photonics to Canadian industry. Based on consultations with 42 Canadian and 20 foreign firms, the study identified a number of opportunity areas and concluded that there were major opportunities for Canadian firms in three sectors: industrial applications, avionics and telecommunications.

The Phase I results were sufficiently encouraging that ISTC decided to proceed with Phase II of the Photonics Sector Campaign, with the objectives of identifying specific business opportunities for Canadian firms arising from the application of photonics, as well as any barriers that may hamper Canadian companies in the effective pursuit of these opportunities, and finally, to recommend strategic approaches for the development of the Canadian photonics sector.

An Industry Steering Committee consisting of key representatives from the private sector and from major public sector research organizations was established to provide input and advice to ISTC during Phase II. A number of activities are being undertaken under this campaign, including an assessment of photonics technology development world-wide and two study contracts to identify opportunities in photonics for Canadian firms, one of which is reported on here.

The output of this study includes, in addition to the identification of business opportunities for the application of photonics technology in Canada, recommendations for mechanisms and structures to start the removal of barriers to the application of non-commodity photonics technologies to telecommunications system design and the dissemination of these technologies to Canadian companies. An estimate of the costs is included.

A parallel contract is examining the application of photonics to other promising sectors, particularly manufacturing and avionics. The recommendations flowing from the two studies will be used by Industry and Science Canada as the major elements of a proposal for an Action Plan for implementation in Phase III of the Photonics Sector Campaign.

1.2 Our Methods

In carrying out the analytical part of this assignment, we have used a three-stage approach:

- an examination of the elements essential to the generation of a sustainable photonics sector - technology, scientific capability, marketing and production capabilities, financial strengths, and managerial willingness;
- synthesis of a vision of potential opportunities, given the realities of these findings; and
- tuning of the vision to obtain acceptance of the involved parties and securing their willingness to proceed in implementing the vision.

A literature search was conducted on current and near future usage of photonics in telecommunications with emphasis on technical trends, the capabilities of present producers of materials, devices, equipment and systems, and the expectation of users.

Critical information on the real capabilities and intentions of key firms and laboratories was gathered through twelve in-person interviews. Information from other firms that were potential participants in the development of the business opportunities was gathered through nineteen telephone interviews. A list of the organizations and persons interviewed is contained in Annex A.

The data gathered from the interviews were analyzed and the key issues were identified (see Subsection 2.5 of this report) and several alternative methods for overcoming the obstacles to success were postulated. These ideas were then discussed in focus group format with four private sector and four research community representatives (see Annex B for the list of attendees and the minutes of the focus group meeting).

A working model for encouraging new business opportunities, which was discussed by the focus group, was refined. The proposed model, which will, in our opinion, overcome some of the structural barriers that were identified during this study, is discussed in Subsections 3.2 and 3.3.

Several specific opportunities that could use the proposed model were identified and discussed with the potential participants on a one-on-one basis. These opportunities are presented in Subsection 3.4. Finally, the resources required to put the proposed model in place were estimated, and are reported in Subsection 3.6.

2.0 OUR OBSERVATIONS

2.1 Trends in Telecommunications Business Which Might Use Photonics

With technological change and regulatory liberalization driving its rapid expansion, the global telecommunications market is truly dynamic, with an enormous growth potential. Even today the worldwide telecommunications market is huge. In 1989, Northern Business Information (NBI), a New York-based telecommunications-consulting firm well respected in the industry, estimated the global telecommunications market at $389.5 billion (1989 U.S. dollars)[2]. Northern Business Information projects that the industry will grow to U.S. $566.6 billion by 1993, and to more than U.S. $1.3 trillion by the year 2000. The scene is set, however, for an even more explosive growth than these projections would indicate. As yet, the largest part of the world market remains undeveloped. Certain major economies, such as China, India, Indonesia, and the Soviet Union are virtually untouched. If these economies take off, a tripling or quadrupling, of even the forecast market by the early years of the next century is possible.

Telecommunications and computer technology sit at the heart of the information revolution. Together they constitute one of the world's fastest growing and strategically most important industries. Much of the impetus for this market growth comes from rapid and far-reaching advances in telecommunications technology. During the 1980s, three major technological innovations - digital switches; fibre-optic transmission; and wireless communications - drove the fundamental changes in telecommunications networks and in the telecommunications industry worldwide. These same three, together with advanced software and associated hardware computer technologies, will continue to drive the telecommunications industry in the 1990s. It is possible, in fact, that the convergence of telecommunications and computer technology could spur growth beyond anything previously experienced.

There are substantial implications for "free space" frequency spectrum allocations in this development. Spectrum is limited by the laws of physics. PCN will put free space spectrum at a premium. In turn this is likely to move certain telecommunication transmissions to cable in the near future.

The increasing trend toward market liberalization and deregulation is also encouraging greater use of cable TV facilities for two-way switched traffic rather than just one-way reception. This trend could lead to true video telecommunications, including "video dial tone", provided competitively by telephone companies. If this does come about there will be a huge increase in demand for bandwidth. This will impact right down to the end user's contact point. It would imply the necessity of extending fibre-optics as far as possible.

Fibre-optics is especially significant. It is the major volume application of photonic technology in telecommunications. It was only in the latter half of the 1980s that optical fibre became the "transmission technology of choice" for a broad spectrum of applications. Until recently, however, fibre was only cost-effective in high-volume, long-distance networks and in intra switching machine links (i.e., voice and data short haul trunking). But this situation is changing. Systems using optical fibre and optoelectronics are increasingly becoming cost-competitive with copper-based systems for the "last mile" to the subscribers' premises for telecommunications and CATV. Together, optical fibre and digital communications provide high-speed information processing and high-bandwidth transmission throughout the network. These technologies provide a network that is simpler and more cost-effective to operate.

Until recently, the worldwide telecommunications market was dominated by protected national monopolies. Most countries had their own Post, Telegraph and Telephone (PTT) organizations, or equivalent administrative systems, that controlled almost everything related to communications. Typically, the national equipment suppliers enjoyed privileged relationships with their national operating companies. In addition, the close relationship between PTTs and a country's indigenous vendors protected domestic service and equipment suppliers, while promoting national network compatibility and universal service.

Today, a trend toward market liberalization is sweeping through the international telecommunications industry, opening the marketplace to competition. In the U.S., deregulation and divestiture began in earnest with the 1968 *Carterfone* case. It was the effects of that decision, which allowed customers to connect their own equipment to the telephone network, that culminated in the 1984 breakup of the U.S. Bell system. In such newly liberalized regulatory environments, a loosening of the relationships between domestic equipment suppliers and operating companies has accompanied the introduction of competitive services.

This growing liberalization in the world telecommunications market presents unprecedented opportunities for equipment and service suppliers. At the same time, of course, these companies must compete - and win - in an increasingly competitive global marketplace. The equipment suppliers must offer the most modern, serviceable and flexible equipment to the marketplace.

Nevertheless, despite this undeniable growth potential, in developed countries some market segments are at, or approaching, saturation. The switching fabric has been heavily digitized and backbone fibre routes have been installed during the past five to seven years. Telephone utilities with their defined geographic coverage are showing signs of being slow-growth companies.

Moreover, telecommunications utilities are increasingly dependent upon their equipment suppliers to provide the lead in equipment specification. This is in large part because the margins available to the utilities are shrinking (and in the face of competition in a deregulated market likely to further erode) and they are no longer investing in product development or even new product specifications. The cable TV industry in Canada has also not invested significantly in new product development or new product specification activity. In this vacuum the equipment supplier is the logical and necessary focus for R&D.

Northern Telecom, Canada's flagship company in telecommunications equipment manufacturing, is now ranked fifth worldwide in sales. This company was built upon the application of custom silicon to telecommunications equipment coincident with the commercial restructuring of the telecommunications industry in the U.S.A. Northern Telecom's silicon applied research which started in a serious way in 1961 had significant payoffs in product designs one and two decades later. Products with significant sales volume enabled by that research reached market in 1972, 1975 and 1979. The competitive interval between applied research and product availability are much shorter today than they were then.

Again, a technology and commercial evolution is possible in the telecommunications equipment sector. This time, the technology is photonics rather than silicon and the commercial change is the combination of the worldwide liberation of telecommunications equipment trade and the possibility of large demands for equipment from the developing world.

Today, many new opportunities for specialty products and markets are surfacing in the industry, and new players are entering the field. With the rapid increase of variety in telecommunications, medium-sized companies - such as Newbridge, Gandalf, and NovAtel in Canada - are typically focusing on a particular market segment. There is a growing understanding among system designers that applications demand is lagging their potential to deliver bandwidth. There is therefore broad support among system designers for applications studies, experiments and demonstrations in the hope that a genuine market pull for bandwidth will again develop.

2.2 Trends in Relevant Technologies

Our interests lie primarily in the photonics technologies which are not yet commodities. We will therefore not address commodity technologies, such as displays, utility fibre or utility lasers and detectors. Rather, our interest is in the system design possibilities of emerging high bandwidth applications. We include advanced concepts, such as the possibilities of optical interconnection at the board or backplane level, as these technologies may be critical to the implementation of switching and multiplexing functions at high bandwidth.

Digital communications over fibre-optic cable has become the preferred mode of communication for the fundamental reasons of its immunity to noise, its bandwidth potential and its low signal attenuation. As noted in the preceding subsection, fibre optics is in widespread use in long-distance networks - in transoceanic cables, for intercity trunks, interoffice trunks, etc. In 1991, about 5.6 million km of fibre-optic cable were installed worldwide, and the installed amount is expected to double by 1995[3]. While fibre is becoming cost-competitive with copper-based systems in local distribution, the full deployment of fibre optics in local loops, however, is not expected to materialize until well into the next century.

Since the beginning, the evolution of fibre-optics communications technology has mainly been in the exploitation of the properties of silica-based glass fibres, i.e., short wavelength (840 nm) to longer wavelengths (1300 and 1550 nm), multi-mode to single-mode fibre, etc. The use of single-mode fibres eliminates modal dispersion, but chromatic dispersion is still present even in digital systems, since light of slightly different wavelengths within the output spectrum of a semiconductor laser travels at different speeds. Chromatic dispersion forces a trade-off between the spacing of repeaters and the effective bit rate. The introduction of single-mode dispersion-shifted fibres has alleviated this problem to some extent.

