Evolution of Innovation:

Fiber Optics and the Communications Industry

By

Rodan Zadeh

Bachelor of Science, Electronics Engineering
California State University, Northridge 1996

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Signature of author

Rodan Zadeh
Sloan School of Management
May 7, 2004

Certified by

Henry Birdseye Weil
Senior Lecturer, Sloan School of Management
Thesis Supervisor

Accepted by

David Weber
Director, Sloan Fellows in Innovation and Global Leadership Program
Sloan School of Management

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Of three metamorphoses of the spirit I tell you: how the spirit becomes a camel; and the camel, a lion; and the lion, finally, a child.

Nietzsche, *Thus spoke Zarathustra*

ABSTRACT:

Innovations can be the single source of industry's growth. How innovations themselves grow or decline also has a direct affect on the health of the industry in which they play. This thesis looks at fiber optic technologies and their impact on the communications industry.

The relative importance of the fiber optic technology is evidenced by its speed and effectiveness in shaping the communications infrastructure in a short period of the recent years. Advent of this relatively new technology, coupled with deregulation policies and the changes in the nature of the network traffic, has caused several disruptions to the communications value chain. Effects of these disruptions and their eventualities are the focus of this thesis.

To study these effects, this thesis looks in detail at the interplay of various life cycle stages of innovations and industry. The innovation stages are classified as: *Fluid*, *Transitional*, and *Specific*. Each of these three stages affects the dynamics value chain of the industry in different ways. The characteristics of each stage are studied in detail.

There are few innovations that can bring about an impact as extensive as the advent of fiber optics communications has. The review of the processes in the evolution of innovation from birth to potential re-birth provides great insights on the industry's life cycle. The study is based on current theories on the subject of management of technology applied to the communications sector. Most examples and data are based on the telecommunication networks in North America; the timeline of the study is the decade from mid 1990's to present.

In closing various strategies in treading the evolution of innovation are described. The evolution life cycle model can be used in several other industries for managing innovation and technologies. Several related research topics are described, and citations for further suggested readings on the topic are provided.

Thesis Supervisor: Henry Birdseye Weil
Title: Senior Lecturer of Sloan School of Management

To my family

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Works like this are never accomplished single handedly; there have been many whose help made this work such a wonderful experience. I thank my professors at MIT Sloan who made my graduate studies unforgettable. My thanks go to Charlie Fine, S.P. Khotari, Shlomo Maital, Arnoldo Hax, James Utterback, Eric von Hippel, Ed Roberts, Rebecca Henderson, Don Rosenfield, John Sterman, and Ralph Katz.

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To my early teachers who inspired me to learn, and sow the seeds of curiosity, I owe a great deal of gratitude. From Mel Stave and Miss Paley of Grant High School, to Profs. Dermendjian and DiJulio of CSUN, I thank you for teaching me never to stop questioning. All that is written here is due to their support and teachings. And although they taught me what I know, all the errors are my own. It is because I have been standing on shoulders of these giants that I have come to see the world.

This work is dedicated to my parents whom I owe more than my life, they both are beacons of devotion and candor. It is also dedicated to my surrogate families: the Mandles of Vienna and Goldschmidts of Geneva, and to my new adapted family, the Saffers of Orange.

There has been one person who stood by me in every step of this year at MIT, without whom life would not be the same, a person who exemplifies the concept of tenderness and care. Not only she accepted to walk down the aisle with me this year, she even carried me through the travails of academic life when my own will to carry-on was starting to fail me. Mine cup overfloweth, Emily.

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1 Introduction:

1.1 Motivation:

One look at the fiber optic communications industry today reveals a seeming state of chaos. Most of the companies credited with invention of the communications infrastructure no longer exist. The ones that do are a complete change of who they were just a few years back. Industry leaders who created many of the innovations in fiber optics are no longer in business. Their products have changed, their R&D cycles and goals have changed, and even their target industries have changed. Large traditional companies have given a way to small number of startups. Many of the startups that existed just a few years ago don't have the funds to continue and will not be around in the future. The companies that have stayed on have benefited from the favorable IPO market of 1990's, and despite financial losses are being held together through their cash savings. Some have used this cash to buy other companies, many of them from the former leaders who are throwing in the towel and exiting the markets.

Of the companies in the fiber optic communication industry today many are unrecognizable to someone from the just 5 years ago. In this small time only some firms have survived, some have consolidated with others, some have changed direction and got a new name, but most have gone out of business for good. Today, a company like AT&T who was essential in research, development, deployment, and commercialization of fiber optics is barely holding on, and is fiercely competing with its rivals.

The upheavals, the chaos, and the dizzying rate of change are no stranger to history books and case studies. Similar changes have taken place in other industries and at other times, mostly over a longer time span. Fiber optic industry is experiencing changes that are well understood and studied, yet these changes have rarely happened as fast. The goal of the author is to review these changes, and take lessons to create strategies. This thesis aims to delve into the abyss and seek out to learn the dynamics that were the cause of this evolution. The assertion is that a closer look should reveal a mixture of various dynamics playing together, and at times against each other.

1.2 Research Methodology:

This thesis uses theoretical resources to introduce the concepts of industrial innovations and their relative lifecycles. In the first chapter these models and additional industry background are presented to set the stage for analysis and review of key data points for the upcoming chapters.

To better present the communication industry, in light of these major changes, a system dynamic model will be used. The model will help in identifying the changes to the industry conditions, technology, governance and policies, competition, customer needs and preferences, and the industry's own competencies.

The changes to the system of the communication industry are focused on financial, technical and societal forces brought about by advent of the internet. These changes combined have affects on each other; in that they are systemic and their behavior is interlinked. Presenting these forces using models from the field of System Dynamics is the best choice as it shows reinforcing events or causes for the industry's change as systemic.

The data is based on extensive interviews, industry reports, and articles on the fiber optics industry. The information is from public, private, and academic sources. Many of ideas covered in the evolutionary model are results of research by several leading authors in topics of innovation methodologies. Theories are result of combinations of reading, lectures and class discussion while attending MIT Sloan School of management. The collection and treatment order of these ideas are based on the authors own research and is primarily based on application of life cycle analysis treatment to process of innovation. The work is divided into a methodology and a theoretical construct, and is followed by extensive examples of key indicators in upcoming chapters.

1.3 Research Scope:

As this report is to examine the spread and the life of an innovation, one that saw its major deployment in North America, it was essential to have most of the focus in this geographic region. Thus, the research is mainly focused on the U.S. industry for fiber optic technologies. The examination of academic and theoretical sources exhibited many stages in the life of technologies may be identified across several different industries. The time frame of this study is mostly concerned with the mid to late 1990's. Nonetheless, there are some discussions surrounding the early adaptation of fiber optics in the telecommunication networks starting from early 1970's.

Although it may be somewhat cavalier to use theories that cut across different industries, it became clear that there is much more in common across various technology fields than not. It may be further cavalier to jump references across the value chain of fiber optic industry and in treating in the same references for both service providers and system suppliers. However, the field of fiber optics is reliant on the complete value chain. The structure and the makeup of the value chain is indeed one aspect of the evolution of the innovation in the communication industry.

1.4 Communication Value Chain:

Having described the stages of innovation, the changes they cause in the innovation regimes, external forces of open innovation (decentralization of R&D), and formation of alliances; the following describes the value chain of the telecommunication industry. In this section a snapshot of players in the value chain of telecom is provided to allow for better analysis in the upcoming chapters.

The communication industry is comprised of many levels of products and services, each of which is evolving to meet its own perceived customer demand and dynamics of the industry. This chapter explains how these sectors interplay with each other, some of their some of their origins, and how they have evolved.

Materials & Equipment	Components	Equipment Suppliers	Network Owners	Service Providers	Content & Applications	Appliances	End Users
•Silicon •GaAs •InP •Polymers •Steppers •Etchers •Chemicals •Etc..	•Lasers •Amplifiers •Transceiver •Filters •Processors •Memories •Fiber •ASICS •MEMS •DSP's •Etc..	•Routers •Switches •Hubs •Base Stations •Satellites •Servers •Software •O/S •Etc..	•Wireless •Backbone •Metro •Access •Substations •Satellites •Broadcast Spectrum •Communication Spectrum •Etc..	•Long dist. •Local •Cellular •ISP •Broadcast •Hot Spots •Cable TV •Satellite TV •VPN's •MVNO's •Etc..	•Music •Movies •Email •VoIP •POTS •Shopping •ERP •SCM, CRM •Surveillance •eBusiness •Etc..	•Computers •Phones •Media Players • Cameras •PDA's •Weapons •Etc..	•Business •Consumer •Gov't •Military •Education •Medical •Etc..

Figure 2-1 Simplified Telecom Value Chain (Fine)

In order to simplify this complicated chain of suppliers and customers, the tiering approach is used to describe each level of the value chain and its relative contribution. The generalized Figure 1-1 is used to describe each tier of the industry as part contributor to the whole of the industry. Today there are many sub-tiers, and several exceptions to each level. However, this simplified view provides the foundation necessary for further analysis. As the industry continues to evolve, each level is evolving differently. Indeed some tiers of this value chain have seen little change over their history and are immune from most of the dynamics taking place, while others evolve much more rapidly.

At the heart of this value chain are tier 2 and 3 suppliers; they will be the main focus of upcoming chapters. These suppliers are often the key enablers of the technical innovations in the fiber optics industry as their devices, modules, and equipment make explicit use of fiber optic technologies. In the early days of fiber optics industry, when AT&T had the complete value chain under one roof, the technical innovation across all tiers was happening concurrently as a companywide effort. With the separation of each of these segments as a stand alone firm, companies in each category are mostly concerned with their own domain for innovation. As a supplier to a larger industry, fiber optic suppliers deal with several competing dynamics. These forces push each supplier to specialize and to stay within its own boundary.

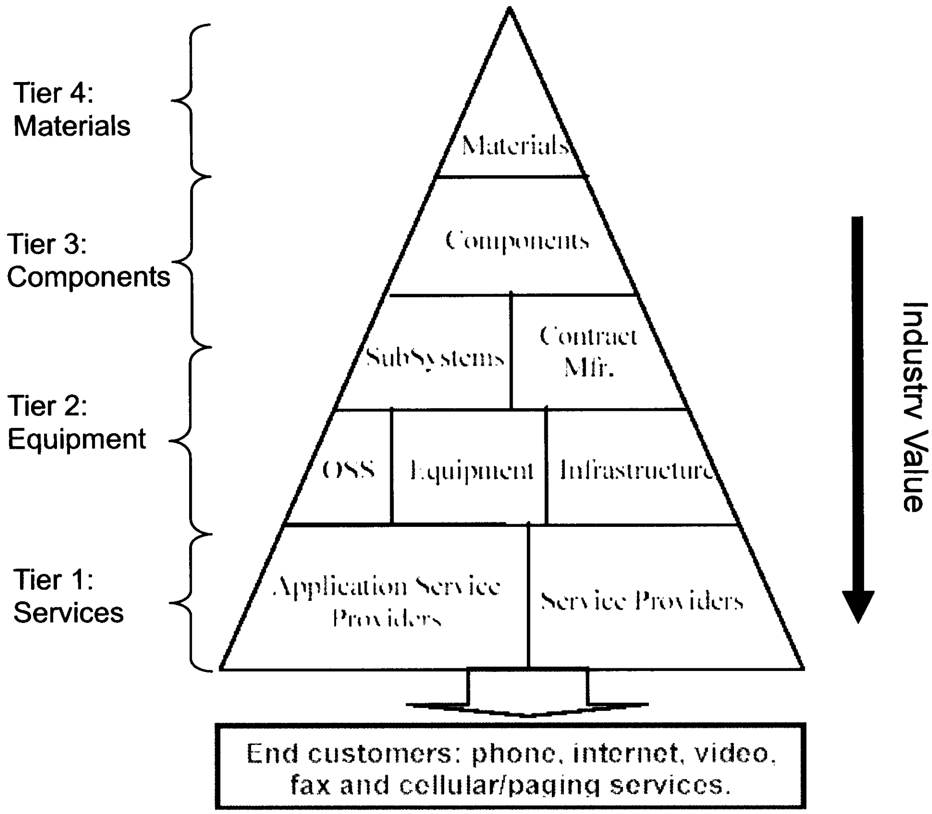


Figure 1-2 Telecom Food chain, how customers are touched.

Each of the company represented in the boxes in Figure 1-2 provides product or services to the next box below it that in turn uses these products and services for the other supplier down the food chain. This succession of the creating products and services continues until the end-customer is reached. In this chart; the size of each layer is representative of the dollar value of that segment; the value devoted to telecom applications. In this model the end customers are users of services outlined as: phone, internet, video, fax and cellular services. All of these services are created through interactions of various players in this value chain. The following are example and definition of the different companies that fill each of these boxes.

1. <u>Materials:</u> These companies provide the underlying materials, mineral or gases -such as Silicon, Nitrogen, plastics – that are ultimately used in production of components or subsystems. Examples of these companies are AirProducts, AirLiquide, BASF, Mitsubishi Chemicals, and LG Chemicals.

2. Components: Such players provide the electronic or optoelectronic devices that are used to actually build larger more complex systems. The devices and components include semiconductors, transistors, capacitors and batteries. Some of the companies that supply these components are: Intel, Agere Systems, JDS Uniphase, Finisar, and Infineon.

   Other products under this category are:
   Photo-Detectors, Laser diodes, Vertical Cavity Surface Emitting Laser (VCSEL), LED's, Transmitters, Receivers, Pump Lasers, Optical Filters, Isolators, Optical Multiplexers, Demultiplexers, Optical Switches, Semiconductor Optical Amplifier (SAO), Fiber Bragg Grating, Circulators and Optical Fibers.

3. Subsystems and Contract manufacturers: As the interface between the users of the components and the engineers and designers in the equipment chain (next link) these companies provide turnkey solutions that are custom designed to serve a specific application. The work of these companies is to create a *mass customized* portfolio to the players in the next link. Some of the better known companies in this field are: Celestica, Solectron, Flextronics, Jabil Circuits, and SCI automation (Sanmina).

   Subsystems products are:
   Erbium Doped Fiber Amplifier (EDFA), Erbium Doped Waveguide Amplifier (EDWA), Optical Transceiver, Optical Transmitter, Transponders, Reconfigurable Optical Add/Drop Multiplexer, and Dispersion Compensators.

4. OSS, Infrastructure, and Equipment: Companies that create the OEM systems and software used by the telephone companies are those that create the platform which the actual telecommunications networks operate on. In this space equipment companies make switches and systems that are responsible for routing calls and providing connectivity. Some of the companies in this space are: Lucent Technologies, Nortel Networks, Alcatel and Siemens. Additionally, construction companies help in installation of the equipment and the cables that link these systems. These include firms like; Bechtel, and Tyco Submarine. Lastly, OSS stands for Operational Support Systems these companies provide software and intelligent services such as route provisioning

and billing to the service providers. Some of these companies are; Metasolve, AmDocs, and Convergys.

5. Service and Application Providers: These companies focus on providing the end customers uninterrupted, highly available, and ubiquitous connectivity from any location to any location. Companies in this category are ultimately the owners of the infrastructure and the users of the telecom food chain. The services provided can take many different shapes; for example two banks linking their operations, or residents in cities access to phone and DSL services. Most of these companies are often well known to the public and enjoy great brand recognition and customer awareness. List of these companies includes; Verizon, AT&T, MCI, and Williams Communications. Additionally, application service providers are those companies that provide applications such as ring-tones, mobile video games, or voicemail systems. Some of the companies in this space are: Kenan Systems, Octel, and Lightbridge.

In this analysis a review of contributions of the fiber optics component in the telecommunications industry is used to identify key factors essential for making those choices. The aim is to describe methods and strategies that ensure the longevity of the lower tier suppliers to any technical industry. The winning strategic technical path of these suppliers is strongly tied to the dynamics of various elements both inside and outside of the industry they play part in. A rigorous approach to industry dynamics and economic indicator are essential to identify role these suppliers play in the value chain.

1.5 Thesis outline:

This thesis is divided into 5 chapters. The first two chapters are introductory in their nature. The first chapter outlines the structure of the communication industry through the description of the value chain. This chapter also outlines the motivation and structure of the thesis. Chapter 2 is an overview of current theories in the topic of management of technology. This description uses the industry life cycle view to describe the three stages in the structure of innovation. It further introduces dynamic shifts in nature of company's' research from a centralized and well defined structure, to one that is 'open' and virtual. This process of decentralization is manifested in the innovation network. Innovation network is described in details with some examples.

Chapter 2 outlines the causes of commoditization process as seen in communication industry. The chapter provides a detailed description of current theories and frameworks used to classify the industry life cycle and evolution. As product innovations proliferate, the industry dynamics require shift to production and process advancement. Firms at this stage need to focus on innovations that help in reducing cost of taking the product innovation to market; this is through excellence in manufacturing, sourcing, or other operational dynamics. The phase of evolutionary dynamics of innovation leads to exits in the supply chain. This is mainly due to firm's core ability is focused only in one area; either product innovation or process innovation, not both. It is during this stage that companies with superior process innovation overtake the market. As the processes focus is cost reduction and value chain optimization process of commoditization sets in. In this environment the customers' choice of vendor is based only on price, thus suppliers have little differentiation. Some create this differentiation through the process of de-commoditization and by providing superior services. It is also possible that in some cases a de-commoditization effort by surviving suppliers takes place. This is done through combining product and services such that a superior customer experience creates a degree of responsibility and trust between the customer and suppliers. This ultimately leads to the process of de-commoditization.

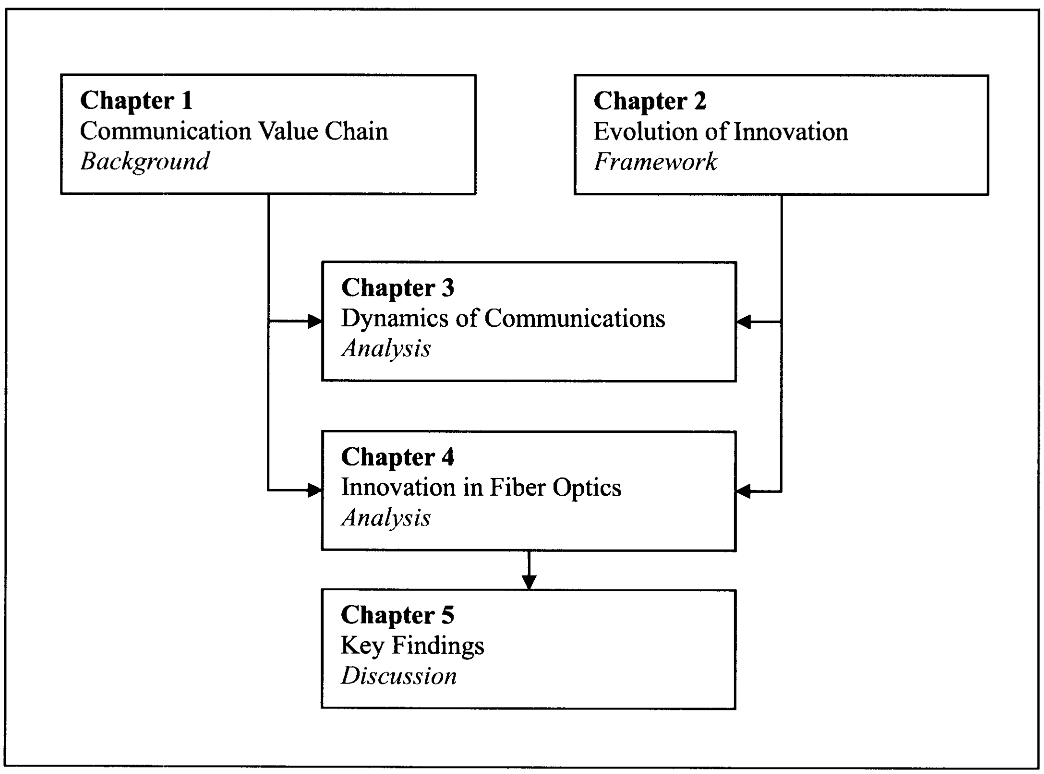
In Chapter 3 a system dynamics approach is used to outline the forces responsible for influencing the structural changes to the communication industry. Using this model, different aspects of innovation diffusion and commoditization process are described. As complexity of communication industry is not easy to capture, this thesis uses both real world examples in showing financial and technological dynamics. To that effort, system dynamics serves as one of the key tools capable of capturing this complexity.