Distributed-feedback lasers, which produce output in a very narrow lasing spectrum, even when modulated at high speeds, has further reduced pulse broadening. Surface-emitting distributed-feedback lasers have now been produced experimentally with narrow beam angles, thus making coupling to fibres more efficient.

The technology evolution is nearing the end for long-distance communications, with attenuation of commercially available fibres lowered to the theoretical limit, and fibre designs modified so that the wavelength of zero dispersion shifted (in the dispersion-shifted fibre) to coincide with the wavelength of minimum attenuation. Other fibre materials have been examined with limited success, due to fundamental problems such as difficulties in making high strength fibres. With the recent introduction of optical amplifiers, the need for lower loss fibres has receded. With the lasers and detectors required for these systems now available commercially, it will be reasonable to assume that silica-based fibres will remain as the preferred means for long distance telecommunications and that the optical amplifier will be used extensively.

A means of overcoming the bandwidth limitation due to dispersion has been discovered utilizing two non-linear optical properties of fibres to allow soliton (high energy waves) transmission. The feasibility of soliton transmission over distances equivalent to transoceanic distances has been demonstrated in a simulated link in a laboratory, with optical amplifiers to overcome fibre attenuation losses. A bandwidth/distance product of 125 km-Tb/s has been achieved, which equates to the transmission of 10 Gb/s over 12,500 km. This may eliminate the need for repeaters on intercontinental transmission systems, and by implication, their total elimination. High power lasers and improved laser-to-fibre coupling are key to its practical implementation.

As the deployment of fibre optics penetrates beyond trunk applications, a wide variety of technologies will emerge, for example, passive and active components such as splitters, couplers, modulators, optical switches, etc. Optical amplifiers may also play a key role. For example, a head-end optical power amplifier might be required for analog video transmission. In spite of the excellent linearity and power handling capability of the currently available erbium-doped fibre amplifier, its operating wavelength of 1550 nm and the large chromatic dispersion of the conventional single-mode fibre preclude this approach. What would be required would be a chromatic dispersion compensator, an amplifier for 1300 nm, or the installation of dispersion-shifted fibres.

The most dramatic optical technologies will emerge for very short distance transmission, for example, for distances of 1 m or less, where a backplane may be connected by polymer optical waveguides, and passive and active components integrated on a chip, with the functional elements within the chip interconnected by channel waveguides. Furthermore, free space optical communication between electronic chip and the mother board, chip-to-chip and board-to-board will overcome several of the current and anticipated problems of VLSI technology, such as pin-out.

Very high speed bipolar transistors may be fabricated from the same materials (III-V compounds) as many optical devices, and share many of the fundamental physics and device engineering solutions. Advances are being made in the integration of optical and electronic functions on the same substrate. Such advances are important to the production cost of subsystems. The integration of several optical functions on a single substrate is the goal of many research programs around the world. Of particular interest is the integration of a laser, a waveguide with built-in amplifier and a detector. Realization of a reliable laser on a silicon substrate is a significant issue.

Any large telecommunications switch must perform both time and space switching functions. The vertical-to-surface-transmission electro-photonic devices (VSTEPs), which are essentially a vertical stack of different heterostructure elements that generate a functional optical operation, can exhibit optical bistable switching characteristics. They are suitable for two-dimensional integration, and, therefore, parallel integration, i.e. they will permit horizontal electronic interconnection and vertical optical input and output. Many other types of bistable devices have been demonstrated, and a bistable optical device whose transmission can be controlled by another optical beam - an optical "triode" - has now been demonstrated.

Wavelength division multiplexing (WDM) enables the capacity of transmission systems to be increased by the use of multiple beams of light carried in a single fibre without interaction. WDM holds promise for both space switching and transmission applications. The issue of coherent detection of light transmission has receded recently due to the enormous bandwidths promised through WDM techniques, which are likely to be more readily implemented.

Standards development will play an important role in making photonics-based equipment deployable. Recent examples of standards being developed concurrent with equipment development are the synchronous optical network (SONET) protocol, which defines a set of standards for a synchronous optical hierarchy that has the flexibility to transport many digital signals that have different capacities, and the asynchronous transfer mode (ATM) protocol, which combines the capabilities of time division multiplexing and packet switching to permit the transport and switching of a wide variety of services carried on a broadband integrated services digital network.

In summary, applied research is being carried out on a very broad front for the application of photonics capabilities to telecommunications.

2.3 Canadian Capabilities

Canada's telecommunications equipment sector[4] is dominated by one large Canadian-based multinational systems house, Northern Telecom. It also includes a number of branch plants of foreign-based firms, several medium-sized suppliers, a series of smaller product development companies, and several systems integrators. There are about 500 firms in all. The sector is involved in the production and marketing of a broad spectrum of systems and equipment used in the public switched network, in private networks and by end users, and has an annual Canadian production in the range of $6 billion.

In photonics-based telecommunications technology, the dominance of Northern Telecom is even more striking. Other than Northern Telecom, the main photonics expertise resides in 15 to 20 small companies whose sales range from less than $1 million to about $50 million. These companies are mainly suppliers of test equipment and sub-components, and lack large system design capability. Their time horizons are necessarily extremely short, and are dependent upon larger laboratories for the generation of the technology that they in turn apply to their niche markets. Bell-Northern Research, which is owned jointly by Northern Telecom and Bell Canada, is the only Canadian industrial laboratory that is carrying on medium-term research activities in photonics technology for application in telecommunications.

Canadian capability in photonics R&D is enhanced by the existence of a number of government and university-based laboratories and by several R&D consortia. In the following subsections, we will give a brief description of some of the more important components of Canada's photonics R&D capability of relevance for telecommunications applications.

2.3.1 Bell-Northern Research

Bell-Northern Research (BNR) is jointly owned and funded by Northern Telecom and Bell Canada. With the acquisition by Northern Telecom of STC and its research laboratory STL, located in the U.K., BNR's photonics research is carried out in both Canada and the U.K. This subsection describes the activities and capabilities only of the Canadian facility.

BNR's photonics activities fall into two broad categories:

- system design and testing of long-distance high-speed transmission systems; and
- optoelectronic component development.

The main thrust is on the former activity, with more than 100 researchers working on various aspects of the technology.

BNR has capabilities as a systems designer and as a systems integrator, as well as a component supplier and subsystem assembler. BNR has capabilities for modelling, simulating and testing long-distance high-speed transmission links for speeds of up to 10 Gb/s. Several optical amplifiers are available and can be incorporated to simulate a long distance link. Device design and fabrication capabilities include laser diodes, external modulators and heterojunction bipolar transistors, all as part of the development of 10 Gb/s transmission systems. Major capital equipment includes facilities for molecular beam epitaxy, chemical beam epitaxy and metal oxide chemical vapour deposition, and a 10 Gb/s bit-error-rate test set. BNR has the only facility in Canada for the testing of long-distance extremely high-speed links.
BNR also makes use of external laboratories for exploratory work, because its mandate is primarily for product development work and also because laboratory facilities are becoming increasingly capital intensive and specialized.

2.3.2 Solid State Optoelectronics Consortium

The Solid State Optoelectronics Consortium (SSOC) was established in 1988 as a research consortium with the mission to create a Canadian capability in integrated optoelectronics research and to establish an environment and infrastructure that will enable Canadian industry to achieve leadership in the introduction and profitable exploitation of systems and products based on this technology.

SSOC's activities have progressed from the establishment of the facility and the development of advanced discrete devices in the first two years, to the development of integrable advanced devices for the chosen technology demonstrator, a wavelength dependent processor. Its current emphasis is in the direction of systems and applications.

At present there are eleven members in SSOC, seven of which are from the private sector, including BNR, EG&G Optoelectronics Canada and MPR Teltech Ltd. Public sector members include the National Optics Institute, the Communications Research Centre and TRLabs, as well as the National Research Council (NRC).

SSOC's annual budget is approximately $1.5 million, with the major part of this amount coming from membership fees and member contributions in-kind. NRC provides research facilities and provides matching funding of up to $2 million to one of its own programs, the SSOC/NRC program, managing this program as part of the SSOC program. In addition, the related activities of the NRC Institute for Microstructural Sciences (IMS) (see Subsection 2.3.3), funded to approximately $4 million annually, are coordinated as far as possible with the SSOC program. Thus, SSOC has leverage on nearly $8 million of funding, 75% of which is provided by NRC. The initial collaborative research agreement was signed for a five-year period (1989-1994). Discussions are now under way on the continuation of SSOC.

The facilities of SSOC are collocated with IMS, occupying 700 m^2 of floor space, 300 m^2 of which are dedicated to a clean room. The staff consists of approximately 20 researchers. SSOC has capabilities for material processing, device fabrication, modelling, design and testing of GaAs and InP-based devices. Actual devices that have been fabricated include superluminescent diodes, optical amplifiers, waveguides, wavelength division multiplexers, modulators, detectors, surface emitting lasers, blue-green light sources based on a second harmonic integrated generator, microwave spectrometer, etc.

The clean room contains a chemical beam epitaxy facility, and is supported by extensive facilities and equipment from IMS, including a molecular beam epitaxy system, a focused ion beam processing system, x-ray photoluminescence and Raman spectrometers, an electron beam writer, reactive ion etching, etc. All of the facilities are state-of-the-art, with approximately a third of the facilities having been developed jointly with equipment suppliers.

In addition to the support received from IMS, SSOC's activities are also supported by the expertise of the consortium members. This arrangement focuses the research topics to meet industry's needs and also facilitates the transfer of technology to industry.

2.3.3 National Research Council

In addition to the activities described above under SSOC, the Institute of Microstructural Sciences (IMS) of the National Research Council carries out a number of related photonics activities in the following areas:

- Optoelectronic devices: demonstrating proof-of-concept novel optoelectronic devices for high-speed communication uses;
- Device physics: research on electrical and optoelectronic devices with the aim of understanding the physical processes that are important to the operation of the devices;
- Advanced laser technology and applications: research in selected areas of advanced laser technology, such as microchip Nd:YAG lasers, intra-cavity frequency doubling and excimer lasers;
- Microfabrication: facilities such as lithography (optical, electron beam and ion beam), focused ion beam; and
- Molecular beam epitaxy: for the epitaxial deposition of semiconductors, particularly for exploratory research of novel optoelectronic device architecture.