Chapter 4 takes a narrower view of the fiber optic segment of the communication industry. Using tools outlined in Chapters 2 & 3 it reviews different phases of the evolutionary life cycle of fiber optics. This is done by reviewing the number of entrants, patent applications and standardization efforts. The chapter also includes examples of commoditization and describes some efforts for de-commoditization by some players in the communication market.

In the concluding chapter a review of the topics discussed and some analysis is provided. The key findings of the research are outlined and explained in some detail. List of additional readings and additional topic for further research is also provided.

The thesis treats the communication industry as a whole. In this view telecommunications, cable companies, and all their suppliers are lumped under the term communication. Additionally, the fiber optics industry has been referred to as photonics, optoelectronics and lightwave communication. For ease of description this research refers to all of these different sub-categories as fiber optics.

The following is a structural view of the thesis. Chapter 1 and 2 provide the background and framework for the analysis of the following chapters 3 and 4. Chapter 5, the conclusionary chapter is basis for discussion and provides implications on strategy based on these frameworks.



2 Evolution of Innovation:

This chapter reviews relevant theories for describing the process of innovation, they are; innovation network[1], life cycle processes, and commoditization. The theories are mostly based on literature review with use of examples. These frameworks are useful in analyzing the dynamics of the industry evolution, and the view of innovation as a network to describe the communication sector. This treatment is suited to identify the fundamentals of the interplay of fiber optic sectors in general with the specific needs of the IT and telecommunication industry[2] in particular. Utilizing this framework will help better evaluate the changes in the technical development and overall competitiveness of the fiber optic technologies.

2.1 Innovation Lifecycle:

The motivating questions behind this chapter are: "How did the evolution of telecom and IT applications help lead innovations in the fiber optics?", and based on this experience follow up with the larger question of: "How best to strategically manage technologies in industries that are rapidly becoming commoditized". These two questions are interrelated, the answer to the first will help us learn lessons and better understand the possible answers to the second question.

In the following sections several theories on the topic of strategic trends of innovations are reviewed. These theories are by several leading authors in science of management theory and are suitable for treatment of the above questions. The collections of these ideas will help shape the framework for analyzing changes in the innovation in the communications industry. By studying innovation cycles the aim is to have a comprehensive set of frameworks that enable better explain the dynamics of fiber optics. This industry exhibits many paradigms that mostly fit with sets of analysis tools introduced in this chapter.

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[1] In "Dynamics of Industrial Collaboration", Saviotti (2001) refers to inter-firms collaborations formed to create new knowledge as "Innovation Network".

[2] In general it must be pointed out that telecommunication and IT are some of the industries that are served by fiber optics technologies. The technology has many other applications in the field of consumer electronics, automotives, aviation, consumer electronic, biology and imaging.

The chapter looks in detail at the interplay of various life cycle stages of innovations. These stages are classified as: *Fluid*, *Transitional*, and *Specific* by Utterback (Utterback 1994). Each stage affects the value chain dynamics of the industry in different ways. In the fluid stage technologies help many new companies to enter the fray, and challenge the incumbents. The addition of these players to the market temporarily causes rapid product innovations and allows for existence of many competing players alongside each other. It also causes an increase in the available capital and investments as illustrated in later chapters.

During the transition phase the nature of innovation changes from product innovation to process innovation. In this stage, defined as market penetration, a dominant design emerges. The transition phase will result in great shifts in the value chain; many consolidations or exits take place during this stage. Only the firms with the lowest cost of manufacturing and improved processes will survive.

As transition phase winds down, the specific phase sets in. During this stage, overall rate of innovation, both in product and process, decrease substantially. Industry becomes mostly price driven, and there is little differentiation among the players. The price erosion will slow down significantly as there is little profit margin and companies cannot offer any major price reductions without negatively affecting their bottom line. It is during this phase that industries become commoditized. This commoditization process is evidenced by the oversupply of resources and high level of price and margin pressure. At this stage only a few rare number of companies successfully transition their own markets and industries by process of de-commoditization. These companies move from mere products to higher level of services and customer experience. The de-commoditization phase brings back birth of innovations in products and processes.

Over the past decade the innovations in the fiber optic industry have gone through a complete cycle of formation (fluid phase), growth (transition phase), and maturation (specific phase). These cycles have lead to several changes across the value chain and nature of innovation of these technologies. At present as the fiber optic communications industry is gradually seeing a much wider use it behaves like commoditized goods. Using the frameworks and theories presented in this chapter, a journey through the evolution of an industry is reviewed. When combined, these frameworks describe a complete lifecycle of innovation; from birth of the idea (within the network), to the rebirth of a commoditized technology through de-commoditization.

The collections of theories are treated in the following order:

- **Dynamics of innovation**
  Survival of the firm is affected by the technological evolution of the industry and how industries move from product to process innovation. This dynamic treatment is extensively relevant in support of describing the innovation processes.
- **Innovation regimes**
  Here an introduction of theories on internal and environmental factors that affect innovation's creation, distribution, use and advocacy is provided.
- **Commoditization of technologies**
  As innovations evolve, several forces push technologies towards commoditization. Affects of commoditization to innovation and vice versa are described. Additionally, as technologies progress through commoditization, innovations in services augment product innovations. They don't always happen, but when they do they rejuvenate their industries.
- **Innovation alliances**
  Here a broad overview in classifying innovation alliances and their trends is provided. This helps better identify economic forces that drive the innovation in today's environment.
- **Open innovation**
  The evolution of research and development from a centralized entity within the firm to a broad based network external to the firm is identified. This section includes examples from several technology firms.

By including dynamics of innovation, and looking at the stages of innovation, a framework is set for describing the generic dynamics and the process of industry evolution. This evolutionary view helps clarify why so many companies enter and exit an industry. They help describe how the nature of innovation must adapt to the market in which it is taking part. Commoditization processes describe innovations that have undergone the last stages of the life cycle. In this stage commoditized products are undifferentiated and are easily replaced. Life cycle is the process of birth, death; industry's' life brings about creation, growth, maturation and finally commoditization.

Innovation regimes point to the very nature of the market, as created by the evolutionary stages of the life cycle. They point to both the environmental and internal forces as they too undergo different stages throughout the life cycle. The innovation regime describes the dynamics of change and how the industry evolves through a lens of feasibility and applicability of innovations. Including the framework of innovation regimes makes the description of the evolutionary and life cycle complete.

Innovation alliances and open innovations help describe the trajectory of the new era of research, the creation and proliferation of innovations. These two sections paint the picture of a global and macro perspective of innovations. Today innovations need their own alliances by use of interoperability studies, industry wide conferences, industry consortia, and standard bodies to make them a reality. As emerging technologies become interdisciplinary, networks of various technical fields become an essential setting for innovations. Any advancement in the modulation speed of lasers, for example, relies on extensive inter-working of material science, electronics, and optical designs. Furthermore, one cannot discount the important shift in the nature of innovations without fully appreciating the structural changes caused by decentralization of R&D and the move to open innovation. For this very reason they are included in this chapter to identify the dynamics of innovations in a richer scope.

2.2 Dynamics of innovation:

The word "innovation" as used in this report, means a methodology that encompasses process of research and development as well as the act of invention itself. The definition is not just concerned with the pure creation of ideas, but also with the industry wide development and use of those ideas. In general, types of innovations can be classified as either incremental or disruptive. A disruptive or discontinuous innovation is the idea or methodology that renders existing technologies and solutions obsolete. As shown in Table 2-1 an example of disruptive innovation is the invention of transistor instead of vacuum tubes for amplification of electrical signals. Incremental innovations are those changes that build upon existing technologies and methodologies. They don't render existing technologies obsolete, but they are a change in configuration and/or architecture; such as transistors used for higher frequencies application. Additionally, another dimension of classifying innovation is to identify their nature. An innovation in the product often changes the functionality of the product itself. A process innovation changes how the product is made. See examples of glass processes below.

	Product	**Process**
Disruptive	Transistors	Pilkington's floating glass
Incremental	RF Transistors	Differently colored glass

Table 2-1 Classification of innovations[3]

[3] Based on author's own adaptation of the ideas.

The stage of maturity of a market directly influences the innovation and performance of the firm. Growth of an industry is presented by its structure. New industries normally exhibit competition between many small firms, whereas older industries tend to be more concentrated and dominated by few large firms (Werker 2003).

The designation of technical evolution of innovation includes the fundamental dynamics of life cycle analysis. Lifecycle view of technology predicts patterns of relationship among firms and within the industry at each stage of technical and process development (Utterback & Abernathy 1975). At the early stages of an industry the market preference for the technology is not clearly defined. The industry has little understanding of the new innovation and therefore there are no set standards of how best the innovation will be utilized. At this stage many firms with competing ideas enter the market, each with their own unique design. This stage is referred to as the '*Fluid phase*' (see Figure 2-1).

In the '*Fluid phase*' of technical development there are many innovations in the product features and design. Industries in this stage are charting their course through a risky environment, many designs and innovations will not get wide acceptance, nor do many make it through the manufacturing phase. Collaborations in this environment will inevitably be preliminary in defining industry standards and require several iterations. Modifications and adjustment of innovations (in order to better suit customers) taking place at this stage often lead to creation of standards; or a dominant design (Utterback 1994).

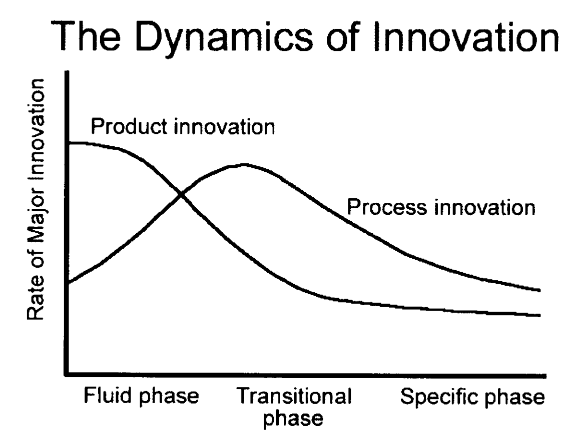

Figure 2-1: Development Stage of Technology and Innovation (Utterback)

In the '*Transitional pha*se' the design of the innovation has been established and widely accepted by consumers. In terms of cooperation and collaborations in between industries this stage sees the most intense level of coordination and competition. Here the manufacturing processes and operational strategies become the key strategic assets, and key differentiator of each firm. During this stage often a sharp shakeout of industry causes a great decrease in the number of players, while the growth rate of the product output of the industry also declines, but not the actual output. According to product life cycle theory, the prices see a sharp decrease during this stage.

2.2.1 Dominant Design:

As product innovations find wider acceptance, and experience greater market pull, they experience much lesser transitions in form and function. Products at this stage have gone through several design iterations and thus have become more dominant. Dominant design imperative increases process innovations. At this stage innovations will have to compete not in forms or functions, but in the manufacturing processes and/or sales stages. The market competition will be in price as the product functions and forms are established at this stage.

The last phase of innovation, namely the '*Specific phase'* (also referred to as maturing phase), the development in both design and manufacturing processes has been highly defined. In this stage products have been fully matured and have gone through several process phases in such stages as manufacturing, sales and transportation. Price erosion is at its lowest point and the rate of innovation in both product and processes substantially drop. In this phase products will start seeing higher rate of defections and will gradually be phased out by introduction of new products and innovations.

The fiber optics industry, first introduced in the 1980's, exhibited a great advantage to competing technologies of other fields. This can be said to have been the 'Fluid phase' of fiber optic technologies. As this technology experienced more widespread attention and was used in larger communications networks, the design dominance set in. Industry moved from fluid stage to transitional phase. Product innovations of the late 1980's and mid 1990's were all essential in building the capabilities necessarily for further process innovation to bring fiber optics to several applications. This time period denotes the *'Transition phase'* of the industry.

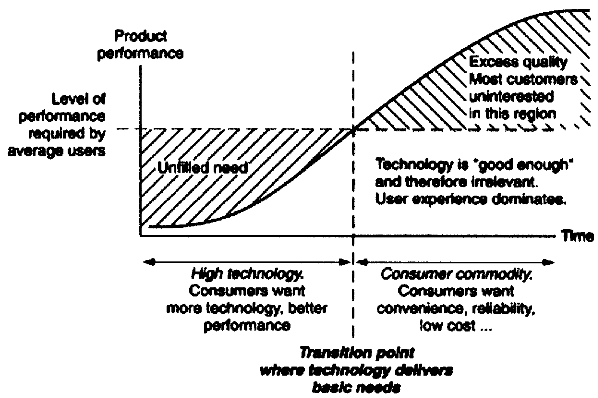

Figure 2-2: Generalized Product Life Cycle Model (Moore)

One indication of the move to transition stage can be seen by their usage in more mature applications. These include IP-routers made by companies like Cisco, and Nortel. Routers are challenged by handling very high speed traffic, and require a very high speed interconnection to their peers. However, they must also be low cost. Until 1995 it would be not common to find optical interfaces in any of these type routers. With the evolution of fiber optics from product to process innovation, the price point of components were driven low enough to justify their usage in variety of IP-routing applications. Today, there are almost no IP-routers without optical interfaces. Price/Performance of optical transceivers has dropped by an order of magnitude over the past decade[4]. This is a clear indication of success of process innovation's in lowering costs.

2.3 Innovation Regimes:

Another framework for understanding the dynamics of the fiber optics evolution is to look at what is referred to technical, or innovation regimes. This theory contributes an explanation to the concept of product life cycle and dynamics.

Advancement of innovation is dependant on industry environment and internal factors as they relate to the nature of the innovation. These factors affect the growth, distribution, and advocacy of the innovations; they are sets of mechanisms that can either advance or inhibit innovation

[4] Analyst reports, industry conferences, and authors experience.

from widespread use[5]. Teece (1987) and Malerba and Orsenigo (1996) regard these forces as 'Technological Regimes'. In their theory treatment is given to several conditions: opportunity, appropriability, and the complexity of knowledge base affecting the innovation's growth.

The ability of the innovator to capture benefit from the innovation, and mechanisms by which her ability in doing so is influenced are referred to as appropriability. The conditions that allow for an innovation to grow or become pervasive are referred to as opportunity; they define opportunity of the innovation in the market place. Another condition to be considered is the notion of complexity of the knowledge base that is required for the innovation. Innovations requiring a large knowledge base evolve in different manner than those with lower need of knowledge base.

2.3.1 Opportunity:

'Opportunity' conditions refer to the level of acceptability of an innovation; they describe how much opportunity an innovation has in being created in the first place. The conditions that allow for innovations to come about define a criterion that can be used to better treat behavior of evolution of the innovation. Once innovations have become part of widespread lifestyles they are hard to change, they leave little opportunity for another innovation to replace it. Looking at innovations through the lens of opportunity can help in understanding the dynamics of the marketplace and scarcity of demand. If there are scarcities that can be met with this innovation, the innovator has higher incentives to innovate. Opportunity refers to the favorability of the conditions for new innovations to see market acceptance.

2.3.2 Appropriability:

The notion of 'appropriability' defines the environmental factors that govern innovator's ability to capture profits from her invention. These include legal protection, trade secrets, continuous innovation, and complimentary assets (Teece 1987). In industries that exhibit low level of appropriability innovations are easily imitated, and thus the innovation itself becomes less important factor of success. The level of innovation in an industry in its later life cycle development stage is mostly process focused (Utterback). Effectively, if the innovation is embedded in the processes inherent in the technology the appropriability applies mostly to trade

[5] Eric von Hippel refers to this mechanism as Locus of Innovation (von Hippel 1979).

secrets since process patents are much easier to "invent around". As such the appropriability will not be highly patent based, in this domain the trade secrets and know-how are the most effective ways of benefiting from innovations.

In the fiber optic industry in the late 90's, as evident from increased level of private capital investment and startup formation, the defection rate of highly knowledgeable scientists increased[6]. As a result of trade secrets and know-how being the only forms of appropriability during this time, the new entrants experienced an ease of entry to this industry. This knocking down of barriers-to-entry not only caused a large entry rate to this industry, it also created many imitations of the same products.

The following matrix of technologies in Figure 2-3 explains the strategies that firms play based on the notion of appropriability and opportunity, as explained above. These two conditions are often independent of each other; there are markets with high appropriability and low opportunity. In a high appropriability condition, quadrant 1 and low opportunity conditions most industries see little innovations. In quadrant 2 when there is little appropriability and low opportunity, most firms exploit their existing innovations and technologies. This is evident in the case of semiconductor firms which introduce new types of circuits to be used in specific applications.

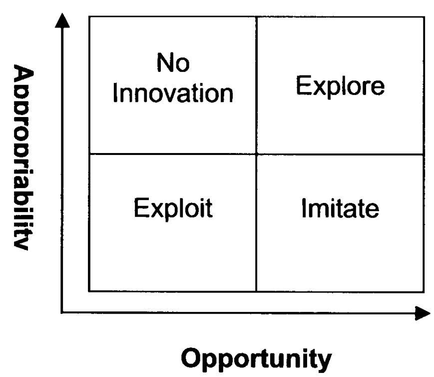

Figure 2-3: Basic Technology Strategy Matrix (Teece)

In the quadrant 3 where there is both high appropriability and high opportunity, firms tend to explore new innovations and technologies. This case sees the highest attractiveness of radical

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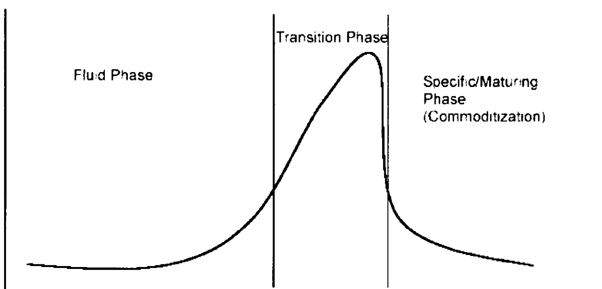
[6] This is in line with Chesbrough's (Chesbrough 2003) view of opening up the innovation in this particular industry.

search and exploration of new technologies. It is in this quadrant that technological progress is very rapid and innovations come from many directions; such as universities, other industries, and other applications. The high opportunity regimes imply that companies will engage in new windows of communications with external sources of innovation to keep up with the changes in the industry.

In quadrant 4 where there is little appropriability but high opportunity firms engage in imitation of technologies and little innovation. In this quadrant there is little need for innovations as the players are able to compete with little impunity. Most firms will pursue production and process innovations to lower their costs. However, as there is little appropriability of complementary assets like production technology or access to markets there is minimal differentiation between the firms.



Regimes				
	Appropriability	Low	High	Low
	Opportunity	High	Reducing	Low

Figure 2-4: Relationship of Life Cycle & Regimes[7]

2.3.3 Complexity and tacitness of the knowledge base:

The level of closeness of the innovation to fundamental science or applied science defines sets of other criteria affecting the evolution process. Innovations requiring complex knowledge base need higher input and interaction with other industries in order to make the innovation

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[7] Based on author's adaptation of the Product Life Cycle idea by Utterback and Teece theory of technological regimes.

successful. In today's innovative environment, the complexity of the products and industries has greatly increased. Most technical industries require combination of several different fields to bring about a prolific innovation, such as Bio-Informatics.

Innovation growth is also related to the firm's knowledge base. The more technical knowledge is tacit, complex and systemic, the more outside industry interaction will be needed. One can expect a greater concentration of innovators, as this type of knowledge can only be learned through collaborations, and requires technical exchanges between players. The innovations that can be made wholly firm specific have tacitness to their knowledge base. They require less involvement from other industries or other firms.

To make a cellular phone device, Motorola requires a complex set of knowledge base. Each device requires understanding of plastics for the physical form and fit of the device; optoelectronics for display of information, brightness and power usage; software processes to create animation and specific voice services; and Radio Frequency characteristics to determine the antennae to be used. Motorola works with several outside innovator to support its activities in mobile phone sets. These include GE Plastics, Qualcomm for RF components and Sun Microsystems for software.

2.4 Commoditization of industries:

The process of commoditization can be identified with two major characteristics; product differentiation is minimal among rivals, and available-to-use supplies regularly outstrip their demand. At this stage all suppliers compete only on costs. Other symptoms of a commoditized market can be low price elasticity of demand, and lower profit margins for provider of the technology. Commoditization of technologies is a real force affecting dynamics of the markets.