Photonics research activities and capabilities exist in several other NRC Institutes. The Institute for Information Technology (IIT) has a program in photonics systems, working on systems level applications of photonics in high performance computers, optical interconnections in and between computers and sensing, new paradigms in parallel computing for pattern recognition with the use of photonics. IIT collaborates with a number of Canadian telecommunications companies, including BNR and MPB Technologies, and with several Canadian universities.

The Industrial Materials Institute (IMI) is a world leader in the field of material inspection using laser ultrasound. IMI has a line focused-beam scanning acoustic microscope, which is used for material inspection of fibre, semiconductor devices and active and passive components. It is the only such operational facility outside Japan.

The Institute for National Measurement Standard has expertise and facilities for the calibrations of photonics components, such as detectors, filters and light sources.

2.3.4 National Optics Institute

The National Optics Institute (NOI) was founded in 1985 jointly by the Federal Government and by the Province of Quebec to bolster the Canadian optics industry. NOI has a staff of approximately 85, including 50 researchers. It has various lasers covering the spectrum from sub-millimetre to the UV, including tunable lasers and fibre lasers; fibre fabrication facilities; a crystal growth facility; a diamond-like coating (DLC) system and a laser pantography system. NOI provides R&D and assistance to Canadian firms on a contract basis in the following areas:

- Optical design and testing: design, fabrication and testing capabilities for binary and holographic diffractive optical elements, in addition to conventional optical systems;

- Optical coating: mirror coating for lasers, DLC coating for protection, metal coating for fibre-device packaging and for fabrication of active planar devices;

- Waveguide design, fabrication and testing: specialty fibre fabrication such as Er-doped fibre for optical amplifiers, fabrication of polymer and high silica planar waveguide, active devices based on lithium niobate and proton exchanged lithium tantalate and fibre-device interconnection technology, BPM CAD software for device design;

- Micromachining and pantography: IC repair and modification, Si etching, waveguide and photomask fabrication by direct writing;

- Laser applications: metrology, sensors and processing; and
- Optical information processing: design and test bench of spatial light modulator, industrial inspection, digital processing of visual information.

The facilities and equipment of NOI are state-of-the-art, and were designed and are being operated to fulfil industry's needs for optics or photonics technologies. The global capability of NOI, which includes not only the equipment but also the staff skills, design knowledge and know-how, and software for modelling, makes it unique in its field. NOI is attracting research contracts, not only from Canadian firms, but also from the U.S., Europe and Japan.

From the viewpoint of photonics technology for telecommunications applications, NOI can serve as a development laboratory for components such as passive and active devices, special fibres, optical coating, packaging of optical components and optical interconnect.

NOI is supported by eleven industrial affiliate members and fourteen industrial associate members. Its budget in 1992 was approximately $10 million. In 1992-93, more than 30% of its activities were directly supported by industry. This percentage should gradually increase to 50%. During its initial five years of operation (1985-1990), NOI received government grants totalling $18 million. NOI's mandate has been renewed for another five years (1990-1995), during which period it will receive additional government funding of $36 million.

2.3.5 Communications Research Centre

The Communications Research Centre (CRC) is the federal Department of Communications' major research facility, with a staff of over 250 and an annual budget of nearly $50 million. About 2% of these resources are applied to the following three activities that are relevant to the application of photonics to telecommunications:

- Optoelectronics: development of advanced hybrid optoelectronics circuits, including the growth of alternative semiconductor materials, such as GaInAs, and design and fabrication of new optoelectronic devices and optical waveguide structures that will permit optoelectronic components to be integrated with microwave and high-speed digital technologies;
- Optical communications: research to extend the photonic network to the subscriber, including the development of wavelength tunable passive components, sources and detectors; and
- Non-linear optical materials: development of non-linear materials for use in optical switching, optical logic and high-frequency conversion.

2.3.6 University Networks of Excellence

Photonics-related research in Canadian universities takes place in a number of universities. Many of which are loosely organized into networks of excellence, three of which are described below.

Canadian Institute for Telecommunications Research

The Canadian Institute for Telecommunications Research (CITR) is a federally supported Network of Centres of Excellence with the objective of enhancing the competitiveness of the Canadian telecommunications industry through university-based post-graduate studies and research. It is funded by the Natural Sciences and Engineering Research Council (NSERC) to a total of approximately $15 million for an initial 4-year period which expires in July 1994. At that time, CITR's mandate will probably be renewed for another term.

CITR carries out market-oriented, pre-competitive research at 17 Canadian universities and research centres. The following universities and centres carry out photonics-related research under CITR's Optoelectronics Devices and Systems program, which had a budget of $705,000 in 1992:

- McGill University: Photonics Systems;
- University of Ottawa: Fibre LANs;
- University of Waterloo: Modelling and Analysis of Guided Wave Devices;
- McMaster University: Optoelectronic Devices; and
- TRLabs: Optoelectronic Switching.

CITR has ten industrial members at present, including Bell Canada, Bell-Northern Research, MPR Teltech, NovAtel and Teleglobe.

The Telecommunications Research Institute of Ontario

The Telecommunications Research Institute of Ontario (TRIO) was established by the Province of Ontario in 1987 to enhance the technological competitiveness of Canadian telecommunications companies. Its current membership includes four university members, several associate members and about twenty industrial members. Its mandate was renewed last year for a second five years until 1997. The Province contributes the major portion of the research funds, with industrial members contributing about 10%. Bell-Northern Research is a member of TRIO. The research budget of TRIO is approximately $6 million, with photonics research accounting for just under $1 million.

The following photonics-related activities are carried out under TRIO:

- University of Ottawa: Photonics Networks and Architecture;
- Queen's University: Coherent Lightwave Communications, Image Transmission & Processing; and
- McMaster University: Extremely High Speed Networks.

Ontario Laser and Lightwave Research Centre

The Ontario Laser and Lightwave Research Centre (OLLRC) exists to stimulate advanced laser and lightwave research in Ontario and the technical application of this research and to encourage the transfer and diffusion of technology to industry. OLLRC was funded for an initial five years (1987-1992) under the Ontario Centres of Excellence program; its funding was recently renewed for another five years. NSERC contributed over $7 million, or more than half of the research funds during the initial five-year period.

OLLRC's research activities are carried out at several southern Ontario universities, including the University of Toronto, the University of Western Ontario and Wilfrid Laurier University. Projects that are related to the application of photonics to telecommunications include the development of high performance integrated optoelectronic circuits for future telecommunications and computing applications.

2.3.7 TRLabs

TRLabs, a private, non-profit research institute established in 1986, was the first telecommunications research consortium in Canada. It resulted from a strategic alliance between Bell-Northern Research, the University of Alberta and the Government of Alberta. Industrial membership has now expanded to include thirteen sponsor companies, including BNR, AGT Ltd., ED TEL, LSI Logic Corp. of Canada Ltd., Digital Equipment of Canada Ltd., NovAtel Communications Ltd. TRLabs is affiliated with the University of Alberta, the University of Calgary and the University of Saskatchewan, and is a member of SSOC and CITR.

TRLabs has four research division, including the Photonics Division, which has activities in:

- high-capacity optical transmission;
- photonic switching for very broadband signals;
- integrated optical interconnections;
- optical subscriber systems; and
- optical sensing.

The total resources of the Photonics Division of TRLabs are approximately 10 persons, including graduate students, and a research budget of the order of $1 million.

2.3.8 Summary and Foreign Comparison

The total amount spent annually in Canada on applied research in photonics for telecommunications applications probably does not exceed $25 million. In making this estimate, we have often had to separate telecommunications photonics research from non telecommunications research somewhat arbitrarily and we have had to assign some costs proportionate to staffing estimates. Nevertheless, we believe that the numbers which follow are sufficiently accurate to draw meaningful conclusions regarding the relative sizes of Canadian and non Canadian levels of investment. The major components of the Canadian effort in Canada are detailed in Exhibit 2-1.

Exhibit 2-1

Annual Expenditures in Canada for Applied Research in the Application of Photonics to Telecommunications

ORGANIZATION	ANNUAL EXPENDITURES $ Millions
Bell-Northern Research (BNR)	10.0
Solid State Optoelectronics Consortium (SSOC)	1.5
NRC/SSOC (Direct NRC participation in SSOC)	2.0
National Research Council (NRC)	4.0
National Optics Institute (NOI)	1.4
Communications Research Centre (CRC)	1.0

Canadian Institute for Telecommunications Research (CITR)	0.7
The Telecommunications Research Institute of Ontario (TRIO)	1.0
Ontario Laser and Lightwave Research Centre (OLLRC)	0.5
TRLabs	1.0
TOTAL	23.1

Naturally, many countries have similar research underway. In Germany the Photonik I Project (mainly, but not exclusively, focused on telecom applications) is funded publicly to $125 million total (DM165) over a five-year period from 1990-1994, with matching amounts from the private sector participants. The Photonik II Project is to start in 1994, but funding figures not available.

The European Community has two large scientific efforts underway which include photonics components. However, no breakdown for a photonics category is available. Within EUREKA in the category of "Lasers" we find 11 projects (for the most part not telecom related) with total investment of 240 million Ecus ($370 million) by 1990. Additionally there are probably applicable photonics activities buried in the communications category.

The Community also operates RACE which has some photonics in the context of "Techniques for Basic IBC Functions", e.g., Applications of Optical Amplification, Applications of Photonics Switching, Advanced Concepts in Optical Communications, Optical Networks Layout: Optical Cables and Passive Components Design and Installation Practice. STC (a Northern Telecom company in Britain) has participated in RACE programs.

In Japan the Optoelectronics Technology Research Corporation (mainly non-telecom) is a pre-competitive R&D consortium focusing on materials technologies needed for the future demands of information processing optoelectronics at a basic research level funded at $8 million per year. Real World Computing (mainly non-telecom) has an annual budget of $60 million.

Additionally, we can assume that most of the work done by the Optoelectronics Lab of NTT is directed at telecommunications. This lab has a staff of about 240 people and an annual budget of about $40 million. We estimate that there are five times this number of people working on photonics issues throughout the twelve laboratories and two development centres within NTT. Our estimate of the NTT effort is thus $200 million annually.

We know that there is photonics work being done within the ARPA and NIST organizations in the U.S.A., but we have no reliable figures on the total applicable to telecommunications.

As seen above, there are a number of Canadian laboratories engaged in a range of photonics research topics, but the total Canadian spending is small relative to that of other jurisdictions. This, in itself, is a warning, but it does not mean that the situation is hopeless. Success depends on both the funding level and the degree of focus. We believe that the Canadian program is well focussed.