2.4.1 Product Life Cycle:

According to Innovator's Solution (Christensen & Raynor 2003) commoditization is a result of the product life cycle and the technology improvement curve. The claim is that "the process that transforms a profitable, differentiated, propriety product into a commodity is the process of overshooting and modularization." The overshooting of the technology or product performance are brought about when suppliers seek to differentiate themselves with product superiority, their main focus is to fight off forces of Specific phase and reduced demand growth.

During the early phases of product innovation, when available products do not meet the needs of customers, innovators that deliver unique solutions with the desired feature set and performance get more customers. The customers at this stage are less sensitive to the price and are more concerned with product performance. As product performance increases so do the number of customers; during this stage technology dominates.

Once the level of required performance by customers is met by products, customers have little incentive for paying higher prices for higher performing products. Inevitably, product performance overshoots the customers' requirements; technology becomes "good enough" and irrelevant. As shown in Figure 2-5 by Geoffrey Moore's Crossing the Chasm, after this transition point the basis of competition changes from functionality and performance to price and convenience. At this stage the sustainable firms will have their focus on the process innovation.

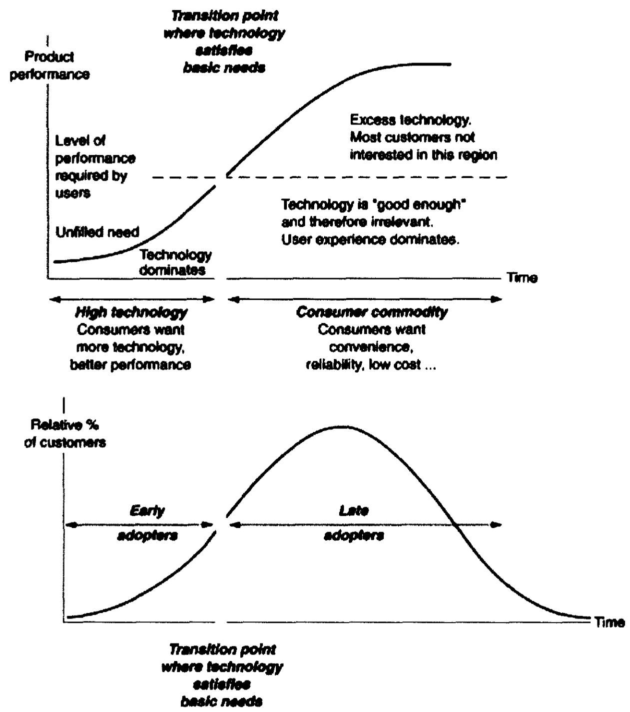

Figure 2-5: Product Commoditization Process (Moore)

As customer's knowledge awareness of the products become substantial, the competitive dynamics of the industry shift. In this shift the power is no longer with the firms, markets become transparent and potential customer defection increases. This shift of power to customers creates a transparent marketplace where the value of technology or innovations is readily available. Customers easily shop around for products; yet another cause of the commoditization process.

2.4.2 Dynamics of commoditization:

Analysis of market and industry dynamics is better treated as a system of interconnected variables and causal relationships. The field of treating management and policy subjects as a system, much like engineering control systems, is a result of work done at MIT by Jay Forrester in the 1960's. The motivation is to review interlinking of the environmental and internal conditions through a systematic analysis. System Dynamic models help use of computers to simulate and explain complex problems that assist in giving a higher level strategic view of the industry. According to Weil (Weil 1996, Weil & Stoughton 1998), commoditization forces are very suitable for a system dynamic model as they incorporate dynamics of consumer behavior, management decision framework, and cost and utilization rates. Weil has used this model for air transportation, petrochemical, telecommunications industries using the model in the Figure 2-6.

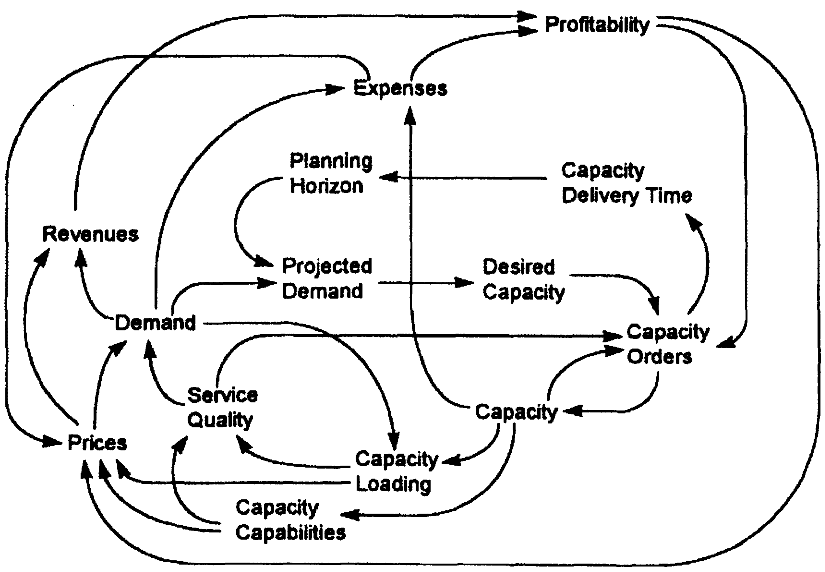

Figure 2-6: Generic Market Model for Commoditization Process (Weil)

Using this model consumer demand is dependant on factors of price, quality of service (both shown in the model), and external inputs like GDP. The relationship between price and demand is not necessarily linear. This relationship is described by price elasticity curve of the product or service. Customer demand affects both revenue and expenses of the firm; it is also used by the firm to estimate and forecast future demand of its customer base. The price-demand-expense loop contributes to the revenue and profitability of the firm. The projected demand and wanted capacity drive orders for more capacity with consideration of the time it takes for new capacity to arrive. The orders for capacity are related to capacity availability and the quality of service the firm offers. These dynamics show that the market behavior is based on its structure; any boom and bust cycle is caused by forces within the system. There are complex sets of scenarios for commoditization as applied to this model:

- Overestimation of projected demand
- Planning errors accumulations
- Entry of many new players
- Abundance of external finance
- Technical breakthroughs
- Social forces
- Market liberalization

The first four scenarios mentioned above can clearly be explained with the system dynamic model described above. *Overestimation of demand* will cause increased orders for more capacity and reduce capacity loading. This phenomenon will ultimately lead to lowered prices to create more demand. However, any increased demand as a result of lower prices will ultimately affect the profitability of the firm. This further drives the firm's management to increase incentives for customers and will cause the firm to make its products more attractive from the competition. This coupled in with explanation of product life cycle in the earlier section drive product and technology performance to surpass above the customer required threshold.

Additionally, an *error in the planning process* will be amplified through the supply chain system and will result in either too little or too much access capacity. With any planning errors on the side of the firm, the suppliers will create their own push for more supplies and thus compound the error. *Entry of new players* will also cause the firms to increase their products performance, or lowered prices, in order to differentiate themselves from the other players. *Abundance of* *capital* will provide more incentive for new entrants to enter the market and thus create market saturation. These forces as described in the last two paragraphs are very real causes of commoditization.

The following is a review of other causes of commoditization (i.e. liberalization, internationalization, technological breakthroughs, and social forces) as applied to this model.

2.4.3 Causes of Commoditization:

The system dynamics model in Figure 2-7 focuses on several sources of commoditization among those described above. These interrelated forces are caused by economic trends and are self reinforcing. *Liberalization* is an act of opening up of the markets to other player; such as deregulation of the airline industry in U.S., or the Telecom Act of 1996. In both of these cases, government allowed for new entrants to enter the existing market where they had little presence before. Through the enactment of these regulatory forces, new competitors change the market landscape and cause shifts to the whole value chain, affecting the profit margins.

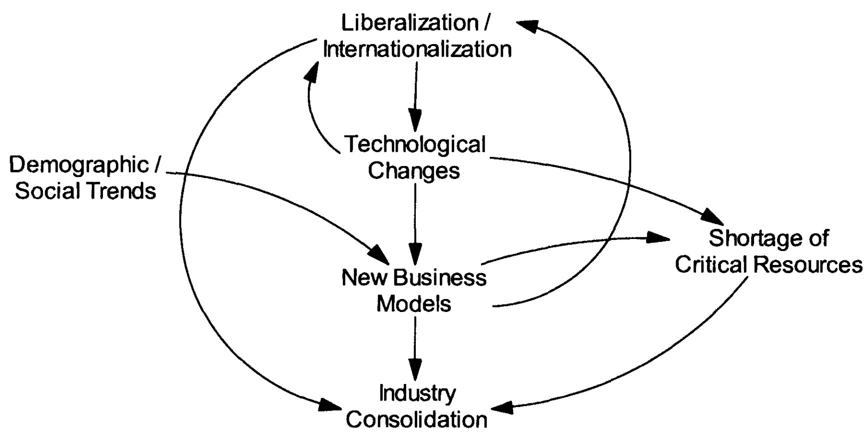

Figure 2-7: Environmental Driving Forces of Commoditization (Weil)

Liberalization and/or internationalization often lead to changes in the underpinning technologies. This change is caused by incumbent and new firm's desire to overcome eroded margins. They can also be due to firms desire to differentiate themselves from others by having different process technologies. Liberalization and internalization can also cause wider industry consolidation. Industry consolidation is a result of both the increased competition and also shortages of critical resources caused by technological change. Resources broadly refer to both tangible assets like equipment, technologies, people, and cash; and intangibles like brand name, product design, and relationships with suppliers and distributors (Christrensen & Overdorf 2000). The shortages are brought about due to increased rate of entry to the market and the rapid depletion of the resources, requiring time for replenishment.

Demographic and social needs also affect the nature of industries and can create a commoditization process. These forces, such as the internet, cause viable new business models to be created and prosper by changes in the social norms. Social norms affected by internet have allowed more reach and scope for firms in accessing their customers. This inevitably has created new business models and business processes. The new class of merchants like Egg financial services in U.K., or E*Trade, challenge the norms of their industries and often create levels of competition much to their advantage of lower overhead and broader customer reach.

Commoditized products are undifferentiated; the firms can only extract a fixed (and often shrinking) value from such products. As products become commoditized, suppliers fight with providing services as a differentiator to battle competitors and thus move up the stage of economic value. This evolution of goods to services often travels through suppliers as each tier of the supply chain moves to increase its own value. In this case the providers of products are not relying on product evolution alone to create value. They transition to the services as a way of creating more value to their customers.

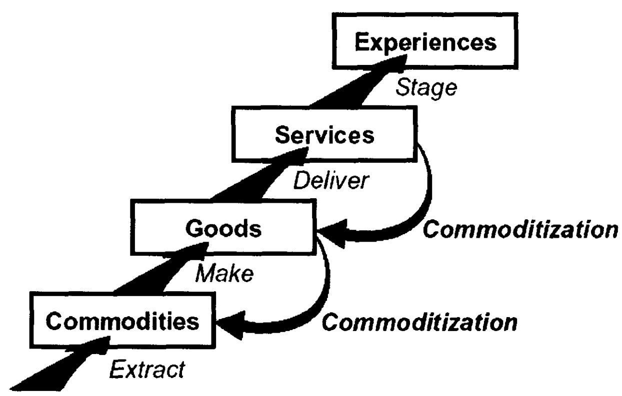

Figure 2-8: Progression of Economic Value (Pine)

There is a process of evolution for product centric companies to fight commoditization by providing services along with their products. For example, in the 1960's and 1970's IBM provided its services of installation, testing and maintenance as a part of the Mainframe computers they sold (Pine & Gilmore 1998). IBM's products at this stage were not a commodity. With the entrance of Wang, Burroughs, and DEC, IBM was inching closer towards commoditization. Once the plug-compatible peripherals entered the market, the Mainframe computers started to become more of a commodity.

After the unbundling of its software from the hardware, IBM sought to maximize profits from its software and services group. Today with its focus and growth mostly from its services arm (IBM Global Services) IBM is fighting the commoditization of its mainframe computers and has moved up in it economic value. In addition to computer industry, the move from products to services can also be seen in the telecommunication industry. There was a time that phone sets were part of the network of AT&T's Bell Systems. Services in the telecommunications industry are evident through the changes from simple voice calls to offerings of new additional call features such as call waiting or call forwarding.

As commoditization causes firms to shift their focus to services (and experiences according to Pine), the processes throughout the value chain also shift. IBM uses extensive network of contracts to manage its activities to provide computer and network services. Additionally, it routinely stations its technicians at customers' locations. IBM's supply chain is altered by use of offshore and outsourcing facilities in order to manufacture computers and other peripherals.

By the process of innovation in services, commoditized products see creative destruction[8]. Transition from the destruction of existing products to creation of new services through innovation is a tool to fight back commodity markets. The creative companies look for ways to innovate solutions that satisfy their customers' needs better than their competitors. As Pine explains, the evolution from products to services, and then on to experiences often create 'markets of one'. The core of this theory is based on driving off commoditization, as the value offered to the customer is no longer limited to the product. In the case of experiences and higher level of economic progression as shown in Figure 2-8, product innovation is no longer the focus

[8] First coined by Schumpeter in 1930's, today the term has come to re-innovation and creation of new products by destroying existing ones.

of the firm. Offerings in service or creation of experience see the most innovation. As individual firms move from products to services, the industry itself transitions to service (or experience) economy. Through the innovations in services the markets move from a commodity centered product to a more service oriented solution. This is the process of de-commoditization.

2.5 Innovation alliances:

Innovations are rarely result of an individuals act, they are often formed by collaborations and concerted efforts of several individuals or organizations. As one focuses on nature and results of innovations, the dimension of alliances and collaborations must be viewed as well. The following is an overview of these topics.

2.5.1 Innovation networks:

The concept of industry collaboration as a strategic tool for innovation and knowledge creation has its roots in the early part of the 1980's (Saviotti 2001). In just a couple of decades the notion of collaboration between industries has become the creator of many new product and service innovations. Often these innovations when formed create a total value as a single unit. Each party's contribution on its own has low relative importance to the project, but once integrated the results are captured by both parties. This is the case of whole being greater than sum of the parts. One example of such collaboration can be seen in use of microelectronic systems in automotive safety applications. In this case microelectronic based mechanical sensors are utilized to detect collision or sudden stop of the vehicle and rapidly actuating the airbag system in response. This is a clear interplay of two completely different industries (that of automotive and microelectronics); this alliance has created a technology that is deployed in almost every vehicle made.

The realm of alliances can be broken down into three main categories. The first are the alliances and cooperation that can be viewed *within an organization* or the firm itself. This view looks at organizational and behavioral modes of interactions within the company's various divisions. Second classification is given to *alliances and cooperation of various organizations* within the same technology industry, competitors included. In this classification the overall industry is treated as one entity whose relational interactions shape the behavior of its customers (e.g. alliance of suppliers of VHS VCRs to shift markets from BetaMax). These firms use technology diffusion as a cause to engage in alliances between each other. Third classification describes the interplay and cooperation between two different parts of industry that ally to improve their operational and research strategies.

In the case of fiber optics technologies the level of alliance and cooperation can be seen almost in all levels and in many products. For example, these levels of cooperation can all be seen in the fiber optic's pump laser module[9] industry. From the manufacturers of pump laser chips to parties that package these pump lasers the cooperation has historically been a necessity. In the year immediately following the 1997 breakup of Lucent Micro-Electronics (fiber optics component) group from AT&T, an IBM spinout called Uniphase was the sole supplier of the laser chip that went into making this device. Lucent ME had not been successful in building its own chip technology suitable for using in pump laser applications. It thus required a partner who would provide the essential semiconductor heart of the pump laser module. This relation required detailed collaborations between Uniphase and Lucent ME in ways to integrate the chip technology in packaging the electronic feeds of the pump. In addition to this two node network of Uniphase and Lucent ME there were several other (albeit less significant) innovators, these included solid state electronic cooling elements, instrumentation firms in charge of the assembly and test technologies, and electroplating technologies. This exhibits a complete network of innovators linked through a collaboration network.

2.5.2 Specialization and complexity:

There are several emerging forces that cause inter-industry collaborations. One force is created by the specialization of the technology driven changes within many advanced industries. Industries move to innovate in different and more heterogeneous ways. Consistently industries are developing more and more niches (Plunkett 2001 and Adner & Levinthal 2002). The advancement of technologies and the natural growth of research have consistently been towards more specialization. Diversified firms by their nature lack this specialization; thus need to utilize capabilities from external organizations and industries. For them the most efficient way of fulfilling the need to innovate is to cross share of resources and to collaborate on a wide scale

[9] Pump laser modules are used primarily to provide a very high intensity constant level optical input required for optical amplification of input optical signals. This is analogous to the current drivers used on powering the Collector pin of the transistors for signal amplification.

and domain.

Another force pulling industries together is the dynamics of product complexity and the significance of technical exchange (Chesnais 1988) [10]. As products become more complex they integrate resources from various industries across the globe to reduce costs and stay competitive; thus further emphasizing the importance of collaborations with other industries in order to share resources. Taken together, these two forces (specialized technical advances and their complexity as described by Uniphase and GM examples) have created an even greater importance on the need for innovative networks[11].

2.5.3 Depth and breadth:

In addition to companies of similar size and industry, innovation networks span domain of various company sizes. In his research in the field of innovation networks P. Saviotti finds a steady growth in the appearance and frequency of industry collaborations across several industries. He found the rate of occurrence to be even higher in technology related fields; evident in industries such as IT, Biotechnology and new materials. The process of evolution of these technologies has lead to creation of what he calls New Technology Firms (NTF)[12] having more depth and specifity. Importance of the emergence of NTFs is that their focus and dedication is solely devoted to discoveries and improving of these emerging technologies. Their explicit focus combined with their knowledge depth makes them ideally suited for partnership with larger incumbent firms; Figure 2-9.

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[10] Original source of this point is credited to F. Chesnais by author C-A Michalet. Michalet's work it titled "Strategic partnerships and the changing internationalization process".

[11] In her book "Strategic Partnerships" Mytelka cites empirical evidence from IT, aircraft, and telecommunication industries to describe the economic and technical forces driving alliance networks. She further provides evidence from EC and EUREKA frameworks used to evaluate research based joint ventures.

[12] The term NTF is used extensively by Saviotti in describing the breed of new companies that are at the technical forefront of their industries. These firms are most evident in the field of high technology and related to biomedicine. In biomedicine the dedicated firms were the first to be able to understand and use new technologies in gene sequencing. These firms are generally startups.

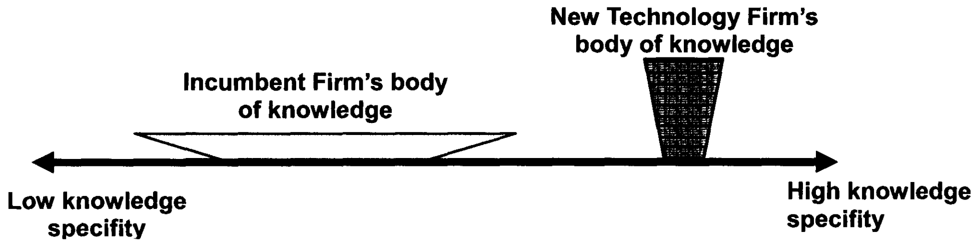

Figure 2-9: Firm's knowledge depth and breadth[13].

The NTFs benefit the larger incumbent firms with their innovations; and the larger firms provide scale and resources (complimentary assets) to the NTFs. In the case of biotechnology these NTFs play a significant role in forming new dynamics of the industry. So much so that many large pharmaceutical firms mostly rely on their alliances with these specialized biotechnical enterprises for the introduction of their newest blockbuster treatments.

Although historically a great degree of collaboration and knowledge transfer existed between the established firms and the public research institutions (such as universities), today NTFs have also changed the way these two work together. The new technology firms have the capability and the capacity to better understand the dynamics of new technology and their potential to the industry than universities do. Here NTFs close the knowledge gap between public research institutions and larger more established firms, offering better understanding of the impact of technologies to the relevant industry. In short the NTFs have become the catalysts for adoption of new technologies by larger diversified firms as well as public research institutions.

The rate of knowledge creation and utilization in most industries has reached an ever increasing pace. The imperative is that the overall firm activities have become more and more knowledge based (David & Foray 1994). Due to its long evolutionary history, scientific knowledge of industries has become more complex. Thus, knowledge creation and utilization have become the leading factors of competitive advantage of firms (not just for those in technical fields).

Subsequently, at any given time the external knowledge available to a technology firm is far more advanced than those available within the firm itself (Saviotti 2000). This is yet another force amplifying the need for various industry collaborations and innovation networks.

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[13] Based on author's representation of the ideas represented by Saviotti et al.

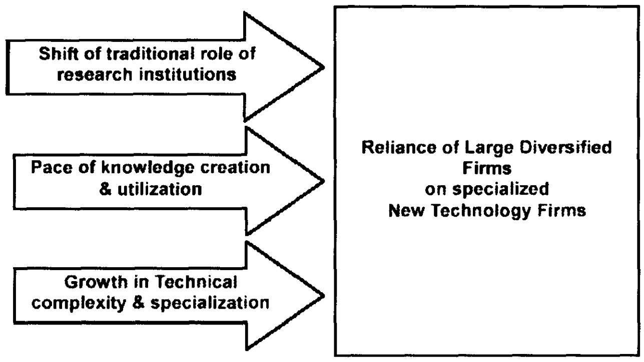

Figure 2-10: Forces driving need for industry collaboration and innovation networks[14].

2.6 Open Innovation:

Innovation networks and decentralization of research are adequately described by Chesbrough as Open innovations (Chesbrough 2004). The assertion is that the nature of research and invention has over the years shifted to a more disparate and distributed network, thus the term 'open'. Today many established and leading firms have difficulty to justify keeping their internal R&D centers alive. These firms see little benefit for internal investments for research and creating internal knowledge silos, where the knowledgeable customers and suppliers are challenging profitability from this knowledge base. Instead these companies are closing down their internal research and doing away with core R&D departments.

For example, Bell Labs as the core research arm for AT&T, and later its spin off Lucent Technologies mentioned above, was responsible for creation of many innovative communications products. Bell Labs endowed Lucent a wealth of innovations which subsequently Lucent brought to market. These new products allowed Lucent to stay ahead of its competitors in the communications market for sometime. However, a more nimble competitor, Cisco Systems, was able to match most of Lucent's new products. Cisco was able to do this despite its size and almost no internal research activity. Lucent continued to pursue fundamental research across the complete telecom value chain; these included materials, components, network systems, operation and software systems, and new services. Cisco, however, was

[14] The diagram is based on author's representation of the ideas represented by Saviotti et al.

focusing its activities in partnerships and research in very niche areas of network systems and software. Cisco scanned the communications landscape of small and medium established firms along with startups and newcomers. To be competitive, Lucent has cut down its R&D budget substantially and has partnered with startups like Juniper[15] and Movaz Networks[16].

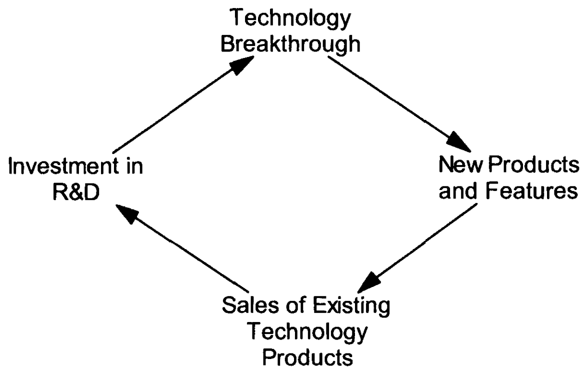

Figure 2-11: Closed Innovation Virtuous Cycle (Chesbrough)

Firm centric innovations like those of Bell Labs are referred by Chesbrough as '*Closed Innovations*'. The paradigm of 'Closed Innovations' refers to a mental model that is based on the notion that larger firms carry out most of the research of their respective industries, and that their capability in scope and scale of research is unsurpassed by others. They saw this scale and scope as a necessity for competitive advantage. Industry leaders such as IBM, AT&T, Xerox, DuPont, Merck, and GE were the quintessential firms that operated with this mental model. Innovations of this form have been responsible for success of many firms in the late nineteen and early twentieth centuries. Many of inventions prevalent in our daily lives, such as Penicillin and the photocopy machines have been results of these types of innovations. This paradigm works well with companies in vertically integrated industries where the company's great knowledge is a barrier to entry for new comers.

The notion of closed innovations involves a 'virtuous cycle' (Figure 2-11) in which only companies who invested in their internal R&D benefited from creation of fundamental technology breakthroughs. These breakthroughs enabled the company to further benefit by

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[15] Company press release; Juniper Networks and Lucent Technologies announce partnership to deliver unified solutions for service providers, May 5, 2003

[16] Company press release; Lucent Technologies and Movaz Networks announce agreement to develop next-generation metro optical solutions, February 24, 2004

increasing sales based in this new breakthrough. Using the proceeds of the existing product ideas, or innovation, the company would increase investment in research and development of related innovations. The cycle made it extremely difficult for any competing companies to join the fray mid stream. Without the benefit of this process any new innovation would fall short of the previous required background of breakthrough and essential funds for development of new innovations.

Closed innovations have recently been challenged by Venture Capitals and mobility of highly experienced and very skillful employees. Together, these have created opportunity for many of the leading scientists of larger more established firms to pursue their own ventures. This erosion of the closed innovations created favorable environment for individuals who were the lead researchers and core of the research group of the larger firms to defect. These scientists go in pursuit of the same fortunes as many of their former colleagues did, there were potential of millions to be made when these startups were sold or went IPO.

The 'virtuous cycle' model is broken (Figure 2-12) with the help of the venture capitalists, the key personnel are given the option of defection to form their own company. As they defect, they disrupt available resources for internal innovations in their previous company. Any successful idea of these innovators benefits only the individuals and the investor community at large; there is no longer reinvestment of the winning innovation back into the original firms for further innovation.

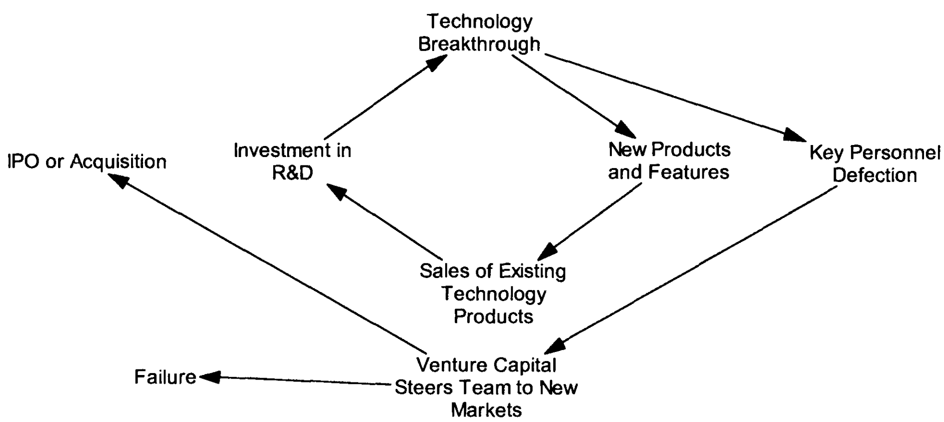

Figure 2-12: Virtuous Cycle Challenged (Chesbrough)

Another factor in changing the nature of the closed innovation is ever shortening of product lifecycles and times to markets. The change in the innovation shelf-life of new products and services does not allow a great deal of time for companies to pursue only one line of product research and development. Today companies, large and small alike, cannot risk to discover, develop, resource allocate, produce, and market products single-handedly. Any bottleneck or shortfall in any aspects of this product evolution process destroys the overall resources of all of the company. It is a much more prudent strategy to partner with outside resources whose scale and scope in each stage of product innovation process surpasses any one company alone. Most firms faced with decision to partner or risk the market window for their products often chose to partner.

Today, Quanta Computers of Taiwan is responsible for both design and manufacture of laptops for both Hewlett Packard and Dell concurrently[17]. These design outsourcing houses have proven to be a critical source of product innovation in the field of technology. Original Design and Manufacture (ODM) carry out both development and manufacture of products with instructions from the firms that hire them. Since their focus is often very narrow these shops are able to innovate to the specific needs of the products and services their customers expect of them.

2.7 Summary:

Various frameworks and analysis tools were introduced for better describing evolution of innovation. Prevalent in all these frameworks were the relative technical, environmental and internal imperatives which are responsible for the outcome of the growth of the industry. These sets of theories can be used to better understand the changes in the fiber optics industry as related the telecommunications and IT markets. The themes of these analyses were based on the view of innovation as having both internal and external properties. External forces such as; *appropriability, opportunity, industry phase (i.e. dominant design), and venture capital* create conditions that directly affect the advocacy and pervasiveness of the innovations. Internal forces such as; *employee defection, knowledge base, internal R&D expenditures, and company's alliance choices* affect the sustainability of the innovation or the industry.

During the late 90's fiber optics industry experienced a tremendous financial input in the form of

[17] Company presentation during visit and tour by the author.

venture capital. The interest of financial industry was the growth outlook and opportunity of this innovation. By reviewing the dynamics of 'innovative regimes' the reasons for such influx become evident. There was clearly a high level of *opportunity*. Due to the *transitional phase* of the fiber optic industry, there was little *patentable appropriability*. Most of the *appropriability* was in the form of *trade secrets* that left the companies with high *employee defection* rates. Innovations in the communications industry tend to be very complex and as such require a larger *codified knowledge base*. They require extensive *innovation network* and require a higher reliance of larger companies on startups for a deeper understanding of the underlying technologies.

As industries move from transitional phases of their evolution to a mature phase, process of commoditization sets in. In this stage competitors are all battling for differentiation of their products and through lowering costs of production. Product innovation gives away to process innovation; industry thus becomes more concentrated. As some of the new entrants exit the market, a process of consolidation takes place. The defection of players leaves the market to specialized firms that have better process innovation. In this phase of the industry price becomes the key competing force for the remaining firms.

Not all firms escape the commoditization phase of their respective industry. For those who survive the dynamics by maneuvering their innovation according to the industry needs, or by having deep pockets to survive the massive consolidation, the outcome is to re-innovate. The few remaining players create services for their customers and define the industry with a higher *economic value*. These dynamics of shift of innovation through various stages are the essence of economics of the industry. The evolution of innovation is a result of many of these dynamic forces and paradigms. Frameworks mentioned in this paper are useful in better describing the tectonic shifts of taking place in the innovation domain of the subject.

3 Dynamics of Communications:

In the previous chapter we outlined a framework for analysis of the fiber optics and broader telecommunications industry. These frameworks shall be used in light of the larger dynamics of the communication industry. The following is a treatment of communication industries using system dynamics to describe these forces and their influence. Three system dynamic models are represented; the first model in Figure 3-1 is of the overall industry interactions with macro-economic drivers, the second in Figure 3-8 shows the dynamics of the value chain as part of the larger model, and Figure 3-15 focuses on the dynamics that focus on technology diffusion of the whole industry. These three models are interlinked by focusing on a particular dynamic of the overall industry; they show macro, value chain, and technology related forces respectively. Together they are a comprehensive look at the complete dynamics of communications market.

3.1 Introduction:

The factors leading to the dynamic changes of the fiber optics industry are complex. The complexity of this industry's relationship with other sectors of the telecommunications industry points to an even more dynamic and complex interplay of both internal and external factors. To better understand these complexities and their relative impact to the innovative output of the fiber optic industry at first a comprehensive review of the dynamics in the telecommunication industry is needed.

In this section we refer to network service providers, or telecommunication carriers as CLECs, ILECs, IXC and RBOC. For the purpose of this study a distinction between these levels of players is not essential. Additionally, in this chapter fiber optics, or optical component industry, is treated as a contributor to the overall telecommunication industry. The set of information are combined in this chapter for further analysis using a systems approach. Both historical information and system analysis of these factors follows.

3.2 Generic Model of Communication Industry:

The North American communication industry has undergone a tremendous change over the past several decades. Complexity of these changes has steadily pointed to an industry borne of cyclicality, and a commoditized market facing commodity pressures from many angles. In the past seven years the advent of new applications such as internet, email, and video has added some more dimensions on how the telecom network is used. This new dimension of usage has created some temporary shifts in the dynamics of the network and thus the entire industry. However, as the industry has undergone the cycles of consolidation and has had time to digest the challenges of these new applications the dynamics of the telecom market are getting back to their historic norms and exhibiting commoditized behavior.

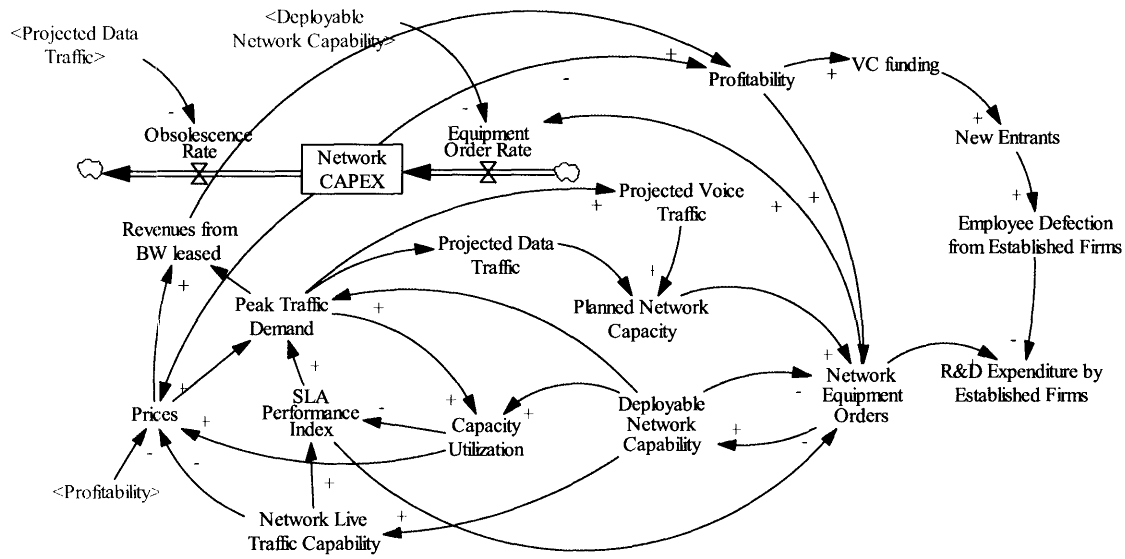

Figure 3-1: Dynamics of the Communications Industry

The macro affects of commoditization of the communication industry is best seen using a system dynamic approach. Doing so helps us describe the drivers of various elements of the industry more richly. Industries in the commodity markets show similar cyclicality traits in many levels, including: capacity utilization, capital investment, price changes and demand growth. The system dynamic model used here is mainly based on a generic model of mature markets, developed at MIT Sloan School of Management by Professor Henry B. Weil. Using this model, different stages of market maturity and dynamics can be represented and analyzed; these include liberalization, consolidation and overestimation of demand growth. The version used here is a modified version of the original generic model developed by Prof. Henry B. Weil[18].

The core focus for us of this model is the representation of the *Network Equipment Orders*. These orders are a function of profitability, planned network capacity, current state of deployable network capability, and projected voice and data traffic types. Later in this section we take a closer look at the dynamics of the supply chain and how the equipment orders affect the fiber optic component orders. The view will include consideration of the whole value chain – from components to network capacity. Additionally, we will take a closer look at dynamics of innovation in migration to new and innovative network technologies. These two system dynamic models are interlinked with the general dynamics shown in Figure 3-1.

In this modified version a special treatment is given to projected demand growth for voice versus projection of demand growth for data. The differentiation is primarily due to the difference between traffic based on voice[19] and those such as video and email that are generally treated as data[20]. This helps conceptually show the dynamic of new services beyond 1997 that ultimately led to the innovation of network topologies and technologies. Additionally, as available network capacity increases, the traffic demand of the network is affected directly in a positive direction. This relationship is not linear, however. In general, user behavior changes as the access to faster networks (networks with more capacity) increases[21]. This factor is indicated by the link between the peak traffic demand and the supplied active capacity highlighted in special color.

The deployable network capability is a measure of the network's availability for rapid deployment. These are network equipment that are ready to be deployed but have not yet been put in operation; they represent the unpopulated channels of the fiber optic transmission equipment ready to be "lit-up".

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[18] Henry Birdseye Weil; "Commoditization of technology-based products and services", Sloan Working Paper 3887, WP#144-96, March 1996.

[19] The growth of voice traffic has been projected for many years and had a relatively well understood growth pattern using Erlang models along other actuarial and statistical frameworks.

[20] Data based traffic is handled as 'packets' and does not require a constant connection between the nodes of the network. Traditional voice based traffic required a semi permanent circuit connection between the nodes for the duration of the call. Thus data traffic projected demand needs to incorporate a lower weighting on the overall network load.

[21] Pew Internet & American Life Project, "The broadband difference: how online Americans' behavior changes with high-speed internet connection at home," 2002

Planned network capacity is determined by the projections of the overall traffic that the network demands, this is based on forecasts, market studies and historical data. Historically the growth of the voice traffic has been close to 8% annually, for the decades leading up to 2000 data traffic was doubling every year with the exception of 1995 growth explosion[22]. The live traffic capability is a measure of the networks total capacity that is able to be provisioned without any further addition of capacity. It is analogous to total number of seats on all the flights an airline flies, regardless of them being occupied or empty. It is a measure of total available capacity. Overall backbone traffic carrying capacity of U.S. network was close to 10 Petabytes per month in 1997[23].

Capacity utilization of the network paints a clearer picture of the dynamics of the year 2000 to 2001. In years proceeding to this period a large number of networks were deployed beyond the traffic demand to justify this growth. During this time the overall deployable network capability had increased dramatically. The dynamics of the overbuilt fiber plant and massive deployment of communications equipment in the prior years are evident in Figure 3-2. The effect of the lower capacity loading mean that the equipment order rate undergoes a decline until the equilibrium is met. That is exactly what is happening at the time of writing this research and is exhibited in Figure 3-3 a & b.

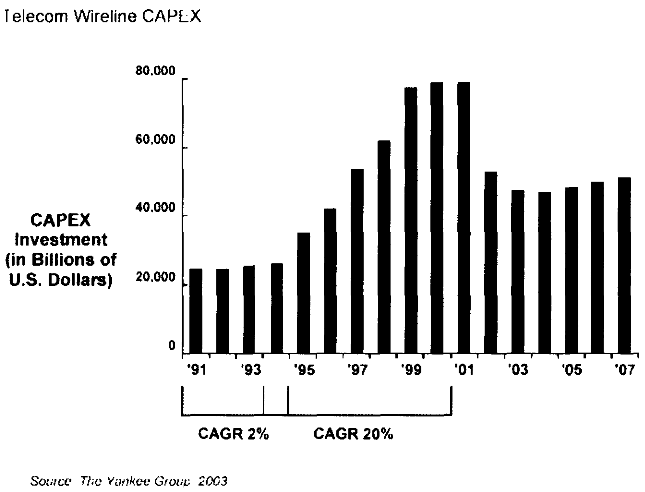

Figure 3-2: Capital Expenditure for Wireline Equipment (Yankee Group 2003)

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[22] K.G. Coffman and A.M. Olyzko, "The size and growth rate of the Internet", First Monday, vol. 3, no. 10, October 1998

[23] Telecommunications Industry Association, "*Fiber Optic Network Capacity and Utilization*", September 2002.

Service Level Agreement or SLAs are sets of contractual and physical obligations which the network carrier signs up to when initiating new services. Meeting the agreed terms can be used as measure of merit in the quality and service level of the networks. SLA performance is a result of network utilization and the network's live traffic capability.