It is unrealistic to expect Canadian laboratories to take a keen interest in all of the relevant photonics technologies, because of the breadth of the field. If, however, these Canadian research groups make superior contributions in their respective fields of expertise, they will be able to access and trade for much of the rest, both formally and informally, so that a viable photonics segment can be established in the Canadian telecommunications industry.

It can be seen that there are already a number of cross memberships among the established consortia: SSOC, TRLabs, CITR, TRIO, etc. The informal flow of information among the various players already exists to some degree, and can be induced further through the modest use of funds for topical meetings and conferences. The rationalization of the programs carried out by these consortia would be a major undertaking, but the potential is there. On the industrial side, the competitive situation between various combinations of Canadian-based telecommunications equipment suppliers may place constraints on their willingness to cooperate in photonics.

Taken collectively, the facilities of the National Research Council, Bell-Northern Research and the National Optics Institute provide a complete fabrication and test facility in photonics that is equal to any one facility anywhere in the world. Given the status of SSOC, whose continuation is now under review, it is imperative that, as a minimum, the individual facilities be preserved, so that their collaboration as the core of an industrially oriented photonics R&D consortium can be pursued.

2.4 Resultant Long-term Drivers

The telecommunications equipment industry is undergoing a radical restructuring driven by the pressures of world-wide competition among the major equipment suppliers. These suppliers maintain a research presence in all new technologies including photonics, that could affect the competition balance. It is highly probable that many of these technologies will result in new products. The increasingly commodity-like characteristics of the product lines of the major suppliers have resulted in reduced financial margins.

Given the current situation just described as a backdrop, we see five important long-term drivers of the industry. Any intervention, such as an effort to encourage the rapid pull through of photonics technology to commercial product, must be designed to take these drivers into account. We now briefly describe each of the five long-term drivers.

2.4.1 A Research Base

A Canadian-based world-class research capability is essential for the next few years, if Canadian companies are to use the new photonics technologies in product. The highly competitive global telecommunications market is characterized by an increasing trend towards alliances and mergers. In Canada, however, most of the equipment suppliers view other Canadian suppliers as their competitors, rather than as potential partners in the development of new equipment. An important key to the widespread and successful application of photonics by Canadian firms is their willingness and ability to hold the research community together long enough to extract a product pay-off for a substantial number of these companies.

Public funding of photonics research activities in Canada is administered through a large number of mechanisms in a very fragmented manner. The total operating budgets of NRC and NOI in the area of photonics (not all for telecommunications) is of the order of $20 million annually. In addition to the above amount, another $10 million or so is spent annually through CITR, other NSERC grants, TRIO, OLLRC, TRLabs, etc. If the existing Canadian capability is to be kept at the state-of-the-art, an annual expenditure of this level will be required on an ongoing basis. A modest amount of additional funds that could lever the ongoing activities in a direction that would result more effectively in products that could be manufactured by Canadian small and medium-sized enterprises (SMEs) could have an enormous impact on the Canadian photonics industry.

Canada should keep its public funding options open to increased support of its photonics research base in the mid term. It is likely that other jurisdictions will increase their research support levels for photonics technologies as a better defined market pull emerges for photonics-based telecommunications equipment.

2.4.2 An Applications Base

There are few applications at this time which demand high bandwidth. Suggestions abound in both the popular press and in the technical press. A good recent example can be found in the IEEE Spectrum of March 1993[5] which lists interactive applications in education, multimedia publishing, electronic newspapers and movies or audio on demand. The article does not address the human interface problems nor does it make any assumptions as to the price of transmission. Most serious writers point out that determining likely end use of high bandwidth is an extremely complex problem because an intricate convergence of technologies and business issues are involved.[6]

The issue of applications has to be addressed on two levels. The first issue is services to the end user. The second issue is the equipment needed to provide those services. We first address the end user needs.

The CANARIE Business Plan[7] lists a number of sectors that could be impacted by early adoption of networking applications, such as health care, aerospace, agriculture, fisheries, forestry, education and training, finance and banking, etc. To this list we add entertainment applications such as movies on demand.

For many of the suggested applications, the bandwidth time product is not a very large number relative to the bandwidth which photonics can make available. The application of broadband telecommunications to education is one of the frequently mentioned applications.

The report of the Steering Group on Prosperity, "Inventing Our Future: An Action Plan for Canada's Prosperity", recognized the contribution which telecommunications and information technology could make to learning.[8] The report recommends the expansion of the use of telecommunications and information technology such as computer-assisted learning, distance education, video/television, computers, cab;e television drops and telephone links in schools. The report also recommends incorporating the latest learning technologies into other learning situations. In particular, the report raises the challenge of bring learning to people in the home, the classroom and the workplace by the better use of existing communications links. The report recommends using existing telephone and cable lines to create an effective and inexpensive electronic learning network.

The challenges of the Prosperity Report are being met by a number of groups across the country. For example, the Canadian Educational Network Coalition was formed in May 1993 to facilitate national educational and training networking, particularly in schools across Canada.[1] Formation of the Coalition was preceded by a study to determine the feasibility, strategy and implementation plan for SchoolNet, a concept for providing schools with access to the worldwide interconnected research and educational networks known collectively as the Internet.[9]

Whereas much of the current activity is directed toward the use of available technologies, the networking and applications development thrusts that have been spurred by the Prosperity Report, the CANARIE and by developments in other countries will result in the requirement for multimedia technologies and high bandwidth. To the extent that photonics technologies can be integrated into these applications and that fibre-based transmission systems are required, there will be a market stimulation for photonics in Canada and in many other countries through the demand for new educational tools.

To date, the application of networking to libraries has been limited to cataloguing. Recently, there have also been discussions about the concept of virtual libraries. When this concept is implemented there will be a requirement for very large bandwidth for very short periods of time if the requested material is to be delivered promptly. The application of networking to libraries will become much more extensive when current and/or future library materials are available in digital form. An initiative of particular interest is Project Gutenburg, originating at Illinois Benedictine College, which has the objective of making 10,000 books available in electronic form by the year 2001 and to have them available for distribution at low cost over networks such as the Internet.

We now turn to the issue of the equipment needed to provide the services. In a publisher's note in the June 1993 issue of Business Communications Review[10] we read, "The last thing the communications industry needs is another 'Field of Dreams' technology. (If you build it, they will come.)" In an environment where the end user demand is hypothetical, the equipment provider proceeds with caution.

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1 Contact Dr. Harvey Weir, Chair, Canadian Educational Network Coalition, Memorial University of Newfoundland, St. John's, Newfoundland.

Present development work for the CATV industry is focussed on electronic solutions or upon electronic support for fibre cables. As direct broadcast from satellites is a looming threat to the industry, the industry is motivated to consider service offerings which enhance the ability of subscribers to send messages to the system through an upstream channel - a feature which no satellite system can match at reasonable cost. This function would allow for central switching of video signals, give the subscriber access to many more sources than can a satellite, enhance the flexibility of billing and reintroduce the encoder box as a viable CATV rental offering. The importance to photonics is that much of the CATV plant would have to be fibre based. The provider of the plant could be the telephone company or maybe a utility such as Hydro if the regulator had no objection.[11]

Many people in industry see the ATM switch as an important step in delivering real services to end users. An article entitled, "ATM: All Things to All People"[12] casts doubt as to the eventual ubiquity of this solution. A somewhat conflicting point of view can be found in a series of articles published concurrently in Electronics[13]. Maybe a major early role for the ATM switch is in association with LANs[14,15] However, the application of WDM techniques to LANs is also being investigated. With WDM one physical LAN could provide many separate message channels for different classes of users thus solving some security, pricing and bandwidth sharing problems.

On the other hand, we note that the rapidly decreasing incremental costs of transmission (assuming that the technically available capacity is used) promotes the restructuring of the public network. In the emerging scenario, the number of switches will be reduced, but the bandwidth requirements for the remaining switches will increase dramatically.[16] This will help pull photonics technologies into the exploratory design of telecommunications switching equipment.

It is possible that end user demand will be constrained by the traditional high price of bandwidth which has been set somewhat by the price of a voice channel. Incremental costs of a channel have plummeted. While the 1958 cost of a transatlantic voice channel was $6 million, the cost today is closer to $4,000 due mainly to technology's ability to carry more channels on each infrastructure.[17] The regulatory environment will play an important role in the timing of the demand for high bandwidth product as it plays a critical role in price setting.

The utilities are less interested in system design activity than they were in the past. The ability to generate and trial or display applications which will spark the interest of the utilities will therefore be an important driver to the introduction of photonics in telecommunications, and the availability of a test bed will be important to the equipment suppliers.

Project CANARIE (Canadian Network for the Advancement of Research, Industry and Education), which was announced earlier this year, may provide a suitable applications vehicle for demonstrating photonics equipment. CANARIE's mission is "to support the development of the communications infrastructure of a knowledge-based Canada and in so doing contribute to Canadian competitiveness in all sectors of the economy, to wealth and job creation and to our quality of life".[18] With a total estimated budget of nearly $900 million over its six-year life from 1993 to 1999, CANARIE could be the cornerstone for substantial applications demonstrations.

The aspects of CANARIE that are of most relevance to the development and application of photonics technology to telecommunications are the following:

- Cooperative product and service development; and
- CANARIE high-speed test network.

CANARIE Inc., the organization that was established to implement Project CANARIE, will provide funding for the cooperative development of new high-speed networking products and services, many of which are likely to photonics-based. The budget proposed for this activity during the first two phases is $116 million, of which $60 million is proposed to be provided by the Federal Government and the remainder by the members of CANARIE Inc. Federal funding has been approved for Phase I of the project. The CANARIE high-speed (gigabit) test network will be made widely available for the testing of networking technologies, products, applications, software and services.

In summary, the situation in applications for user services can be described as strong on hypothesis and weak on analysis. On the assumption that analysis of the real user needs will eventually spark a genuine market pull, the equipment suppliers are exploring equipment solutions which require photonics elements. Only exploratory system design work combined with market experiments will resolve the issues and pull photonics technology into major new telecommunications equipment commercialized product.