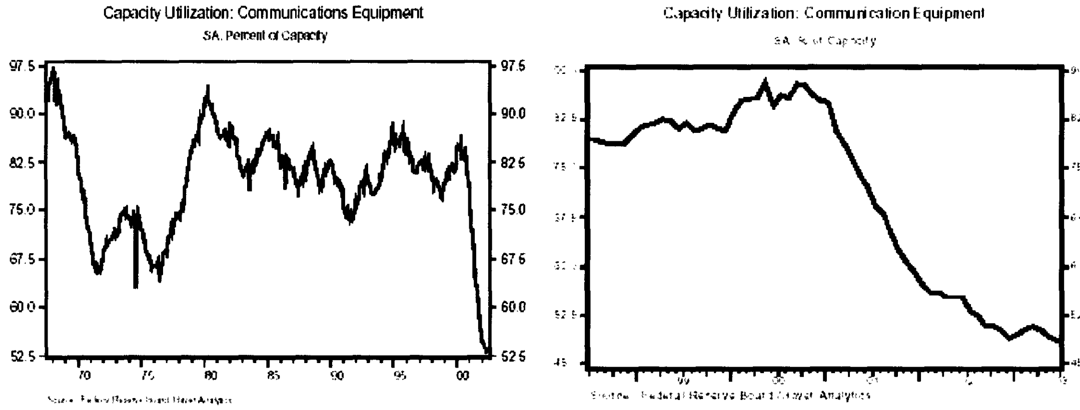
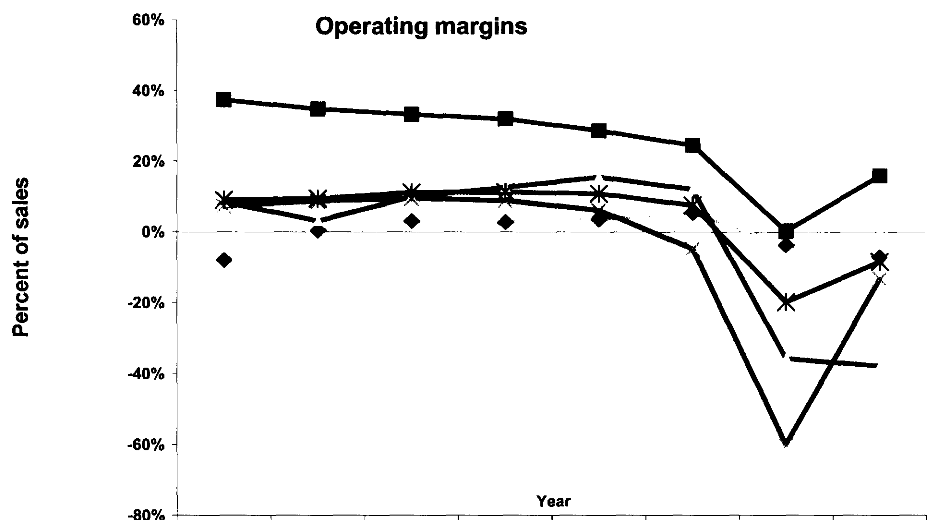


Figure 3-3: Capacity Utilizations; A Historical View (Federal Reserve Board)

An operator's profitability and revenue are tied into its pricing of its Service Level Agreement lease terms based on traffic (also referred to settlement agreement or leased channels). In the case of the communications network providers in 2000 and 2001 this dynamic was drastically affected by capacity utilization, and network live traffic capability. The prices were driven down and affected the operating margins across the board (in this case the profit margins of the suppliers to the industry were negatively affected and are exhibited). This is a clear case of proliferation of players where the market over capacity drove down prices and caused reduced margins for all players. These dynamics are part and parcel of commoditized markets as shown in Figure 3-4.



	1995	1996	1997	1998	1999	2000	2001	2002
ALCATEL -ADS	-8%	0%	3%	3%	3%	5%	-4%	-7%
CISCO SYSTEMS INC	37%	35%	33%	32%	29%	24%	0%	16%
LUCENT TECHNOLOGIES INC	8%	3%	10%	13%	15%	12%	-36%	-38%
NORTEL NETWORKS CORP	7%	9%	9%	9%	6%	-5%	-60%	-13%
Avg margin	9%	9%	11%	11%	11%	7%	-20%	-8%

Figure 3-4: Equipment manufacturers Operating Margins

3.2.1 Human Factors:

As depicted in Figure 3-1, as the number of profitable ventures increased, so did the entry rate of new employees into the industry and movement of scientists to these new ventures. The job market became favorable to those workers with communications experience that could help these new ventures. The increase was later followed by a decline as more and more companies were forced to flee the market and exit. The effects of R&D efforts are directly related to the number of employees and their relative activities. During this phase of employment rise and fall the R&D efforts of the larger companies increased. As indicated in Figure 3-5 the research funds for all the telecom equipment manufacturers fell by a great degree during the years 2001 and 2002. This was caused by the overall conditions of the industry combined with change in the dynamics of funding for research due to presence of venture capital firms (open innovation). Many companies during this time focused more on acquisitions and collaborations with the new ventures, thus reducing some internal R&D as indicated by the graph.

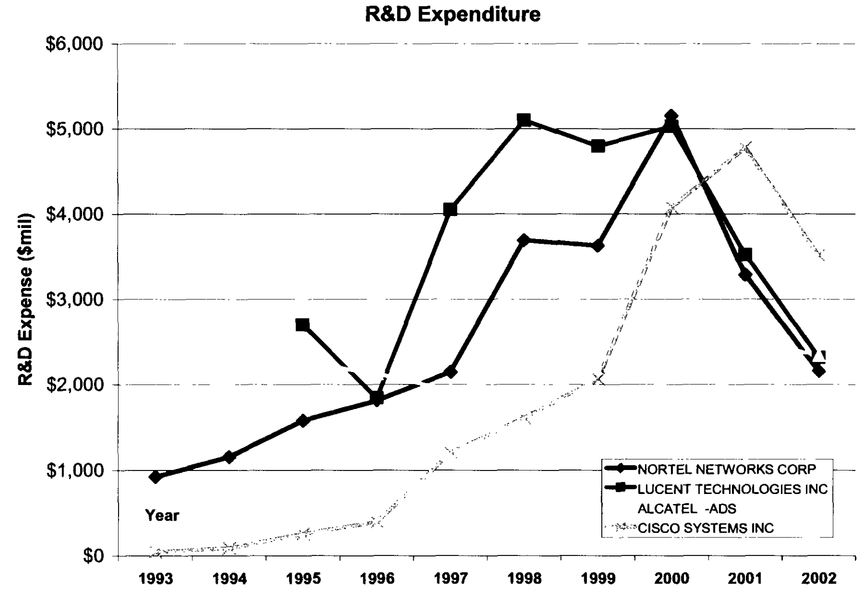
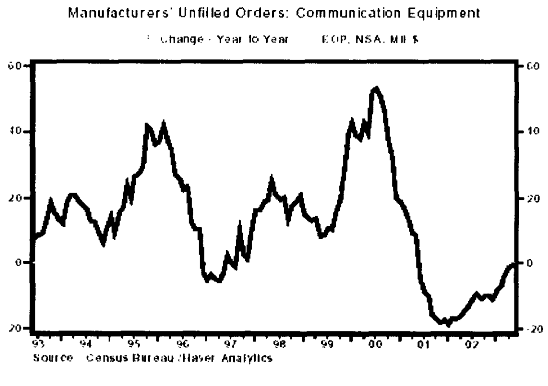


Figure 3-5: R&D Expenses, Equipment Manufacturers

3.3 <u>Supply Chain Dynamics:</u>

Within the larger model of the communications, described in Figure 3-1, is an embedded and complex interworking of various stages of the supply chain (shown in Figure 3-8). As in any supply chain, the dynamics of demand driven capacity and production are systemic. That is, they have extensive feedback throughout the various tiers of the network. Each sector of the supply chain seeks to maximize its operations by having available only parts that can be sold, and holding only limited inventory.



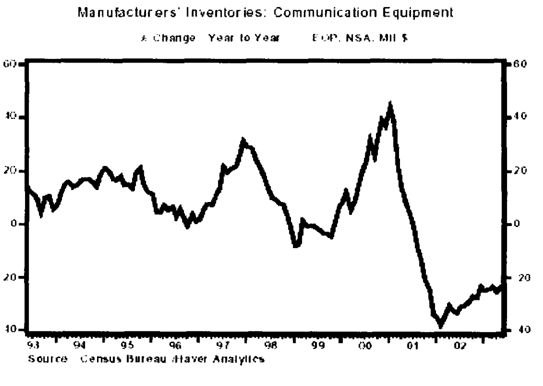


Figure 3-6 Unfilled Orders Change Year to Year **Figure 3-7: Inventories Change Year to Year (Census Bureau)**

The suppliers of communications equipment to the carriers are under contract to deploy their systems on timely basis. As it takes several months to build, modify and test these complex systems for interoperability, service providers and network carriers are under pressure from their competitors. Thus, they will are not able to immediately fulfill the projected demand on their own networks. This is a natural delay of the overall dynamics of the telecom industry. Faced with delays in the delivery time of the communications equipment and supplies, and due to immediate shortage of telecommunications gears caused by positive feedback forces outlined above, they increase their order rate beyond the forecasted demand. This dynamic is evident in Figures 3-6 & 3-7 which show that in the year 1999 there were historically very large number orders on hand for equipment, all the while manufacturers of telecom equipment were holding more inventories to be shipped.

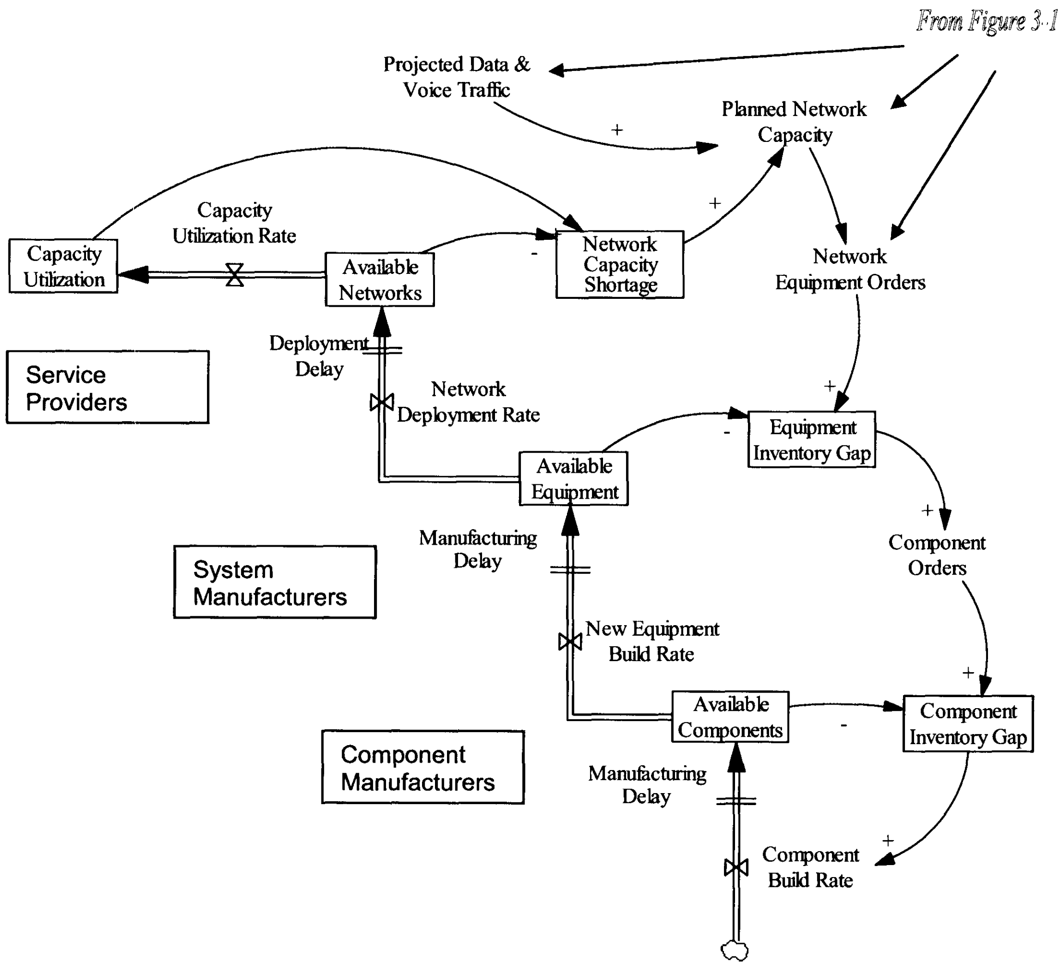


Figure 3-8: Supply Chain Amplification

As equipment (or systems) manufacturers received such increased immediate term demands, they too increased their order rate to their own suppliers, the fiber optic component suppliers. The perturbation caused by projected increase in demand created a tsunami of demand down the supply chain. The growth of the demand was a first order exponential feedback loop. In a global and disjoint industry facing many new entrants the adjustment time (time to achieve the desired level of systems) was truly unknown. Many of the carriers such as Qwest, Level 3, XO and Williams were less in-tuned with fulfillment time of their orders and could not accurately anticipate the delivery time of these new generation systems. Nor could the supplier of the communications equipment anticipate the large incoming orders and the time it took to fulfill them. In general, product shortages and long lead times cause buyers to increase their orders. As the supply chain gets larger delays cause the feedback loops to oscillate and cause manufacturers across the board to hold large inventories as followed by large equipment shortages. The order dynamics and inventory increases are well evidenced in Figures 3-9, 3-10 and 3-11.

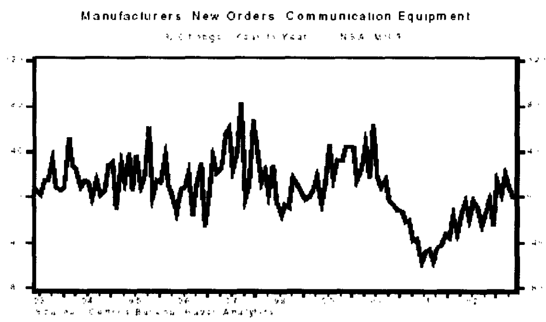


Figure 3-9: New Orders (Census Bureau)

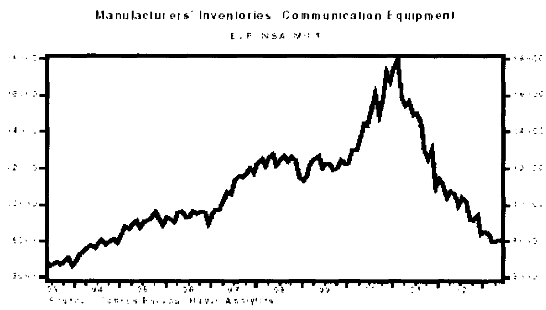


Figure 3-10: Inventories (ibid)

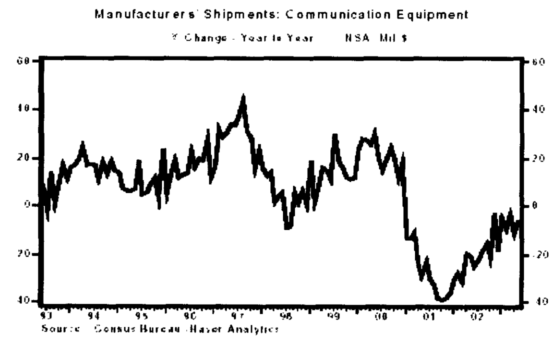


Figure 3-11: Shipments (ibid)

The projection of future traffic usage as an exogenous input to the system was one of the sources which caused perturbations throughout the system. Once the network capacity deployment was increased due to this forecast, the sudden jump in demand worked its way through the system. The delay between projected demand increase and the actual network capacity increase (network capacity deployment) was substantial.

As the planned network capacity increases, so do the orders for equipments. The magnitude of these orders is predicated by the shortage experienced based available network capacity and the capacity utilization. Due to the delay in deployment of network capacity, the perceived shortage of capacity appears much larger than it really is. This effect is even more amplified the further down the food chain one travels.

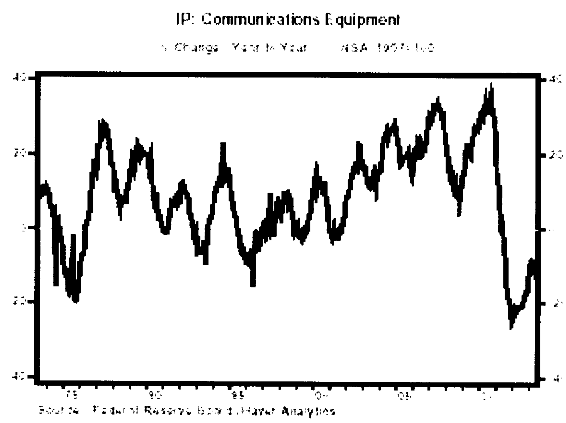


Figure 3-12: IP Communication Equipment (The Federal Reserve Board)

In the case of the equipment manufacturer who is on the receiving end of these orders she too creates an amplification of her own supplier. This is due to the time it takes for the new equipments that are in her pipeline to work their way through finished goods. The gap in the equipment inventory and the equipment orders creates an impetus for larger orders of components from her suppliers.

As the supplier of parts to this industry, the fiber optics suppliers face an extremely volatile demand cycle. This volatility creates obstacles to robust production control and overall cost management. They further create a hindrance to product innovation cycles and new product development for these component suppliers.

This epidemic has a negative effect on the production capabilities of the suppliers of components to this industry. But it also creates further negative impact to the innovative research and development phase of future products. The effects are caused by the focus suppliers have on development of novel manufacturing methods and cost reductions instead of focusing on the application needs of the future. Whole organization's energies are directed in meeting the ever increasing customer orders rather than innovating what's next. The dynamics of the value chain as shown above are directly related to the larger generic model of communications and help us zoom in this aspect of the industry dynamics.

3.4 Market Cyclicality & Timing:

As evident from the initial model, telecom has historically been cyclical. This cyclicality when combined with the dynamics of the supply chain that has these third order long delays creates amplification in the supplier network.

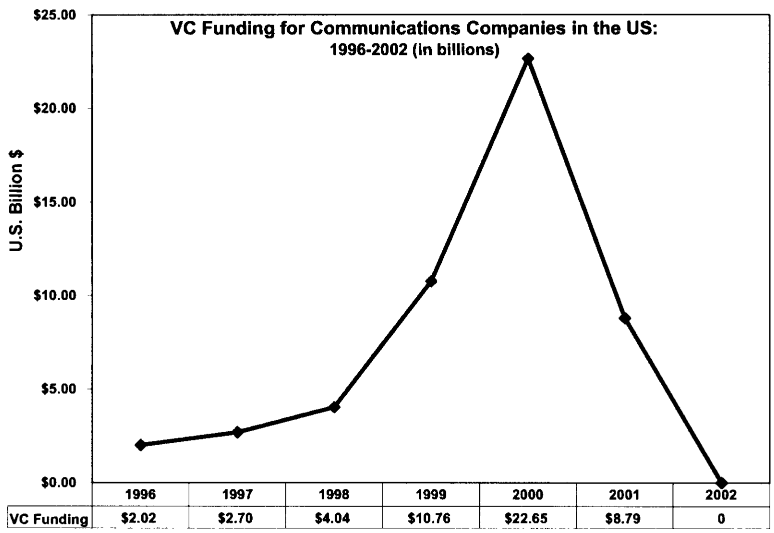
In innovating for a cyclical market the players timing plays an important part in the innovators process and future success. The cycle of commercialization of these innovations must not coincide with a downturn in demand, as that would mean that this phase would receive no feedback or meaningful support. As the demand cycle of the telecom equipment has been shown to be cyclical, with peaks starting in the year 2000, many of the new company's innovations would face a tough market acceptance beyond that time.

This is evident by the number of fiber optics companies that were started in the year 2000 facing the challenge of a severely depressed market in the years following 2001. For names and more detailed information on these companies please refer to Appendix. The yearly revenue from optical components in that year was substantially lower than years preceding. Some of the demand created by the equipment manufactures in this year came from unsustainable firms who were also at the wrong end of the innovation cycle and who would miss the CAPEX spending cycle of the network service providers.

Impact of financial factors that arrest of the competitive development of fiber optic technologies is exhibited on several levels. Each of these factors has its own effect on the health of the fiber optic component industry.

3.5 Investment Inflow & Outflow:

In 1999 and 2000 the rate of investment in SME in the fiber optic equipment and component markets increased rapidly. In the year 2000 alone *$700 million* was invested in communication firms working with fiber optic technologies, this figure tripled in the following year to $2.4 billion dollars[24]. These funds went to start 31 and 99 companies in 1999 and 2000 respectively.