2.4.3 The Regulatory Environment

A convergence of cable television and public carrier utilities, which has already begun to a limited degree in some European countries, would stimulate the need for photonics in switching and transmission. The Canadian cable television companies, which are characterized by their large debt load, by and large are not interested in technology development at the present time. They are also constrained by the Canadian regulatory environment, which has been less sympathetic to their interests in recent years. Changes to the regulatory environment which would encourage or at least permit closer cooperation between Canadian cable TV and telephone utilities would have many effects. Almost certainly it would encourage the development within Canada of photonics-based equipment for joint cable TV and telephone utility use.

As already mentioned in Subsection 2.4.2, regulatory action which affects the price of digital bandwidth will also affect the attractiveness of photonics-derived applications.

2.4.4 Perception of Competition Among Canadian Equipment Suppliers

The perceived competitive environment between the larger and smaller Canadian telecommunications equipment supply companies is an important element in determining how photonics is applied to Canadian designed product and therefore to the dissemination of the technology in Canadian industry.

By default, with direct market demand minimal today, the system designer, either in independent system design houses or in the R&D arms of the major equipment suppliers, will play the pivotal role in the introduction of non-commodity photonics technology to telecommunications equipment design. The system designer's willingness to cooperate with third parties is part of the Management Willingness issue addressed in Subsection 2.5.5 below.

2.4.5 Photonic Technologies as a Substitute for Electronics

It is possible that photonics will initially be employed to provide the functionality of earlier equipment with the added flexibility for handling very large bandwidths, although there will be no demonstrated mass market for this bandwidth capability when the equipment is first available. This phenomenon was a major factor in the commercialization of digital switching. Any substitute application will generate a natural pull through of photonics technologies into product. A study done for SSOC[19] which covers all electronics production shows that photonics components will rise from 6.1% of the costs of electronics production in 1990 to 14.2% by the turn of the century.

We can summarize the drivers as follows. For success, we must retain an applied research base and we must be prepared to enhance it. To move technology from research toward commercialization, we have to solve the marketing issue by providing a vision to users who will then create a genuine market pull. The telecommunications regulator could help by encouraging cooperation between transport providers (primarily the telephone companies and the CATV operators). Closer cooperation between the large and small equipment providers would also help. Finally, although photonics components will increasingly displace electronic components in electronic equipment, this will probably not be a major factor in the Canadian telecommunications equipment market.

2.5 Issues - Canadian Opportunities and Barriers

The long term drivers of the industry described in the preceding subsection interact to produce opportunities for the industry and some barriers to industrial success. The goal, from the standpoint of Canada's national economy, is the generation of sustainable businesses. A number of key elements which constitute opportunities and barriers have to be considered in any assessment as to whether sustainable businesses can be generated by the application of non-commodity photonics technology to telecommunications by Canadian companies.

We now address the important opportunities and barriers to the application of photonics technology to telecommunications in Canada in terms of the issues in **technology and scientific capability, marketing, production, financial strengths and managerial willingness**. As will be seen below, the main issues that have been identified relate to the problems faced by SMEs.

2.5.1 Technology and Scientific Capability

Canada has the nucleus of critical mass for successful applied research in photonics technology. This nucleus consists of three parts - the Solid State Optoelectronics Consortium, the applied research components of Bell-Northern Research and the National Optics Institute (see Subsection 2.3 above). Among them, these three organizations control the activities of approximately 140 researchers directly related to photonics. This is the equal of any other single laboratory in the world, even if other countries, most notably Japan and the U.S., have more than one such laboratory within their borders. Thus, it seems fair to say that Canadian technological capability in photonics does surpass minimum threshold scale.

However, there may well be opportunities to enhance the focus of Canadian photonic technology efforts. We feel that the timing is right to apply strong encouragement to pull the technologies out of the applied research environment into the exploratory development environment. The essential interpersonal network to allow further enhancements already exists, largely due to the membership of SSOC. This consortium provides input to the NRC's Institute for Microstructural Sciences, which is the basis of SSOC's R&D program. BNR contributes to, and is a member of, SSOC, as well as conducting its own photonics R&D. MPR Teltech is also a member of SSOC, as are NOI, TRLabs and CRC.

Consistently in the course of this study, the smaller Canadian firms indicated that existing R&D consortia in telecommunications and/or photonics were too "R" oriented (as opposed to being "D" oriented). Although it may have been too early to move strongly from the "R" phase to the "D" phase in the recent past, the fact that the nature of the consortia programs is now being criticized lends credence to the earlier statement that the time to move in this direction has come.

The technology opportunity is to pull technology from the applied research environment into the exploratory development environment. To accomplish this, the applied research base activity must remain intact for the next few years. We also have the opportunity to transfer important photonics technologies to the SMEs in the process rather than wait for diffusion at a later date. Without this early transfer, the photonics SMEs face a barrier to their continued development in the face of rapid technology change.

2.5.2 Marketing

The great characteristic of fibre-optic transmission is its potential bandwidth, i.e. carrying capacity. Currently this capacity is really not being challenged by existing services. For example, out of 12 optical fibre strands in the Stentor trans-national cable, only four are equipped with the electronics to make them available for service - two in each East/West direction; and the second in each direction is only activated as a standby. The actual traffic carried is thus less than the capacity of a single strand in each direction.

Until the need for transmission capacity is demonstrated, the need for photonics-based multiplexing and switching equipment is also problematic (unless the acceptance of photonics is on the basis of the cost reduction of current functionality). The need is thus for marketing trials of user services. Getting to a trial of a complex technology which offers services for which there is no well demonstrated need is not easy, and most certainly places the funds used for the trial at considerable risk. Public funding will almost certainly speed the process. Trials of this nature have been announced in several other jurisdictions, but very few Canadian companies will have the opportunity to participate in these foreign trials at an early date.

Given the very large bandwidth potential of the media and photonics-based equipment, trials which help solve the problems of joint commercial use of the media and equipment might be particularly important. The marketing barrier is the lack of information on the reality of the demand for large bandwidth. Given the widespread sense globally that the need will probably be demonstrated, the marketing opportunity is participation in application trials.

2.5.3 Production and Opportunities for SMEs

The development of photonics capability in Canada also raises production issues, in particular specialized components. In the new "tiering" model of alliances and division of labour that is now emerging in numerous high-technology industries such as electronics and automotive, a key ingredient is so-called "Tier 2" product development companies. Typically, these are SMEs and they are suppliers to the system deliverers. They may bid in competition with other potential suppliers for subsystem design and supply contracts or they may be sole source. A significant technology transfer takes place in both directions under good contracting conditions.

The issue is an important, perhaps even vital, one. Modern technology development often is so diffuse that no one company, however skilful or knowledgeable, can possibly foresee all the applications. The smaller product development companies must provide the specialized, niche products that emerge from their imagination and vision and which no large systems house can emulate as speedily. If Canada does not have this secondary tier of creative SMEs, then the system suppliers will become inefficient relative to their global competitors and major opportunities for technology transfer to the SMEs will be lost.

It is important that a component development laboratory provide sample quantities of early product to trial projects and even for early production. Nevertheless, the development laboratory cannot be relied upon to deliver components to ongoing production without dedicating equipment to the task. In this case the equipment becomes unavailable for ongoing product development. This is not always a problem, but it usually is. Thus, our solution to the problem of pulling photonics technologies from the research laboratories into the exploratory development environment must accommodate the component supply issue.

The first production opportunity is the involvement of the SMEs as a cost containment opportunity for the large system suppliers. The second production opportunity is the short term involvement of the applied research facilities in the early production of key photonic components and subsystems. Eventually, we face the risk that viable production facilities of appropriate scale are not available in Canada.

Although there are almost certainly opportunities for SMEs to provide niche photonics telecommunications products, we believe that the major new possibility is that they provide subsystems and support products (eg. test sets) in conjunction with the large system suppliers. This mode of product introduction will pull new technology most quickly and cheaply into the SMEs, provide them with an initial market and cash flow where they can rely on some technical support from their customer and provide an opportunity to produce daughter products for third parties.

2.5.4 Financial Strengths

Northern Telecom dominates the Canadian telecommunications equipment sector. Its sales revenues are greater than those of all other Canadian firms in the sector combined. It finances Canada's largest private-sector industrial research laboratory, BNR. It must be a major player in any Canadian photonics technology development agenda.

There are three or four other system companies with potential interest in photonics in telecommunications and with healthy balance sheets. Although these companies might be seen as competitors of Northern Telecom, they are not direct competitors over a broad product line. While negotiations might be difficult, every effort should be made to bring the capabilities of all the major players to a sharing of the risks and rewards of a Canadian base in photonics technology.

The telecommunications utilities have very large cash flow but their operating margins have tended to shrink in the last few years. They still invest heavily in new equipment, including the most recent technology. Although not themselves highly pro-active in new technology development, their procurements, and understanding of their customers' needs, make them potentially valuable allies in Canadian photonics development. Their procurements could be vital elements in technology development.

The cable TV companies are suffering from relatively large debt structures and this limits what can realistically be expected of them. Their somewhat weak balance sheets means they are likely to be only of modest potential assistance.

The financial barrier in the SMEs is the chronic shortage of cash flow. Small companies with high growth rates are chronically short of working capital. It has been estimated[20] that companies in the formative phase require $1 of financing to support each $1 of sales. In this business, even relatively small system designs will require typically in the order of $0.5 million per year expenditure on product development over one to three years before significant sales are achieved.

The problem for the largest companies is the highly visible nature of expenditures on photonics technologies prior to trials which prove viable high bandwidth applications.

2.5.5 Managerial Willingness

The smaller niche equipment suppliers do not have the cash flow which allows them to acquire any major technology they may need for business renewal. They are constrained to incremental growth based upon incremental changes to their existing base. However, if the cash-flow constraint can be alleviated, the management of these businesses are usually willing to accept the new technology. Their other constraint is the availability of in-house talent to execute a successful transfer.

The logical approach for both the large and small supplier is to form alliances in the "tiering" model. The large systems supplier gains a relatively low cost producer of low volume or specialty components or subsystems while the smaller company obtains a low cost technology transfer, temporarily supported by the technical resources of the larger company.

Our interviews with both large and small companies indicate a serious willingness to address the tiering model in respect to the application of photonics technologies to telecommunications. This represents an opportunity where the previous barriers to cooperation are diminishing.

3.0 CAPTURING THE OPPORTUNITIES

3.1 The Rationale for Cooperative Action

Sustainable business relationships are generated only when there is a strong interest in the relationship by all parties involved. In the application of non-commodity photonics to telecommunications, there are several steps ahead of us.