Source: Yankee Group, 3/2003

Figure 3-13: Venture Funding for Communication Firms

In addition to the creation of new ventures in this period there were additional investments made by incumbent service providers themselves for purchase of more equipment. The network operators and service providers in aggregate increased their capital spending by 50% in the year 2000 alone, while their revenue only increased by 11%[25]. This increase is an indication of the money inflow to the equipment suppliers by various types of carriers, including RBOCs, CLECs and IXC. This rate of investment would not be sustainable under the overall economic conditions based on historic data. The dynamics of such inflow of money show an increase in the mid to late 90's and a dramatic decrease following in the year 2000. Such behavior of growth followed by rapid decline is an example of both positive and negative feedback loops in

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[24] Figure is according to Venture Economics, a division of Thompson Financial. It appeared in Red Herring magazine published in April 2, 2001.
[25] Broadband Week, March 5, 2001

a system dynamic model. The inflow of the capital investment into different levels of the communications industry was result of large rate of returns experienced by several firms a few years earlier.

3.5.1 Story of Qwest:

In January of 1997 the major shareowners of railroad and construction company Southern Pacific Rail invested $300 millions to start Qwest Communications. In addition to this initial investment, Qwest secured several loans and debt offering to build a new fiber optic network with total cost of build close to $3 billion dollars. Within a short period of this initial capital investment and the network buildout Qwest won a contract to supply this capacity to Worldcom, GTE and Frontier for a sum close to their cost of $3 billion dollars[26]. A return on investment of such magnitude would lure much more investment in the communication industry for the years that followed.

The new ventures were made available to public via IPO markets. This cash event allowed a financial horizon for the ventures to take back some of their invested capital creating cycle of inflow and outflow of capital.

Other financial outflow events were related to bankruptcies and consolidation of all tiers of the optical communications market. These outflows were indicative of a new cycle in the telecommunications industry. The rate of bankruptcies and consolidations increased to a frantic pace and still continues to this day. This factor is also well representative of a maturing industry and a path towards commoditization, all caused by price erosion and inaccurate projections. Figure 3-14 and Table 3-1 show the details of these bankruptcies. Additionally, since end of 2001 there has been 25 other bankruptcies of service providers. Increase in number of players exiting an industry also points to a creation of dominant design and dominant players (Utterback 1994). This indicates an inflection point in which the industry is moving towards new process improvement rather than product innovations.

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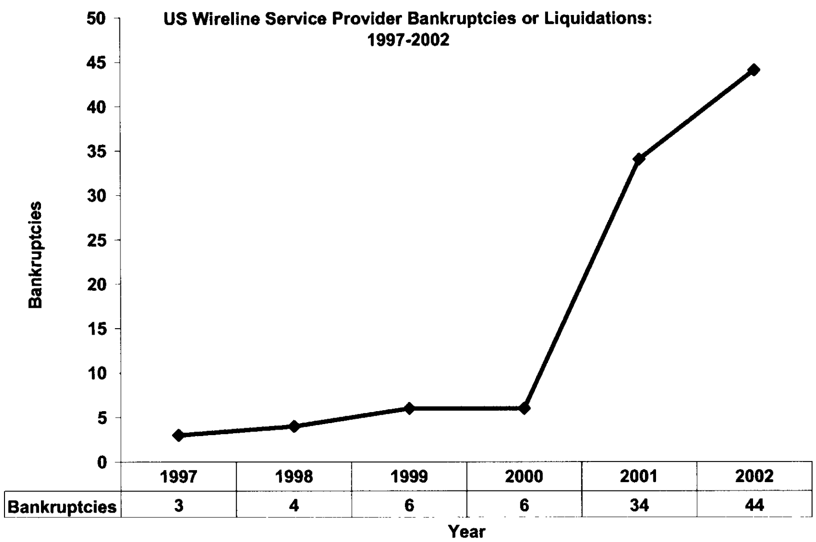
[26] Company financials and articles from Wall Street Journal.

3.5.2 Bankruptcies:



Source: Yankee Group, 3/2003

Figure 3-14: Bankruptcies by US carriers

CLEC Bankruptcy Filings and Consolidation 2000 to 2001		
CLEC	**Bankruptcy/Consolidation**	**Date**
Rhythms Netconnect	Filed for Chapter 11 bankruptcy; WorldCom announced plans to purchase $40 MM of Rhythms' assets	Aug-01 to Sep-01
Covad	Filed for Chapter 11 bankruptcy	Aug-01
ICG Telecom	Filed for bankruptcy protection	May-01
Teligent	Filed for Chapter 11 bankruptcy	May-01
Convergent Comm	Lays off 500 employees, sale of assets	Apr-01
CoreComm	Lost $318 MM, plan to cut operations	Apr-01
Telocity	Acquired by Hughes for $178 MM, 82% less than IPO.	Apr-01
Winstar Comm	Filed for bankruptcy protection	Apr-01
e.spire Comm	Filed for bankruptcy protection	Mar-01
Intermedia Comm	Acquired by WorldCom	Mar-01
NorthPoint	Filed for bankruptcy protection, purchase by AT&T approved	Mar-01
PSI.Net	Filed for Chapter 11 bankruptcy	Mar-01
GST Telecom	Filed for bankruptcy protection, acquired by Time Warner	Jan-01
Inter-Tel	Purchased Convergent's voice integration operations	Jan-01
CapRock	Purchased by McLeod	Dec-00
Concentric	Purchased by Nextlink	Jan-00

Table 3-1: Source Morgan Stanley

3.5.3 Interest Rates:

Companies invest in projects that have higher returns than the market discount rate; otherwise the better ROI is in investing in financial markets rather than any risky project. This means that when interest rates are high companies see fit to pursue riskier projects.

The capital expenditure on modern optical networks and the large build-out project that it entails meant that any capital project had to provide the right returns to justify it. Dynamics of capital projects are highly dependent on the overall financial markets. In the market with high prime rate there is little justification not to keep the money in an investment account. Projects that provide a larger return on invested capital than do capital markets typically get the go-ahead.

With the growth of the corporate discount rates in the 1990's, return on investment of firms with cash at hand also increased linearly. During this period many capital investment projects were started both in the airline, petrochemical and telecommunications industries.

3.5.4 Vendor Financing:

During this growth phase, many equipment vendors sought to provide direct leasing services to their customers. In most cases these equipment manufacturers provided this service to support the service providers that were facing difficult capital markets. By provisioning these leases the equipment manufactures in effect were taking on loans on behalf of their customers, the network service providers. As they supplied money to their customers in order to incentivise their growth and market reach, they themselves were faced with lowered credit ratings. This was a way to contend with slowing sales and missed earning forecast that ensued after telecommunication markets felt the effect of slowing economy in 2000.

The effect of communications equipment vendor financing on their credit rating and reduced liquidity was almost immediate. Lucent Technologies had committed to provide over $6 billion dollars in financing as of December of 2001. To be able to fund this and be financially solvent Lucent resorted to sales of several of its divisions, including Agere Systems. Nonetheless, this risk caused Lucent's credit rating to be cut due to highly leveraged conditions. Another network equipment supplier, Cisco, doubled its provision for bad debts while expecting its receivables to be $3.5 billion. There were 17 loan defaults during year 2001 totaling $33 billion, NorthPoint

Communications and Globalstar were responsible for $9 billion of that figure. This made vendor financing as unfavorable by Moody's and other investment services.

3.5.5 Price War (Commoditization & Marginal Cost):

As suppliers of telecom services pushed to increase their market share by heavy discounting of voice minutes (voice has traditionally been the main source of revenue for incumbent service providers) they created a market reaction that has had far reaching effects on the market. In essence any industry undergoing deep price pressure will become a commodity

> "*For every one percent you drop price, you get a greater than one percent increase in demand.*" James Crowe, Level 3 Communications

For a fully operational network (especially with low capacity utilization) the marginal cost of providing this additional percentage of demand growth is zero. These networks were built to carry a large amount of capacity and without customers the equivalent of planes leaving with many empty seats would ensue. The network operators had every reason to drop price and give incentives for more of their customers to carry their capacity on their networks, whatever the cost of acquiring these customers would pale to the opportunity cost of not having these customers.

3.6 Migration to Optical Networking:

Having described the dynamics of the value chain of the communications market, the following focuses on the technology dynamics of the fiber optics. This is done as part of the larger model introduced in the Figure 3-1. During the late 1990's telecom carriers faced several factors that steered them towards conversion to next generation networks. These networks were more capable and had more flexibility in handling future traffic such as video or data that used Internet Protocol topologies. These factors in themselves had always been present, however, during this period several factors combined to push the growth to artificially high levels in terms of fiber optic technologies. The combination of these factors created amplifications in their effects on each other with little checks and balances.

The technical domain of network topologies is an area of intense competition and cooperation at the same time. A global telecommunication network has the incentive to be upgraded to topologies that enable it to take advantage of growth in usage with minimal financial and technical impact. This was so in order to provide more capability for interoperability and cooperation for generating new services. In system dynamics nomenclature this is referred to as network externality for diffusion of innovation[27]. The model depicted in Figure 3-15 indicates several factors that lead to the early (but short lived) migration to a network architecture referred to as Next Generation optical Networking, or NGN for short.

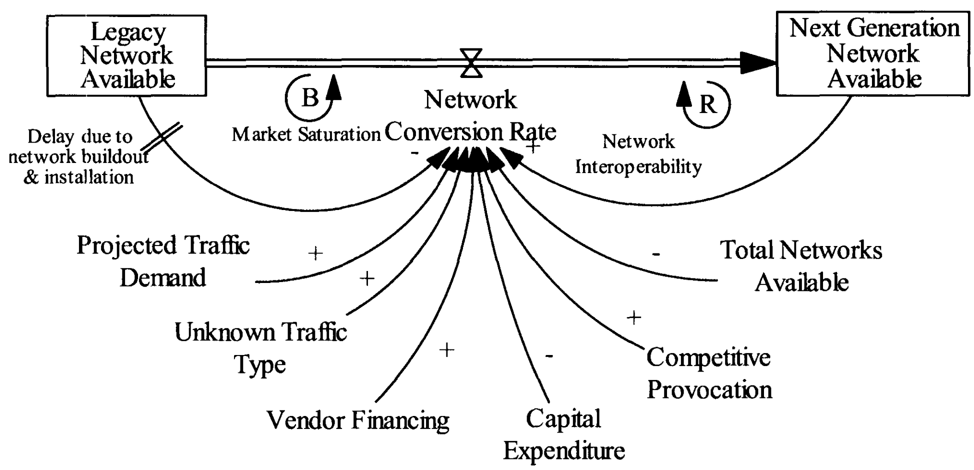


Figure 3-15: Migration to Next Generation Network

3.6.1 Projected traffic demand:

The projected use of telecom traffic was an immediate aftermath of the projection of the internet growth. In the second half of 1990's it was expected that the growth of the internet based services and commerce would double every 3 months. This figure was proven to be correct during the early phases of the internet build-out, however this prediction was proved in accurate for latter part of late 1990's and early 2000.

The extent of the forecast for web based network usage was carried all the way down to the fiber optic component level by professional research firms and forecasters. This rate of projected growth was based more on bandwidth demand forecast than on any historical data.

[27] From Business Dynamics by John D. Sterman; Irwin-McGraw Hill, 2000. Page 325

There also was very little historical data to indicate the growth of optical NGN in particular. The forecasters had no reference point from the past to compare new demand patterns and NGN technologies that would enable their proliferation.

Projected Component Industry Annual Growth Rate	Yankee Group	Actual
1999 Actual	N/A	107%
2000 Actual	N/A	125%
January 2001	25%	-40%
January 2002	15%	-17%[28]

Table 3-2: Changes in Forecast by Analysts

In October of 1998, based on historical arguments and figures, AT&T researcher Andrew Odlyzko measured the growth of the internet traffic to be close to 100% annually. That is a doubling of required capacity in a relative short period, a feat that would have been impossible to implement on time and efficiently using legacy networks. Legacy based networks were designed to accommodate mostly moderate voice traffic growth using several provisioning and grooming technologies. The growth rate was predicted using well known actuarial models of population density and behavior.

3.6.2 Vendor Financing:

Chasing even larger market share and in order to increase their foothold in the market, vendors of telecommunications system equipment provided credit to their customers in order to facilitate their purchasing. This positive force helped the network service providers and operators to deploy newer technologies than only upgrade their legacy networks. With lifting of cash barrier and increasing the purchasing power the telecom carriers had all the reasons to buy more equipment.

3.6.3 Unknown Traffic Type:

Optical communications advantage is in its capability to carry an almost unlimited amount of traffic in a very small number of fiber optic cables. This combined with its capability to be totally

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[28] RHK Data as presented by Banc of America Securities at Optical Fiber Communication conference in 2002.

transparent to the protocols and types of traffic being carried on the networks, makes them a lead candidate for networks with unknown traffic patterns and bandwidth usage.

> "*Our goal is not simply to deploy one generation but to build an entirely new model that assumes technology will change quickly and at times unpredictably.*" James Crowe, Level 3 Communications[29]

3.6.4 Competitive Provocation:

As incumbent carriers faced unprecedented number of competitors entering their markets they found it more and more difficult to sit idly by and not upgrade their network to the Next Generation capabilities, such as those offered by fiber optic switching. In telecommunications, as in all infrastructure-based industries, the initial cost of the building the network is relatively high compared to upkeep of the network and adding additional capacity. Firms that build the larger more capable network based on *higher expected* volume of traffic will ultimately have a lower per user cost for each subscriber of their network.

3.6.5 Total networks available:

This factor is essential in understanding complex systems and their diffusion model. Ultimately there are a finite number of carrier networks and network routes. Once upgraded the number of the networks candidate for upgrade reduces, essentially there won't be much more networks to convert. Additionally, as the number of networks upgrade to NGN the issue of interoperability becomes less and less pronounced and becomes less acute. Currently the migration to NGN is fully completed in several major routes and though it has slowed down drastically it is still continuing on selected routes.

3.6.6 Capital Expenditure:

By investing more and more in their networks the carriers were also tying their capital in the network infrastructure. This financial strain made it less and less likely for companies to continue their expansion ambitions and to convert to NGN. Any network upgrade would require an

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[29] Wall Street Journal; *Overbuilt Web*, June 18, 2001

extensive expense of equipment purchase in addition to the installation costs, insurance, operations support software (OSS), integrated billing functions, and transportation costs.

3.6.7 Network Interoperability:

In order to operate their networks and be compatible with traffic from intermediatory carriers[30], many of the commands and service level agreement languages must be converted to NGN's terms. This conversion from legacy type provisioning to NGN is very extensive and requires a great deal of time and effort. In effect this has a negative impact on the rate of conversion from the legacy to NGN based systems. The issue here is one of compatibility between traffic formats that are of different origin and carry data traffic in different ways.

3.6.8 Delays:

As any complex system, the diffusion dynamics of the telecom conversion to NGN includes delays. One of the most profound delays in these large migration projects is the engineering and project planning requirements of switching the live traffic on legacy networks to new generation network. The traffic is never completely switched from one system to another. This always happens in a very methodic and gradual manner; step-by-step and incrementally the live traffic get migrated. This creates a good deal of delay on its own. Additionally, the deployment and construction of new facilities combined with the equipment delivery lead times are an equally substantial contributor of delays.

Combination of the positive feedback loops that affected the growth of NGN networks meant that networks with largest installed base were at an advantage in terms of compatibility, capability and adaptation to new traffic type. All else being equal, the path dependence of the technical trajectory of NGN would convert most of the carriers to this network type. There were other balancing loops that ultimately caused a reduction in rate of adoption to NGN.

No real quantity can grow forever, and in the case of conversion to NGN the upper limit would

[30] Carriers work with network of service providers to receive and transmit traffic based on previously designated service terms. These hand-offs and service agreements are monitored and provisioned through the use of highly specialized communications traffic control systems (much like air traffic controllers) and tools. For more information please see Telcordia's Common Language library.

come when there would be no more networks to migrate to next generation optical network. Had the demand for telecommunications networks continue its growth rate unscathed as in the late 1990's, the upper limit of migration to NGN may have been reached already. This migration to next generation networks has been followed from terrestrial wireline networks to those of mobile communications. NGN now is used to mean a network that is capable of handling various traffic types including video, mobile telephony, bursty data and traditional circuit based voice telephony.

3.7 Summary:

In this chapter reviewed of the dynamics of the communications broadly. As a case study, it looked at certain themes and markers to better analyze commoditization process in technology. In the case of the suppliers to communications the commoditization has had and will have profound effect on the strategic and operational innovation domain. Firms in the communication industry face challenges of both technology and commercialization. The industry is undergoing a major shift the dynamics of finance, technology and projected demand take center stage. In addition to the need of staying competitive some the players in the communication industry will miss the window of opportunity and may innovate into a wrong cycle.

The themes covered in this section included; commoditization affects to a supply chain, innovation diffusion during change from voice centric network to those of multimedia and internet based applications, and financial factors affecting the entry and exit of firms in various parts of the communication arena. In the next chapter we will review in the affects of these larger dynamics communication markets to fiber industry.

4 Innovation in Fiber Optics:

Previous chapter discussed the dynamics of the communication industry in some details. It also looked at how technological and economical forces have caused the dynamic shifts in many sectors of this industry. In this chapter an analysis of the evolutionary dynamics of the fiber optics industry is provided using the frameworks outlined in Chapter 2. The analysis reviews the fiber optics technologies as part of the larger communication industry. As such, fiber optics is viewed in the light of the dynamics covered in the previous chapter. This chapter will also look at the global dynamics of open innovation and innovation networks, as they point to changes in the nature of innovation in our age and are very current in their views. In closing a discussion of the commoditization process is provided.

4.1 Dynamics of Fiber Optics:

> *AT&T Bell Labs scientists became interested in fiber optic communications in the mid-1960s, when it became apparent that fiber had an enormous capacity for carrying information and was immune from electrical interference. Innovations in lasers, photo-detectors and glass fibers in the following decades led to the installation of the first fiber optic system in an operating telephone company in 1977. This installation was the world's first system to provide a full range of telecommunications service — voice, data, and video — over a public switched network. The system, extending about 1.5 miles under downtown Chicago, used glass fibers that each carried the equivalent of 672 voice channels.*
>
> *AT&T Labs; A technology timeline and history of AT&T Labs*

As the paragraph above describes, fiber optic communications has been known to be technically superior to most other communications techniques since 1970's. In its early days, fiber was already ahead of wireline in terms of speed, capability for multiple services, and exhibited low noise susceptibility. However, these early deployments were limited in their speed, reach and scope when compared to today's networks. From the early application it was evident that fiber optics was not only superior to other technologies of that time, but it was also future proof with almost unlimited capacity. It became the researcher's goal to continually improve speed and reach of their craft. As shown in Figure 4-1, optical fiber systems were a disruption to the capacity (speed) of preceding technologies - such as wired coaxial cables and satellites – due to their trajectory of evolution and continued innovations.

In the 1980's, with the advent of improved technologies in the fiber cable and semiconductor lasers, it was possible to increase the number of channels carried by the system from one to several. The technology of multiplexing several optical channels in one fiber is called Wavelength Division Multiplexing (WDM). This increase in capacity has consistently continued its trajectory to today. Experiments with 256 channels simultaneously traveling in the same fiber are common with several cases of actual deployment and service[31].

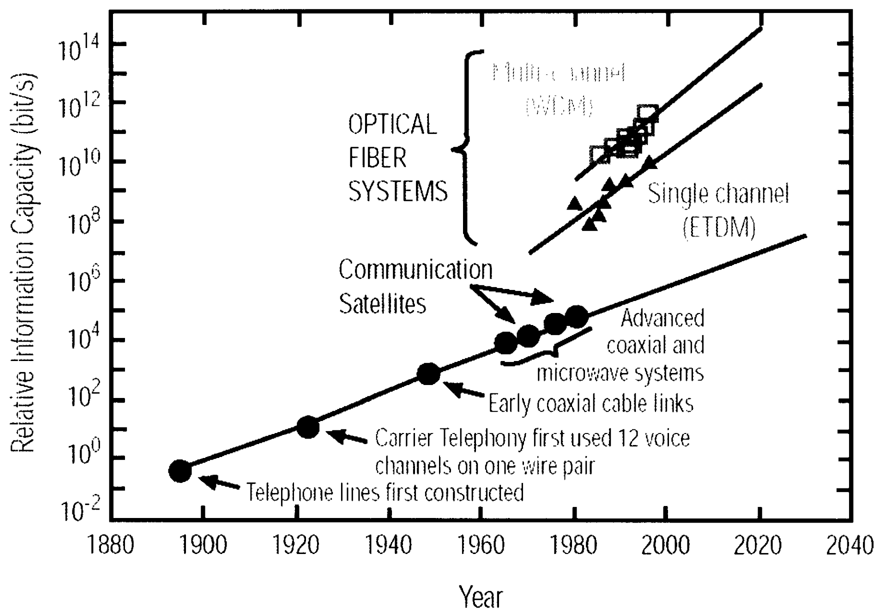

Figure 4-1: Information Capacity Comparison of Communication Technologies[32]

As the capacity of the fiber based networks has increased so has the demand on these networks. This increase in demand is caused by two drivers. First, requirements for raw capacity such as more channels or faster speeds, and second the flexibility of the network in providing array of services. The fiber based networks utilizing multi-wavelength channels provide several

[31] Presented at Optical Fiber Communications 2002: 2.56 Tb/s (256X10 Gb/s) transmission over 11,000 km. By Tyco Telecommunications group; D. G. Foursa, C. R. Davidson, and N. S. Bergano
[32] Kimerling L. (2000); Photons to the rescue: Microelectronics becomes microphotonics, Electrochemical Society Interface, Summer 2000

orders of magnitude increase in their capacity over their wired or satellite based cousins. Also each optical channel acts as an identifier for the traffic that it carries. By selecting specific wavelength the network can provision services much more rapidly, as the routing of each channel will be linked to its wavelength. This combination of more capacity and capability to offer wider services has been the hallmark of the new era of fiber optics.

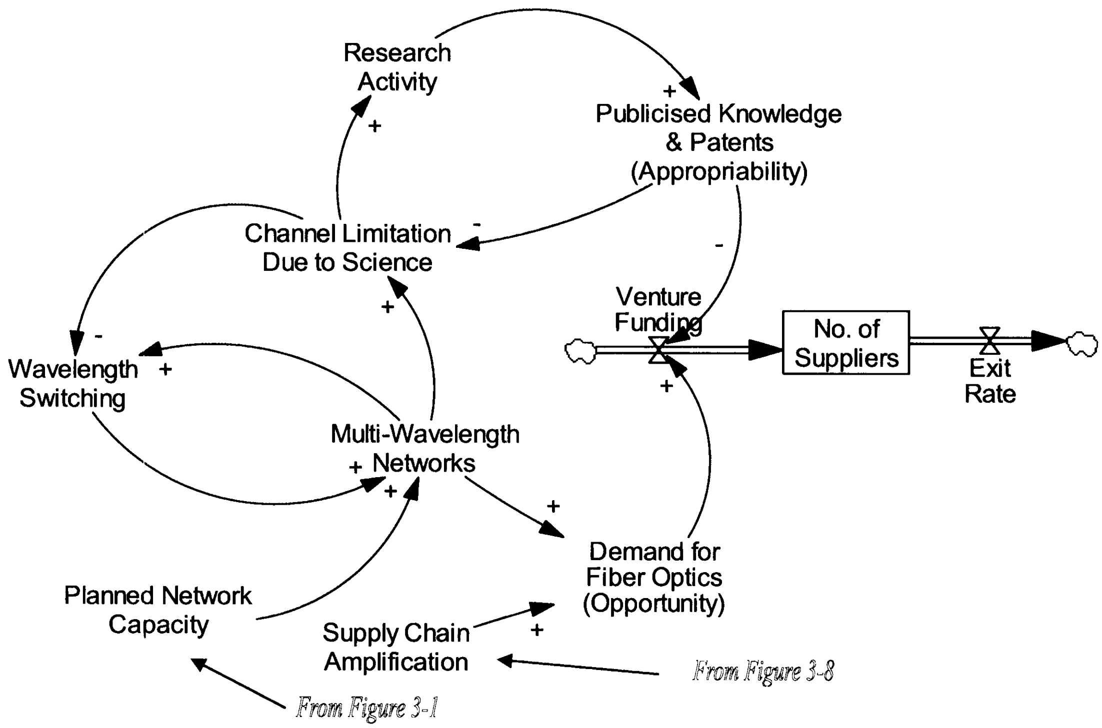

Figure 4-2: Dynamics of Fiber Optics

Using a causal loop diagram in Figure 4-2 the dynamics of the multi wavelength network and how they affect the fiber optics industry is shown. This conceptual model is linked to the models described in Chapter 3, they focus in zeroing-in on the increase in number of suppliers as a result of Planned Network Capacity and Supply Chain Amplifications shown in Figures 3-1 & 3-8 respectively. As this model illustrates, wavelength switching and demand for higher capacity are the key drivers of multi-wavelength network deployment. However, in addition to the reinforcing loop of multi channel network, there is a balancing loop caused by the scientific limitations of the fiber and the devices -such as fiber non-linearity, laser dependant spectral width, and filter design. This is the area of further research and continuous improvements fueled by industry growth. Most of which has been area of much research particularly in the past decade. There has been number of industry conferences, publications, and patents in the field of fiber optics during this time. The appropriability and opportunity regimes are the key influencers of market entry and predicate the exit of suppliers; they will be covered in upcoming sections of this chapter.

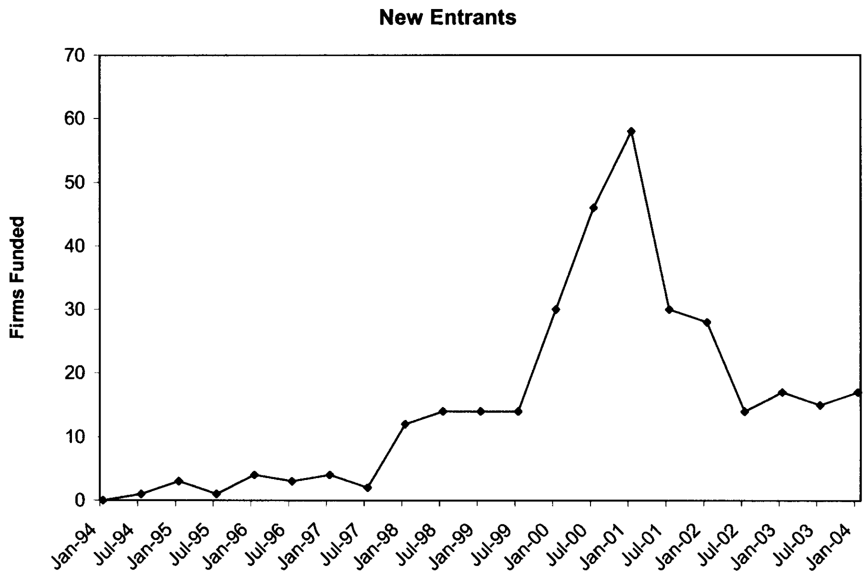

Figure 4-3: New Fiber Optics Suppliers (Thomson Financials)

The number of new entrants is depicted in Figure 4-3. This entry rate is also affected by the overall demand for fiber optic supplies. This demand is influenced by the financial and supply chain driven dynamics covered in the previous chapter. Effectively, increased telecom CAPEX combined with supply chain amplification is responsible for the increase in demand for fiber optics and fiber optics suppliers –also discussed in Chapter 3.

During the years 1999 to 2001, over 150 new firms in the specific domain fiber optic components entered the industry. These newcomers as indicated by the model were venture funded and entered the business due to favorable innovation regimes. This entry rate is the central point of the model. The extent with which these new companies were formed in such a short period points the strength of these forces. The dynamics shifted, however, in the following years as dominant designs were emerging and the industry moved into transitional phase.

4.2 Innovation Life Cycle:

The fiber optic industry has evolved rapidly over the years. Throughout these years the processes of evolution and continuous improvement have been the primary forces in enabling adoption of this technology to mainstream communication networks. Today almost all networks utilize fiber as their primary mode of communications. In the following section the lifecycle view of these innovations is provided. Here is an account of the life cycles of two of the most important inventions in the fiber optics communication. For a more detailed historical view of this industry please refer to the appendix.

4.2.1 The Fiber Cable:

At the heart of fiber optic communication is the low loss silica (glass) based fiber cable. The cable acts as a conduit for a point to point transmission of optical signals as they pass through it. The fiber is essentially a thin narrow piece of glass that is enclosed by a protective plastic housing. Fiber cables have a lower flexibility compared to wire cables, but in comparison are very light weight. This property helped their deployment speed and displacement of cable wires early on.

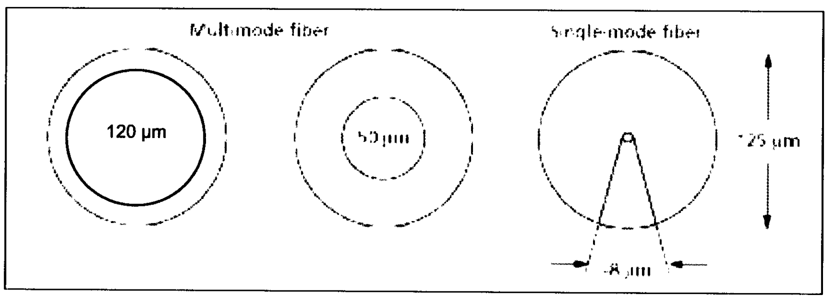

Figure 4-4: Internal Structure of Optical Fiber (Refi)

The early versions of the fiber cable were at first created using industrial glass material, and had lowest achievable core diameter thickness of about 120 μm at best. It was shown that by confining the light in this very small diameter pipe through the process of total internal reflection, the light would travel down the cable at speeds approaching the speed of light[33]. This first design of the fiber cable was invented in 1966 by Kao & Hockham (Glass & DiGiovanni 2000). These early fibers had a loss of 1,000 dB per kilometer, which initially made them not suitable for use in most communication networks. A substantial amount of work was ahead to reduce this loss and increase the reach of these fibers.

In the multi-mode fibers (core thickness of 120 μm) each incident of a mode of light caused interference with other modes that arrive later, modes travel in various directions instead of a straight line. Because the signals do not all arrive at the same time at the photo-detector they are misconstrued as the next bit, thus causing error. Combined with high losses these fibers were not suitable for high speed transmission and needed further improvement in reducing their core diameter thickness.

System	Year	Fiber type	Wavelength	WDM channels	Bit rate/ channel	Bit rate/ fiber	Voice channels per fiber	Regenerator spans
FT3	1980	MM	0.82 μm	1	45 Mb/s	45 Mb/s	672	7 km
FT3C	1983	MM	0.82 μm	1	90 Mb/s	90 Mb/s	1,344	7 km
FTG-417	1985	SM	1.3 μm	1	417 Mb/s	417 Mb/s	6,048	50 km
FTG-1.7	1987	SM	1.3 μm	1	1.7 Gb/s	1.7 Gb/s	24,192	50 km
FTG-1.7 WDM	1989	SM	1.3/1.55 μm	2	1.7 Gb/s	3.4 Gb/s	48,384	50 km
FT-2000	1992	SM	1.3 μm	1	2.5 Gb/s	2.5 Gb/s	32,256	50 km
FT-2000 WDM	—	SM	1.3/1.55 μm	2	2.5 Gb/s	5 Gb/s	64,120	50 km
NGLN	1995	SM	1.55 μm	8	2.5 Gb/s	20 Gb/s	258,000	360 km
NGLN II	1997	SM	1.55 μm	16	2.5 Gb/s	40 Gb/s	516,000	360 km
WaveStar™ 400G	1999	SM	1.55 μm	80 40	2.5 Gb/s 10 Gb/s	200 Gb/s 400 Gb/s	2,580,000 5,160,000	640 km 640 km

MM – Multimode
NGLN – Next-Generation Lightwave Network
SM – Single mode
WDM – Wavelength division multiplexed

Figure 4-5: Evolution of Optical Fiber (Alferness)

It took close to 20 years for new innovations to reach the manufacturing process and to create the right glass material and physical shape; this was necessary for field deployment and for lower optical loss over longer reach. This new process of fabricating fiber cables was first reported by Bell Lab's MacChesney in 1974, yet it took another 15 years to reach a suitable

[33] Speed of light is defined as the speed at which light travels in a vacuum. In the fiber cable since light is traveling in glass the speed is somewhat slower.

production volume. In his experiments he was able to reduce the diameter of the fiber to 8 μm (see Figure 4-5), and thus allow only for a single mode of light to travel down the fiber. By 1980's this process was further perfected by eliminating chlorides and germanium from the fiber and going to an ultra-clean fabrication environment. After transfer from the lab environment to fiber production facilities, these advances have continued to allow for transmission over the longer wavelengths and utilization of the second to fifth transmission windows (see Figure 4-6).

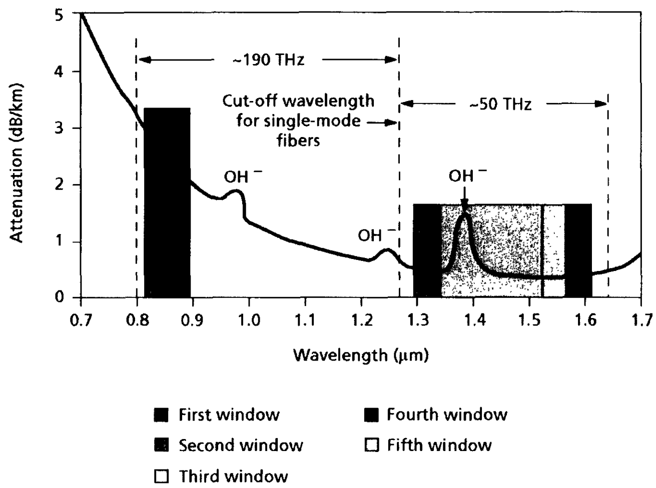

Figure 4-6: Fiber Cable Transmission Windows (Refi)

Today, the fibers deployed in telephone networks have losses of lower than 0.02 dB per kilometer; about three orders of magnitude better than the early experiments. They are all by far single-mode fibers and are less susceptible to reception errors. At the present there are a few proposals for other types of fiber cables with even purer materials suited for lower losses, thus allowing for various transmission windows that increase the fiber capacity. Through improvements in reception manufacturing process, scientists were able to overcome both the loss and the factors that caused reception error issues.

Despite the expensive capital requirement to enter, in the 1980's several companies entered the fiber manufacturing business. This according to Utterback indicates the *fluid phase* of the fiber industry. Some of these companies were: Siecor Corporation, Furukawa, Nordx/CDT, Inc., Corning, CommScope, Alcatel Telecommunications Cable, Optical Fiber Corporation, Pirelli Cables, Hitachi Cable, AMP, Inc., and Belden Wire & Cable. With the advent of MacChesney's design entering into manufacturing the dominant design was proven in the early part of 1990's; the industry entered its *transitional phase*. However, a decade later due to extensive need for process improvements and further need for ongoing cost reductions, fiber cable is now produced by only industrial giants like Furukawa, Hitachi, Sumitomo and Fujikura. Both pioneers of this innovation, Lucent and Corning, have exited this business recently. According to this theory we are entering the *specific phase* of the fiber cable industry[34] today.

In the invention, and the subsequent improvements in production processes exhibited by the fiber optic cable, one observes how the development of innovation has moved from product innovation to process innovation; and from fluid to transitional and subsequently the specific phase. In the early years the fiber cables were of little use for transmission of light-wave signals due to their loss and error susceptibility. As the fabrication processes improved, by reducing the diameter of the fiber and further purification of the glass material, the fiber cables became a great candidate for communication applications.

4.2.2 The Laser:

The other essential innovation in the fiber optics is the advent of the solid state laser. The first solid state light emitting diodes were simultaneously developed at IBM, GE and MIT in the early 1960's (Brinkman 2000). These semiconductor lasers were first fabricated using alloys of Al, Ga, and As; all in a single crystalline structure. The fabrication process was done using liquid-phase epitaxial technique (LPE). In this technique liquid metals of Ga metal, containing Al, GaAs and semiconductor p- and n-type dopants were used to grow thin layers of semiconductor for emitting light. The combination of these materials emits lights at wavelengths between 600 to 900 nm in what is called the "short-wavelength" range, the first window as shown in Figure 4-6. This wavelength is suitable for lower speed modulations and not quite usable for longer distance communications due to its higher loss through the fiber.

Additionally, the earlier lower wavelength lasers were not capable of handling increases in modulation speed (the rate at which the data is encoded on the optical signal) of the light

[34] All of these new proposals deal with improvement of the fiber and materials used. They can not be classified as product innovations, as they are incremental. These all point to supplier base that is looking to De-Commoditize the fiber cable. In its specific phase, the fiber cable has become an industrial commodity in search of De-Commoditization process.

through the fiber. As the modulation speed increase the sampling window for each bit becomes shorter. Thus, it is required that the lasers turn on and off much quicker. Due to their crystalline structure, the early lasers behaved like electrical capacitors and showed high impedance at higher frequencies. The laser structure needed to change.

By making modifications to the structure and change in the use of Al, Ga, As, and P, materials; researchers at Bell Labs were able to create semiconductor lasers for longer wavelengths of 1300 and 1550 nm; the second and third windows. These wavelengths are most suitable for silica based fibers due to very low dispersion of these wavelengths through the optical cables. Using a technique called molecular beam epitaxy (MBE), Al Cho (Cho 1971) was able to grow single crystal layers of AlGaAs metals that were only a few atoms thick[35]. This reduction in size helped reduce the capacitance of the lasers drastically. By this process improvement, and combination of other innovations in use of materials, scientists at Bell Labs were able to push the envelope a bit further to higher modulation speed and higher wavelength lasers. Today, these lasers have both the reliability and characteristics that enable them to live up to 25 years with continuous emission. During the past 40 years in the history of solid state lasers the fabrication process has moved from experimentation with low reliability to creating a $10 laser that can outlast life of many communication networks.

Today, the companies credited with invention of the solid state lasers have either exited the business, or are not directly involved with further commercialization of the communication lasers (such as MIT). IBM sold its laser business to UTP to form Uniphase Corporation back in the early 1990's. Agere systems, after separating from Lucent (who had separated from AT&T four years before), sold its laser products to TriQuint semiconductor[36].

In cases of these two innovations the product innovation was created by central entities like AT&T Bell Labs, or IBM's Watson Labs. These inventions were at first ideas that were not suitable for communication purposes. Through improvement of the processes and refinement of the materials used scientists were able to modify these innovations such that they could be commercialized. In both cases the real inventors of the products were different from those who

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[35] Because MBE can create layers that are very smooth and approaching size of atom, this started a whole new field in 1970's to study behavior of electrons in layers only a few nanometers thick. This was the start of nano-technology.

[36] Company press release, October 22, 2002. Agere systems announces sales of optoelectronics business to TriQuint Semiconductor for $40 Million cash.

actually refined the process. Without the process innovation there would be little commercial application for these technologies. Process innovation often points to move from fluid to transition phase.

4.2.3 Moving up the value chain:

Fiber optic component suppliers started their innovations in the lower tiers of the industry value chain; such as laser diodes, LED's, and photo-detectors. There a few suppliers during the early phase of the fiber optic evolution that manufactured optical modules; like optical transponders. As product innovations in the lower tiers -such as lasers and receivers- increased, suppliers migrated to higher levels of the supply chain.