The business community has had access to digital data on local area networks (LANs) for the past few years. The data manipulated on these LANs are largely from internal sources, i.e. from other local users of the LAN. While bandwidths have been nominally 10 Mb/s, effective bandwidths have more nearly approximated 100 kb/s per user. Broadband connection to the outside world has not been readily available.

Broadband availability to the residential community is restricted to analog one-way video. Thus, we have not yet proven the utility of geographically distributed high bandwidth digital data applications.

There is reasonable agreement that we already have a strong base in appropriate applied research. Our opportunity is to pull business opportunities through from this base to profitable commercial enterprises without destroying or weakening that base in the process. Applied research is the necessary precursor to exploratory systems design. To interfere with the first is to eventually kill the second. Mutual interests must survive each step from applied research through exploratory development, hard development, field trials, and full commercialization.

The marketeer is not being asked urgently by customers for higher bandwidth systems specifically, but the marketeer knows that "increased flexibility" will sell - especially if this comes at no significant price premium. The demonstrator of advanced subsystems cannot demonstrate convincingly. The systems designer (or design house) is thus pivotal in the next step in pulling through business opportunities from research to full commercialization. The systems designer must excite the customer with a demonstrated vision. To the extent that the systems designer finds it necessary to involve third parties, we will achieve sustainable technology transfer.

The technologies are still young. Only the most preliminary systems design thinking has taken place. The issue as to whether the systems design efforts will be driven by corporate networks with applications already waiting in the wings, public telecommunications utilities wanting to prove their commitment to modernization or by the major equipment suppliers discovering that photonics is cost effective for current applications, is unsettled. To generate some sustainable relationships among Canadian equipment suppliers, we must find some fertile common ground in all of this uncertainty.

Because of the current uncertainty as to the real drivers and the general acceptance that there is a photonics opportunity, the burden for the synthesis of a business solution falls upon the exploratory systems designer today.

Some major uncertainties which face the systems designer can be removed through the development and assessment of application trials. Application trials thus become an important ingredient in the generation of sustainable photonics businesses in telecommunications equipment. It will, however, be difficult to draw accurate conclusions from these trials because full utility can be shown for many potential applications only when some business re-engineering is done in conjunction with the application.

Despite all of the uncertainties, there is still strong support for the application of non-commodity photonics to major elements of telecommunications equipment product lines. The key attraction is the possibility of combining the highly desirable qualities of high bandwidth, minimal physical size and protocol flexibility in one product. System design will therefore proceed within the laboratories of the major equipment suppliers around the world. The timely transfer of these technologies to the smaller suppliers in Canada is by no means assured.

The small and large equipment suppliers would like to reduce their financial risks in systems design. Additionally, the large equipment suppliers are increasingly looking for sophisticated suppliers of low volume components and subsystems. The smaller suppliers in particular need to reduce their risks of market failure. The common interest between the large and small suppliers is thus served by involving the smaller company in design and supply arrangements at system design time. In this way, technology transfer also can occur to the smaller company.

The interests of the smaller company are particularly well served if it does not have to pay full price for its part of the design work while it is nevertheless virtually assured of a market for its initial product. To the extent that the smaller company can expect to sell to third parties other product based upon the technology transferred, an even greater interest in cooperation is generated.

We can probably increase the opportunities for the smaller suppliers and at the same time reduce the risks to all participants by encouraging cooperative efforts between the systems designer and the smaller companies. To succeed, all participants must understand the risks and benefits of cooperation. All participants have to be dedicated to minimizing the risks and maximizing the benefits in the spirit of cooperation. The participants have to understand the differing constraints and objectives of the large and small companies and accommodate these differing needs in any agreement for cooperation.

3.1.1 Examples of Cooperative Action

There have been several attempts to accelerate the movement of technology from the laboratory into product in recent years. Success seems to have attended those projects where parties representing the various interests on the road from research through to the end user had serious joint involvement. The paragraphs which follow make this point by examining briefly several experiences.

Alvey

An evaluation by Ken Guy of the University of Sussex at Brighton[21] of the British Alvey Programme, which supported collaborative R&D in information technology showed that, while Alvey was successful in boosting R&D levels, expanding the population of researchers, uniting fragmented resources, nurturing links between academia and industry, it was less successful in improving the competitive position of the UK IT industry. Limiting factors included inadequate management of the R&D/production interface within firms and the limited availability of investment capital. The conclusion was that Alvey was a necessary although insufficient mechanism.

IT4 - Sweden

An evaluation by Ken Guy[22] of the Swedish IT4 programme, the Swedish national programme of pre-competitive collaborative R&D in industrial information technology produced similar conclusions. IT4, which had a total budget of SEK 1000 million ($175 million) over a period of five years from 1987 to 1993, had similar goals to Alvey as well as to the Photonics Sector Campaign (promote industrial capability to develop and produce IT, access international developments in the technology, secure international competitiveness in selected IT areas), showed that it made a significant impact on the national base of IT R&D capabilities, but that other actions are also required to reach international competitiveness goals.

The study also concluded that some aspects of programme management could have been improved. Among the comments:

- IT4 efforts focused strongly on big collaborative projects, involving relatively large numbers of participants, which tend to be hard to manage;
- the implementation was slowed by lack of clarity about strategy;
- the management and decision structure probably was more complex than was necessary;
- the process of establishing an administrative capability was inadequate;
- the bureaucracy was probably too "thin" (it had been decided to spend not more than 1% of the budget on administration);
- the administrative capability needs to be "front-end-loaded" to cope with the influx of work at the beginning, reducing is size over time as procedures become fully routine and the balance of the work shifts from decision and implementation to monitoring.

RACE

This was a European attempt to pull product into industry. It is felt that projects which focused on exploratory system design were the most successful whereas projects which focused on technology had little to show for their efforts. One example of the latter is the effort to develop a process for 0.5 micron silicon geometry which concentrated on the underlying physics. Projects with a systems focus seem to avoid the two extremes of the pedestrian and blue sky.[23]

PRECARN

A recent interview at PRECARN[2] indicates that the pull through issue is recognized. PRECARN is now putting into place a method of selection projects with the greatest potential to lead to commercial benefits.

Strategic Microelectronics Consortium (SMC)

A recent interview with the president[3] of this organization produced the comment that since their Board has essentially full responsibility for funding allocation, the Board was very interested in demonstrating commercial success.

ARPA

A recent interview[4] offered the opinion that successes at ARPA tended to come from equal partnerships between device producers and system designers.

3.2 Ensuring an Infrastructure

There are three modes in which researchers and product developers can work. The first is the one which the general public usually associates with research - the serendipitous or "eureka" discovery. Discovery in this mode is in reality so rare that it can be virtually ignored as a force in the business world.

The second mode is the one now applicable to non-commodity photonics in telecommunications equipment. This mode is characterized by "systematic probing".

The third mode is applicable to the phase yet to come. This mode embodies an "invent-to-schedule" regime.

The infrastructure which will best serve the Canadian telecommunications industry in its application of photonics must support the present needs for systematic probing and be readily metamorphosed when the time comes to support the "invent-to-schedule" regime. The

[2] Jean Claude Gravel, Vice-President

[3] John A. Roberts, President & CEO

[4] Jacek Chrostowski, National Research Council

infrastructure must address the Canadian opportunities and barriers put forth in Subsection 2.5 of this report.

The infrastructure should support opportunities and alleviate barriers as follows:

Remove barriers

- The **marketing barrier** to needed design and trial of applications which require large instantaneous bandwidth;
- The **marketing barrier** faced by SMEs in particular in finding early markets for product based on new technologies;
- The **production barrier** to the availability of fabrication facilities for production in experimental quantities;
- The **technology barrier** faced by the SMEs when they try to import major new technologies; and
- A **financial barrier** to the SMEs in particular by providing a channel through which funds for the support of technology transfer can flow.

Support Opportunities

- The **technology opportunity** for coordination of exploratory work in both systems design and component subsystems;
- The **technology opportunity** for access to exploratory work by all interested systems designers;
- The **marketing opportunity** of multi-company systems design efforts;
- Connections to off-shore knowledge and resources to capture a **technical opportunity** and eventually an offshore **marketing opportunity** for Canadian companies; and
- Personnel networking conducive to the identification of opportunities as a **marketing opportunity**.

An infrastructure which satisfies these requirements is shown in Exhibit 3-1, which depicts:

- Large and small suppliers (the latter earlier referred to as SMEs) delivering goods and services to their customers. An important customer of the SME is the Large System Supplier;

- The strong connection of all parties to applications generation and demonstration;

- An R&D Consortium operating in close association with one or more System Design House(s);

- Design activity by the System Design House(s) for the Large System Supplier(s) including work with the SMEs so that product delivered by the SMEs is incorporated in the product delivered by a Large System Supplier;

- Devices in small quantities available to the SMEs from the R&D Consortium;

- Public funding flowing through a Coordinating Body for approval of requests for grants and then on to the R&D Consortium and to the SMEs in support of design work. As explained later, grants would be made only on projects which involved members of the Photonics Consortium and who belonged to differing membership categories. This will promote the pull of technology as the membership categories represent differing stages of the product evolution from research through to commercialization. The SMEs might pay the System Design House for efforts on their behalf which result in the delivery of designs to the SMEs (usually of subsystems to be delivered to the Large System Suppliers for incorporation in their system deliveries to their customers);

- Membership fees flowing from both the Large System Suppliers and the SMEs to support the Coordinating Body;

- Promotional activities by the Coordinating Body to the Large System Suppliers and through them to their System Design House(s) to encourage the incorporation of SME effort and product in the deliverables of the Large System Suppliers.

Potential Canadian participants in the proposed infrastructure are provided in Subsection 3.3 below.

3.3 Supporting Specific Opportunities

Since the pivotal entity at this time to the movement of photonics out of applied research into exploratory product design is the systems designer, any infrastructure developed should support this activity.

3.3.1 The Photonics Consortium

A Consortium should be formed along the lines depicted in Exhibit 3-1. The purpose of the Consortium is to assist in removing the barriers to commercialization of non-commodity photonics in telecommunications. Barriers to prompt commercialization exist at organizational boundaries. Examples of these boundaries are those between the applied research organizations, the system designers, subsystem suppliers, large system suppliers and the end users.