Year	1990-1998	1998-2001
Laser Diodes	EMCORE, Lasertron, CEL, Honeywell, EG&G, Furukawa, LaserDiodeInc. (Tyco), IBM (Uniphase), Epitaxx, SDL (Seastar), Lucent Technologies, NEC, Marconi, AMP, OptoPower	Tyco, JDS Uniphase, PerkinElmer,
VCSEL	Vixel, MODE, Honeywell, EMCORE, Mitel	Honeywell, Cielo, EMCORE, Novalux
LED	Furukawa, IBM (Uniphase), CEL, Mitsubishi	CEL, Mitel
Photo Detectors	BT&D, Furukawa, Lucent Technologies, Epitaxx	-
Transmitters	OCP, Finisar, Lucent Technologies, Mitsubishi, NEC, MRV, BT&D, Nortel, Ortel,	OCP, MRV, Optillion, Bookham, HP, Mitsubishi
Receivers	OCP, Finisar, Lucent Technolgies,, BT&D, NEC, MRV, Mitsubishi, Nortel	HP, OCP, MRV,
Multiplexer/Demultiplexer	PIRI, Lucent Technologies, E-Tek, NEL, Hitachi	Lightwave Microsystems, JDS Uniphse, Alcatel, Bookham, Hitachi, Nortel, Corning, Wavesplitter,
Erbium Doped Fiber Amplifier	JDS Fitel, Ditech, SDL, Alcatel, Nortel, Lucent Technologies, Corning,	JDS Uniphase, Lucent Tech., Onetta, InLight,
Transceivers*	MRV, OCP, Finisar, Lucent Tech., Mitsubishi, NEC, Nortel, BCP	E2O, MRV, OCP, JDS Uniphase, Pico Light, Cielo, Stratos Lightwave, Molex, Optillion, Alfa Light, Hitachi, Opnext
Transponders*	-	LightLogic (Intel), GTRAN, OCP, MRV, Finisar, Optillion, Pico Light, JDS Uniphse, Agilent, Oak Tech, MultiPlex, CeNIX, Network Elements, Infineon, OptronX, CeNIX, Hitachi
Isolators	E-Tek, Oplink, New Focus, OCL, Barr,	Avanex, WaveSplitter, Corning, FDK,
* Transceivers are combination of optical transmitter and receivers with little electronics. Transponders are transceivers with significant electronic interface capabilities including microcontrollers and decoders for interface.		

Table 4-1: Evolution of Component and Modules

As seen from Table 4-1 during the 1993-1998 there were no suppliers of transponders and little suppliers of transceivers; however in the second phase of the fiber optics evolution (1998-2001) there are many suppliers of transceivers and transponders, while many have exited discrete products. Some of these companies are new entrants; some are companies that once made transmitter and receivers; and some were previously suppliers of devices such as lasers and photo-detectors. At the time of this thesis in 2004, there are only a few small numbers of companies supplying lasers and photo-detectors due to price erosions.

4.3 <u>Innovation Regimes:</u>

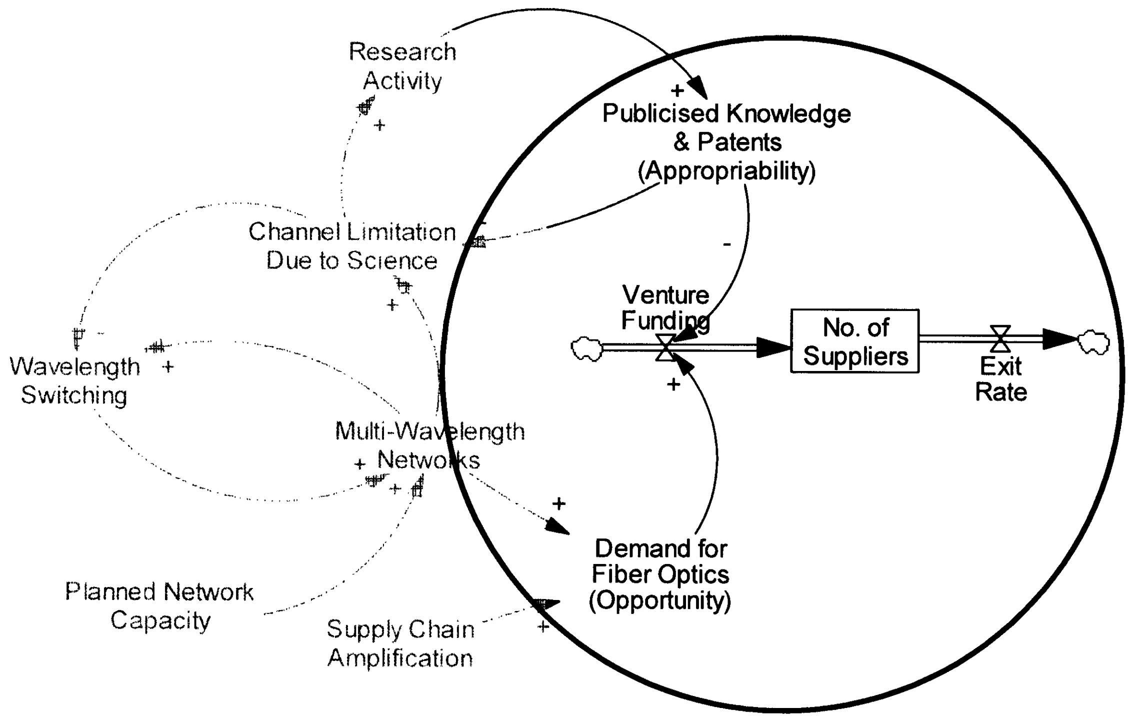

Figure 4-7: Innovation Regimes in the Model

Introduced earlier, the system dynamic model of the fiber optics industry incorporates innovation regimes as processes affecting the entry of new players. Industry life cycle analysis requires an analysis of the entrance and exit of firms in order to identify the various industry phases. The innovation regimes play a significant role in the overall evolution of the fiber optics industry as they indicate the forces influencing each phase of the industry. In this section a look at few metrics in the appropriability and opportunity of the fiber optic communication industry is provided.

4.3.1 Appropriability:

Appropriability in the fiber optics industry refers to the conditions that can halt or in some way reduce the ability of the new optical ventures to benefit from their innovations in the market. One indicator of the appropriability is the patent activity of the industry. Figure 4-8 looks at these activities over the past 25 years.

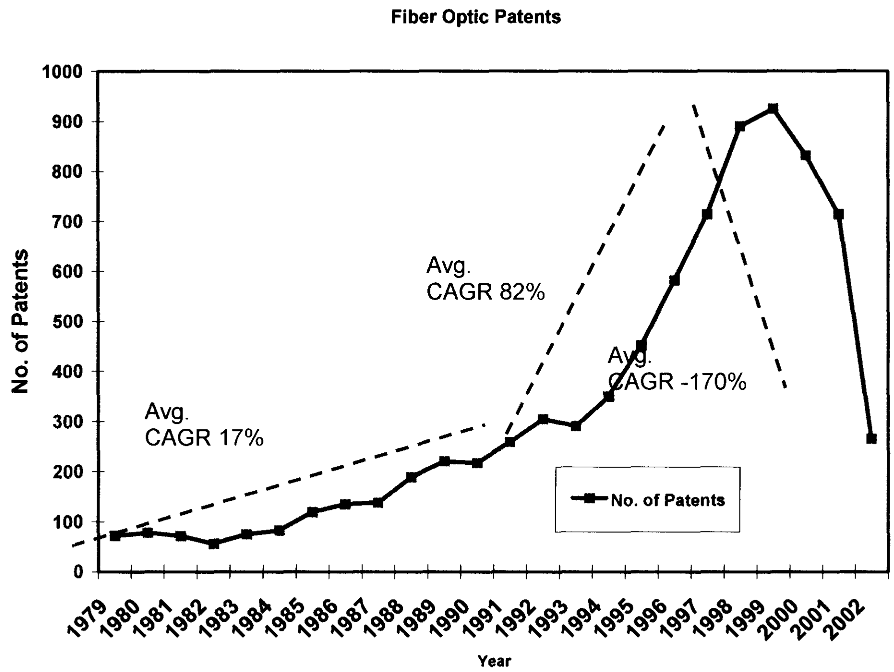

Figure 4-8: Patent Applications in Fiber Optics (USPTO)

Although patents are not the only indicator of the market's innovative environment; however, they are one of the indicators of the industry conditions. During the years 1995 to 1998 the number of patent applications with terms "fiber optic communication" reached peak of its growth. During this time over 2,500 patents were filed in the field of fiber optic communications; this is a clear indicator of the innovative process during that time.

Another reason for this growth may be explained by review of the situation in the early phases of fiber optics. The industry spent a good part of the 1970's and early 1980's as a small niche market inside the larger communication firms. It was during this time that most communication companies envisioned applications for fiber optics specific to their needs and foreseen applications. These companies used their internal research to conduct activities that were subsequently patented. These protective measures, however, proved less effective in the late 1990's as some of these patents expired. Also partly due to the communication dynamics mentioned in the previous chapter (such as liberalization, and capital infusion) number of patents grew substantially during this time.

According to the innovative regime theory, as the number of patents -or other protective action against imitators- grow the market conditions become less favorable for new entrants. To a great extent this was the case according to the entry of new firms as depicted in Figure 4-3, included in the early part of this chapter. During the years from 1995 to 1998 there were less new entrants than during the years 1998 to 2001. The growth rate and number of patent applications sharply dropped during these latter three years. All things being equal this may be one of the best indicators of the competitiveness of the industry at the time.

The patent activity of the fiber optics industry helps explain a bit more about the conditions of the industry. As seen in this analysis in the years from 1970 to early 1990's patent activities were somewhat limited. During the years 1998 to 2001 the industry actually had a lower patent activity. It is during this time where the number of entrants increases substantially. Appropriability through the treatment of patent activities helps clarify the behavior of the industry; further implying the life cycle of the industry shifting towards transitional phase. Additionally, 1998 was start of exodus of many engineers from the established companies to startups. This move created a secretive environment where trade secrets were far more important than accumulation of a diverse patent portfolio. These engineers were in rapid pursuit of innovations, and did not see the patent application process as best use of their limited resources.

Since the number of patents alone is not the only indicator of the industry conditions, the overall forces such as new investments and standardization should also be used to provide a broader view of the innovation regimes. These metrics indicate the opportunity of the industry covered in the next section.

4.3.2 Opportunity:

The opportunity regime refers to the environmental conditions which enable innovations to form. During the late 1990's as the fiber optic was heavily deployed, opportunity for entry of new companies increased. The advent of large scale use of fiber optic components and systems with minimal industry standards[37] meant that there was a little roadblock for new entrants. These new companies were not faced with hurdles of innovating according to set of requirements they could not meet.

4.3.2.1 Multi-Source Agreement

The technical standards in 1990's were limited to small number of components like transmitter and receivers. However, with integration of more electronics and logic circuits there has been an increase in the standardization process. This is true for optical transponders; the subsystems responsible for both electrical and optical communication that do several electronic processes internally. Proposals for standardization of optical transponders are referred to as Multi-Source Agreements (MSA). During the year 2001 JDS Uniphase, Finisar, Infineon Technologies, and Hitachi proposed a MSA for a configuration of transponders to be used in various applications covering various ranges in communication and data networking[38].

Prior to this point most equipment manufacturers were using discrete components such as lasers, photo-detectors, clock recovery unit, and various amplifiers and processors to build the fiber optic interface unit for their equipment. The advent of MSA along with evolution of fiber optic components made it more difficult for new entrants to join the market. At this point any new innovation had to fit a certain predefined mechanical and electrical interface as agreed in the industry-wide consortia. Opportunity limitations were starting to form with the initiation of the MSA during years following 2001. This is yet another cause for the reduction of new entrants to the fiber optic industry around that time.

The MSA design was a modification of packaging, and not a product innovation; it was merely a process innovation in integrating several components on the same board. The lasers and receivers inside these devices did not fundamentally change over the past several years; they were only incrementally getting smaller and more efficient. These new MSA devices function in the same manner and to great extent with the same general specifications as their board level predecessor. This is another indication of move toward process innovation and away from product. The MSA's serve as the notion of dominant design in the fiber optic industry, and they further point to the transition from fluid to transitional phase.

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[37] Fiber optic industry was still in its early phases during the mid to early 1990's. Also, since the market was dominated by only one company AT&T, there were very little standards or standard bodies formed.
[38] Meghan Fuller; XFP not a sure thing yet, Lightwave Magazine, September 2003

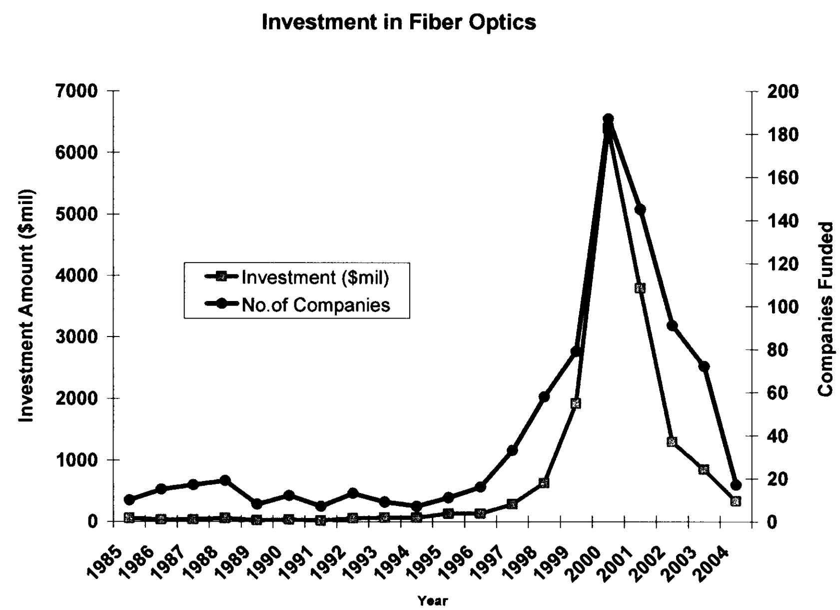

Figure 4-9: Investment Activity in Fiber Optics (Thomson Financial)

The entrants also saw a great potential market due to dynamics of the communications market with infusion of money through venture investments. As seen in Figure 4-9, the number of firms funded in this period was close to 200.

4.3.3 Process or Product Innovation?

According to the Dynamics of Innovation model by Utterback described, the industry life cycle moves to its transitional stage when the product innovation and process innovation curves cross. This indicates that the industry is undergoing a transition where products have found a dominant design and product innovation is no longer rewarded. During this phase process innovation takes the dominant mode in the industry. It is with this frame work that we look at a way to measure mode of innovation in the communication industry.

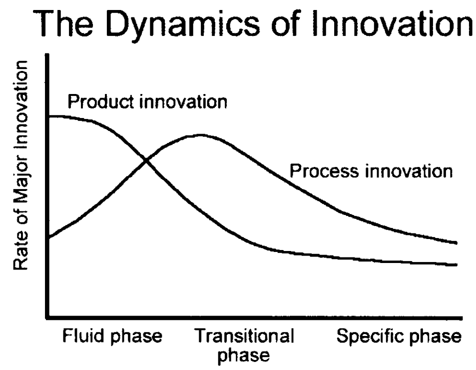

Figure 4-10: Utterback's Innovation Model

Based on this frame work, it is reasonable that by measuring the rate of appropriability of process innovation versus product innovation we may identify the evolution stage of communications industry on the dynamics of innovation curve in Figure 4-10 (Utterback 1993). The appropriability conditions of manufacturing industries in U.S. during the years 1995 to 1998 based on the level of patent activity is shown in Figure 4-11 by Cohen Nelson, Walsh 2000.

Patenting Activity by Industry: In the Last Three Years, Percent of R&D Units Applying for Patents and Percent of Product and Process Innovations

Industry	N	% Applying	N	Mean[1] % Product	N	Mean[1] % Process
1500:Food	87	52.87	78.00	14.64	74.00	15.21
1700:Textiles	23	43.48	21.00	9.49	18.00	6.79
2100:Paper	31	77.42	23.00	59.19	20.00	47.99
2200:Printing/Publishing	12	41.67	12.00	44.37	12.00	19.96
3210:Electronic Components	26	46.15	23.00	34.15	20.00	8.40
3211:Semiconductors and Related Equipment	17	64.71	14.00	48.51	12.00	20.60
3220:Communications Equipment	32	59.38	29.00	59.58	25.00	48.20
3230:TV/Radio	8	62.50	7.00	60.93	6.00	0.00
3311:Medical Equipment	66	89.39	51.00	66.80	42.00	31.16
3312:Precision Instruments	33	69.70	27.00	40.01	24.00	23.04
3314:Search/Navigational Equipment	37	86.49	32.00	50.24	24.00	24.43
3410:Car/Truck	9	88.89	8.00	48.63	5.00	19.62
3430:Autoparts	31	77.42	26.00	53.13	19.00	16.12
3530:Aerospace	49	77.55	42.00	50.81	37.00	35.66
3600:Other Manufacturing	85	64.71	72.00	37.05	62.00	17.22
ALL	1109	69.79	909.00	49.12	781.00	31.43

[1] Dropped respondents where sum of % Product and % Process = 100, suggesting respondent misunderstood question.

Figure 4-11: Patent Activity for Product and Process Innovation[39]

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[39] From: Cohen, W.M., Nelson, R.R., and Walsh, J.P. (2000) "Protecting their intellectual assets: Appropriability conditions and why U.S. Manufacturing firms patent (or not)", NBER Working Paper 7552

During their study period, they found the majority of the firms were focused on product innovation (59% to 48%). Whether this means that the communication industry during that year was focused more on product or process is not clear. The standard deviation of this research is close to the differences in the measure of product vs. process innovation. The 11% margin is also close to the 10% more product companies taking part in the survey. Assuming that these points don't play a major part in the result of their survey, the years 1993 to 1998 were indicators of a fluid phase in the communication industry. It is possible that both process and product innovation were equally important for the communication firms in this period. This would indicate as a move to transition phase during this time (1998).

4.4 Open Innovations:

Today, Cisco has become the company of choice for studying the process of open innovation. Cisco during the past 10 years has become a network of various smaller sized. Rather than relying on its internal ideas like Lucent and Nortel had, Cisco has consistently taken an 'open' approach to its innovation. Most of these acquisitions helped Cisco enter the fiber optic communication market at first. This in part was as an augmentation of Cisco's product line, as Cisco originally was mostly focused on IP routing applications and equipment and not optics. The role of venture capitals in creating opportunities for Cisco to purchase these companies is evident from the funding that was poured in the fiber optics industry.

Company	Paid	Initial Funding By
Altiga	$567M	Bessemer
Cerent	$6.9B	Kleiner Perkins
Crescendo	$93M	USVP
Fibex	$220M	NEA
Grand Junction	$348M	TVI
Growth Networks	$355M	NEA
Kalpana	$207M	Merrill
MaxComm	$143M	Sequoia Ventures
Monterey	$500M	ComVen
Nashoba	$128M	Norwest
Pipelinks	$126M	Sequoia Ventures
Qeyton	$800M	IGC
Sentient	$125M	Accel Partners
Transmedia	$400M	Venrock
V-bits	$128M	Bedrock

Table 4-2: Cisco Acquisitions

The framework for the open innovation paradigm clearly indicates that companies today relay on a network of knowledge sharing and knowledge brokering for their innovation processes. The virtuous cycle of innovation as indicated by Chesbrough (Chesbrough 2003) has been challenged by the entry of Venture financing. To a great extent it is the venture community that is funding the innovation processes of many emerging innovations. The new paradigm of innovation caused a great deal of challenge to the business models in the communication industry for long established companies.

The process of outsourcing of innovations has increased over the years in the communication industry in general. Today all the three traditional players in the communication equipment have changed their position in their research. The new business frame work is to utilize their external network for process of innovation. All the three suppliers of fiber optics equipment have cut back their R&D efforts substantially as indicated by Figure 4-12. Majority of this restructuring of personnel was caused by heavy downsizing in the years 2001 to 2003. However, as evident from its recent news releases, Lucent is not relying on internal R&D to win new deals with Verizon. Lucent is now partnering with Juniper and Movaz Networks in order to complete its offering in multi-service equipment offering[40].

Restructuring progress

No. of staff (000)	December 2000	December 2001	December 2002	December 2003e	2000/03 change	Quarterly B/E target at Dec 03
Alcatel	116.098	102,000	77,000	60,000	48%	€3.0bn
Lucent	106.000	62,000	40,000	35,000	67%	$2.5bn
Nortel	92.900	52,600	37,000	35,000	62%	$2.4bn

Source: Company data and SG Cowen estimates

Figure 4-12: Restructuring

Additionally, according to a recent report by Telephony magazine[41], vendors are spending far less on internal development and will continue to look for M&A or partnerships. In this report pointed to Ciena's acquisition cost of $636 million dollars in the first quarter of 2004. This, according to the report, was three times as much as it spent in R&D all the year before. The companies Ciena bought were Catena Networks, and Internet Photonics, both of which will help

[40] Company press release; "*Juniper