The Consortium should have six categories of members, with each category representing a stage in the evolution of technology from applied research to the end user, as follows:

- The principal **Applied Research Laboratories,** i.e. BNR, NRC, CRC and NOI;
- **Applied Research Consortia,** e.g. CITR, TRLabs, TRIO, SSOC, OPCOM;
- **System Design Groups** which have a serious interest in the design of "stand alone" product, e.g. BNR, MPR Teltech, Newbridge, SPAR;
- **Subsystem Manufacturers** (typically SMEs, but not necessarily so) whose primary interest is in the supply of components, subsystems and test equipment to designs fathered by the System Design Groups;
- **Large System Suppliers,** e.g. Northern Telecom, Newbridge, SPAR;
- **End Users,** e.g. telephone operating companies, cable TV operators, governments.

These membership categories represent the phases of product development from research through to commercialization. Projects undertaken by enterprises from different categories of the membership will tend to pull technology toward commercialization. Some companies might want to be members in more than one category. Cable TV equipment manufacturers are also potential participants, but their current focus is quite short term. An appropriate membership fee structure will have to be derived. Granting mechanisms should encourage interaction between Photonics Consortium members which will result in technology pull through toward commercialization.

It is realized that there are already overlapping memberships buried in the list of organizations used as examples above. There are also clear indications that industrial organizations do not want to see an expansion of the list of consortia and would welcome some rationalization. Discussions on rationalization should proceed in parallel with the formation of The Photonics Consortium.

The Consortium would be supported by a Coordinating Body whose specific duties should include:

- Promotion with the system design staff and management of Canadian equipment suppliers, the benefits of working with other consortium members in the mutual design of systems and the related supply of the subsystems needed;
- Promotion of coordinated acquisition of major capital equipment;
- Evaluation of proposals for funding assistance for the design of subsystems and the management of the funds dispersal function for approved projects. The Consortium will have to constitute a committee to perform this function. It should approve only those grant requests which involve at least two members of the Consortium, operating at arms length and belonging to differing membership categories; and
- Receive and manage contributed public funds and membership fees.

The Consortium could be constituted as a new autonomous body or it could be an extension to some existing and relevant body. We favour the latter solution <u>initially</u> for two reasons:

- This will minimize the additional overheads of administration; and
- It will ease the set-up tasks and allow for the informal operation of the Consortium pending the resolution of administrative issues.

A negative aspect of this solution is that the new body will not be perceived as fully autonomous of its parent organization. For this reason, we believe that the Consortium should quickly become the umbrella body for publicly supported photonics funding in telecommunications in Canada.

We recommend that SSOC be the initial parent organization on the understanding that NRC will not become a "System Design House" within the context of this report. NRC should remain in the applied research role. In that role NRC should be fully supportive of the exploratory development work being undertaken by the System Design Houses which are members of the Consortium.

We believe that the structure of the proposed consortium promotes the needed exploratory systems design work (the common factor in the success of existing consortia as seen in Sec. 3.1.1) while avoiding the problems identified in Sec. 3.1.1 of this report.

3.3.2 Financial Support for Systems Design

A significant rate of infusion of public funds should be made available with the initial establishment of The Photonics Consortium. The intention is to signal in a practical way that some changes at the interface between the large System Suppliers and the smaller companies could be in everybody's interest. We see no need to make a firm commitment which extends beyond three years, but a support program with an expected five year life is both appropriate and consistent with international norms today. If the Consortium is seen to be providing a useful function at the end of the first three years, its requests for renewed public support can stand on their own merits.

A review of the barriers and opportunities listed in Section 3.2 of this report show that system design is the key to generating a market pull. Our discussion of the factors for success in consortia in getting technology to market also indicate the importance of the system designer. It is thus logical that we should provide incentives to system designers to undertake exploratory designs. The intent of these designs should be to interest potential end users in system purchase. Naturally the issue arises as to the extent of the incentive needed.

Most programs appear to provide subsidies of the level of 50%. For projects funded by the Japan Key Technology Center (including the Optoelectronics Technology Research Laboratory), the government subsidy is at the 70% level. Private sector contributions come largely in the form of the salaries of their own researchers who are assigned to the Center's projects.

A recent interview[5] states that Bellcore believes that the degree of subsidy should depend on the degree of risk.

In the Swedish IT4 Programme, a 50% cost sharing average between government and the private sector was achieved. The programme was prepared to pay up to 100% for small feasibility studies, but main projects had to be at least 50% funded by the private sector ("Private Sector" included state-owned enterprises). The 50% rule applied to a whole project and not to individual participants. This meant that the program could pay the full costs of universities, research centres and small firms, provided that the large participants paid a disproportionate share of their own costs.

Funding rules for ESPRIT, RACE, etc. have tended to work at the participant level, effectively excluding small firms and research institutes. It should be noted that the Canadian government has a mechanism for providing funding to small Canadian firms participating in EUREKA, making it easier for them to participate (without using their own funds). Public funding for EUREKA has averaged only about 35 to 40%.

There is thus some rationale for subsidies at rates other than 50%. Factors such as the nature and size of individual organizations and the degree of risk in the project should be taken into account. The participation of research institutes and universities who are not going to share in the intellectual property rights arising from the activity could be fully paid by the government and by the industrial participants. It is probably wise to leave project funding decisions (within broad guidelines) to the Board of the Consortium.

The objective of funding should be to support the system design efforts undertaken between a Large System Supplier and a Subsystem Manufacturer through a System Design Group, all of which are members of the Consortium to a typical (but not absolute) maximum of 50% of the design costs. Substantially all of the grant would have to be spent within the Consortium. Funding would be on the basis of a grant and application would have to be made to the Coordinating Body for this support. Arrangements should be flexible, but it would be preferable to support the Subsystem Manufacturer, which can then allocate and control funds to the System Design Group.

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[5] Dr. Arpad Bergh, Executive Director, Applied Research Program Development, Bellcore.

3.3.3 The Need for Service Marketing Experiments

As mentioned earlier in this report, the scientific literature and the popular press are full of proposed user services which would make use of large communications bandwidth. Most of these suggestions have little basis in serious evaluation of the conditions under which these services would be commercially viable. Serious issues such as the number of potential users, the expected frequency of use, the nature and frequency of the requests which each service user would make of the communications network and the assumptions regarding the pricing of bandwidth are not addressed. In order to initiate a market pull for photonics-based products in telecommunications, a soundly based vision for bandwidth usage has to be formulated.

The required vision can probably be assembled economically with the aid of some cleverly designed experiments. In this context, a cleverly designed experiment is one which does not require the implementation of a proposed service in order to predict its commercial viability. Rather, the experimental environment simulates the availability of the proposed service in a mode which is probably sustainable for only a few seconds and then seeks the subject's reaction. The researcher has to estimate the value of the service to the potential user. The user will probably have to significantly change his habits to become a regular user of the service and is thus not a good judge of the eventual value of the service to him.

While any of the services mentioned earlier in this report can be the subject of an experiment, our preference is for an experiment which will estimate the relationship between the delay in delivering data and the amount of data requested. It is our belief that as this interval narrows, the number of requests per user per hour will increase. This phenomenon itself may be a key ingredient in the vision which will sell the telephone company on the wisdom of restructuring its network. The result will be the rapid pull through of photonics technology into telecommunications equipment design.

3.4 Business Development Opportunities

The relevant photonic technologies are in the research or applied research phase at this time. Significant product will not be delivered during the next two or more years. It is thus important that Canadian capabilities in these technologies remain in place and reasonably focused until saleable product emerges. In practical terms, the function currently being provided by SSOC should remain in place following the expiry of the current SSOC mandate in 1994.

We now present some specific projects in applied research which will attract multi-company interest and thus be candidates for the attention of a Coordinating Body. The projects listed below should not be viewed as a complete list of promising opportunities. Rather, it should be viewed as an indication there is some potential for the application of photonics within the Canadian telecommunications industry. Once the plans for the proposed industry structure gains widespread acceptance and when the Federal Government's intentions become clearer, we would expect a number of other opportunities to emerge.

3.4.1 Photonic Backplanes

In a photonics backplane, signals are carried on light beams from one circuit element to the next rather than being carried on copper tracks. The attraction of the photonics backplane arises from two facts. First, unlike copper tracks which require an insulating layer between them when they cross each other, the light waves can cross each other in space without requiring spacial isolation. Secondly, unlike copper tracks which broadcast unwanted electromagnetic interference signals which are then picked up by other circuits, the light beams are easily contained. However, the photonics backplane requires that transmitters and receivers be incorporated for each beam and that each beam be focused from source to destination. The electrical, photonic and mechanical properties of these transmitters and receivers are the subject of current applied research. It is also probable that the economic solution involves the multiplexing of several signals onto each photonic beam and this implies the need for an ASIC-based multiplexer.

There is interest in the development of the photonics backplane at Newbridge, Digital Equipment of Canada Ltd. and Northern Telecom/BNR. Although the successful techniques in this field will quickly become a commodity application, it is important for systems designers today to understand the possibilities and the likely economics.

3.4.2 Components for an ATM Switch

The ATM switch is a packet switch. It is differentiated from earlier packet switches in that it implements a protocol which was initially published by the ATM Forum. This protocol provides for a fixed length digital packet. The protocol is thought to be particularly appropriate for very high speed digital transmission independent of the user's application which could be anything from voice to massive data transfer or digitized video. The protocol establishes a virtual circuit for the end user.

The electronic technology of currently available ATM switches limits their channels to 640 Mb/s. There have been several papers published recently[24] which propose the future use of photonics technologies for ATM switch implementation due to the very high throughput rates expected. The referenced article suggests that throughputs of one terabit/second level might be attractive.

MPR Teltech, Newbridge, BNR and Northern Telecom have current interests in implementing ATM switches and thus have an interest in the underlying possibilities in photonic technologies.

3.4.3 Wavelength Division Multiplex Components

The possibility that signals could be separated from each other through the use of a different "colour" for each is the basis for all WDM work. This basic concept is of interest to fibre transmission product designers as a means of increasing the capacity of fibre cable or separating the signals of multiple users of a physical cable without resorting to time division multiplexing. The latter technique of necessity introduces signal delays which are uncontrollable by the end user and which are dependant upon the activities of other users of the same physical cable. WDM techniques avoid this problem and may solve other contractual and/or legal problems of multiple user cable.

WDM techniques are also of interest to switching system designers and may be of interest to the more comprehensive approaches to the photonic "backplane".

WDM is of interest to Northern Telecom and Digital Equipment of Canada.

3.4.4 Solid State Waveguide

A solid state waveguide, probably with a built-in amplifier, is a key component in the space division function of any switch. It provides a means of transporting a light beam between a physical input port and a physical output port. This component, which might be integrated with other components, is being researched at BNR and SSOC. While of obvious interest to the designers of switching and multiplexing equipment, it is also of interest to the designers of test sets. Many optical test sets today rely on mechanical switching and a switch for these applications which did not incorporate moving parts would have immediate application.

The parties interested in this technology are thus Northern Telecom and several smaller companies involved in the optical test set business.

3.4.5 Heterojunction Bipolar Transistor

Although not usually categorized as a photonics technology, the heterojunction bipolar transistor (HBT) is based upon many of the same compounds and fabrication techniques relevant to photonics componentry. Because of this and its high power and high speed potentials, it could well become an important component in telecommunications equipment design. It is readily integrable with photonic elements.

BNR and SPAR both have an interest in the development and application of HBTs.

3.5 The Need for Accelerating Canadian R&D Activities

The need for applied research activities is likely to grow as photonics technologies start a strong movement into major new telecommunications equipment applications. The likely magnitude of the need can be estimated by relating it to estimates of product sales. The Elliott Report[1] estimated that the worldwide production of photonics-based telecommunications equipment would rise to $22.5 billion by the year 2000 from the 1994 estimated production of $10.4 billion. Assuming that these predictions are realized and if the Canadian equipment and component suppliers are to continue to have a strong presence in this market, an optimistic target for the Canadian share of that business could be of the order of $2 billion. The target figure is consistent with the industry's own published target of $20 billion by the Year 2000[4] if 10% of the equipment produced is photonics-based. The ongoing photonics-related R&D needed to sustain $2 billion in annual sales is about $200 million annually. Thus, by the Year 2000, photonics-related R&D should climb from the present $25 million annually to $200 million annually.

3.6 Total Funding Requirements

In this subsection, we present a first-cut estimate of the total public sector funding required to support the initiative presented above. A summary of our recommendations on funding can be found in table format as Exhibit 3-2 (see opposite p. 50, 3). Funding will be required in the following four categories:

- Subsidies for applied research;
- Subsidies for systems design projects on a shared-cost basis;
- Subsidies for service marketing experiments;
- Program management, including operation of the Coordinating Body.

Applied Research

Existing funding for applied research in photonics will have to be augmented. As noted in Section 3.5, $200 million R&D annually (research, applied research and continuing product development) will be needed to support annual sales of $2 billion in photonics-based equipment by the Year 2000, whereas the current level of expenditure (mainly applied research) is estimated at $25 million in Section 2.3.8. The cumulative R&D needed in the interval 1994 to 2000 will be in the range of $350 million. We suggest that federal funding of $15 million annually in support of the applied research portion of this total be made available through the 1994 - 1999 interval.

It is expected that the majority of the required expenditures will come from the private sector. However, there is an important catalytic role to be played by government in supporting the research activities. This is particularly important in the early years before the market pull for advanced photonics products, which is expected to materialize, is clearly demonstrated.

Systems Design

It is difficult to estimate the subsidies required for systems design. Current total R&D expenditures by Canadian-based telecommunications equipment suppliers approximate $1.2 billion, of which about $850 million is spent in Canada. It might be appropriate that 10% of this be spent annually on photonics design work in each of the next few years, i.e. $85 million annually. If the system design activity averages 20% of this and an average of 50% of that is supported from grants, then funding of $8.5 million annually is appropriate. In round numbers, we recommend that a modest $25 million be budgeted over a three-year period and that budget provision be made for increases in the following two years.. The resultant increase in system design activity would also serve as an inducement for the existing applied research centres and research consortia to more specifically address R&D topics of current interest to the SMEs and to pull technology into the exploratory systems design phase.

The infusion of the funding proposed here for systems design would be new funding. The new funds are meant to act as a catalyst to bring together the various parties in pursuing new business opportunities in photonics.

Service Marketing Experiments

We expect that there will be scope for the support of photonics-related product development and trials within Project CANARIE. A modest amount of funding is proposed here for the support of service marketing experiments (see Section 3.3.3), which may fall outside the scope of the approved CANARIE Project. We recommend a budget of $5 million over the first three years increasing significantly to $15 million for the subsequent two years to fuel a market pull for technology which will then be ripe for application.

Program Management Costs

No matter what form the Coordinating Body takes, it will require, as a minimum a person or persons who can promote the use of the process described in Subsections 3.2 and 3.3, as well as the staff and the means to administer the funds flowing into and out of it. An examination of a number of existing consortia indicate that the annual operating costs of the coordinating body generally are in the range of $150,000 to $500,000, usually approximately 10% of the total funds administered. If the most economic approach is adopted, namely, an extension to an existing body, the cost would be at the lower end of the above range, namely, $150,000 annually. When the Consortium is fully operating, membership fees may be sufficient to cover this cost, but some public sector funding would allow the Consortium to become operational more quickly. As additional administrative funds for the Phase III Photonics Sector Campaign will be needed outside the Consortium, we believe that a total administrative budget of $1 million annually is prudent.

We recommend that the Phase III Program for Applying Photonics to Telecommunications be approved for an initial three year trial period (Stage One), followed by an additional two years (Stage Two), during which the results achieved during Stage One could be evaluated.

At the end of this five year period, it would be expected that the private sector would be providing most of the required funds. There may remain a few needs for federal government funding such as for collaborative applied research or university-based research activities.

The total funding proposed for Stage One (1994 - 1997) and Stage Two (1998-1999) is show in Exhibit 3-2. We have assumed that federal government subsidies would continue during Stage Two, but at a lower proportionate rate than during Stage One. Total federal government funding required during the five year program is estimated to be $160 million out of a total program cost of $405 million. Depending on the availability of R&D funds from other sources for the continuation of existing institutes, programs and consortia, and depending on the degree to which these entities can be drawn together in their efforts to achieve the industry vision, the additional funding required may be as low as $110 million.

4.0 SUMMARY OF RECOMMENDATIONS

For the convenience of the reader, we here summarize our recommendations:

- A Photonics Consortium be formed with a Coordinating Body (Secretariat) for the purpose of encouraging the commercialization of photonics technology in the Canadian telecommunications industry. As part of this role, the Consortium should promote the cooperation of the Applied Research Laboratories and the Applied Research Consortia in their photonics-related activities. The Consortium should have a special interest in promoting technology transfer to Canadian Subsystem Manufacturers.

- An effort should be made to establish The Photonics Consortium in close coordination with SSOC. The Consortium could be cast as the umbrella body for publicly supported photonics activity and thus be held responsible for the gradual rationalization of these activities.

- A sum of public money available through a granting process to be controlled by the Photonics Consortium sufficient to pay for an average of 50% of the system design work for a period five years should be made available. Work would have to be undertaken between at least two members of The Photonics Consortium operating at arms length and from differing membership categories.

- Experiments be designed and conducted to significantly increase our understanding of the user needs for high bandwidth and the conditions under which a genuine market pull can be developed.

- A total of $160 million in federal government funding be planned over the 1994-1999 period in support of the prompt applications of photonics technologies to telecommunications in Canada.

We believe that these recommendations address the opportunities and barriers identified during this study and take the realities of the long-term drivers into account. The Consortium should be eligible to play an as yet undefined role in photonics for the non-telecommunications sectors.

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ANNEX A

PERSONS INTERVIEWED

ANNEX A - PERSONS INTERVIEWED

NAME	TITLE	ORGANIZATION
(A) In-person Interviews		
Dr. Joe Straus	V.P. Sales & Marketing	JDS Fitel
Mr. Leo Lax	Director, Gov't Relations	Newbridge
Mr. Jim Ellis	Sr. V.P. Finance	Mitel
Mr. Kirk Mandy	V.P. Systems & Semicon	Mitel
Mr. Ron Evans	V.P. Marketing	Mitel
Dr. John Madden	Executive Director	Canadian Cable Labs
Mr. Robert White	V.P. Strategic Development	Teleglobe Canada
Dr. Rudy Kriegler	Assistant V.P.	BNR
Mr. Colin Beaumont	Chief Engineer	BNR
Dr. Peter Scovell	V.P. Advanced Systems	BNR
Dr. Peter Dawson	Director General	IMS - NRC
Dr. Richard Normandin	Optoelectronic Devices	IMS - NRC
(B) Telephone Interviews		
Mr. George Lipski	Product Manager	Newbridge
Mr. Jack Terry	Director	BNR
Mr. Peter Shield	Program Manager	SPAR
Mr. Joe Bedford	Vice President	Canadian Marconi
Dr. Morrel Bachynski	President	MPB Technologies
Mr. Brian Sherk	Marketing Director	Bayly Communications
Dr. Michael Leung	Vice President	TRLabs
Mr. Ron Swarbrick	General Manager	EG&G Optoelectronics
Mr. Bill Palmer	Director, Communications	Ontario Hydro
Mr. Germaine Lamonde	President	EXFO E.O. Engineering
Mr. Graham Bradley	Vice President	Sask Tel
Mr. Ron Phillips	Vice President	Canstar Communications
Mr. Don Blacklock	Sales Engineer	DALSA
Mr. Michael Failes	President	Canadian Instrum. & Res.
Mr. Minas Vassiliadis	President	OPTIKON
Dr. Elmer Hara	Professor	CIBINT
Dr. David Thompson	Professor	Ctr Electrophonic Mat.
Mr. Omur Sezerman	Director of Research	OZ Optics
Mr. Michael Hore	President	AEG Canada

ANNEX B

FOCUS GROUP ATTENDEES AND MINUTES

Exhibit 3-2: Estimate of Funding Required ($ Million)

ACTIVITY	STAGE ONE (1994-1997)		STAGE TWO (1998-1999)		TOTAL S
	Federal	Other	Federal	Other	
Applied Research	$45	$45	$35	$70	$195
System Design	25	25	30	60	140
Service Marketing Experiments[6]	5	15	15	30	65
Program Management	3	-	2	-	5
TOTALS	$78	$85	$82	$160	$405

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[6] This funding is in addition to the $16 million which has been approved for Product/Service development for the first two years of Project CANARIE. Some of the money from CANARIE might nevertheless be made available through CANARIE support of the programs suggested in this report.

DATE DUE
DATE DE RETOUR
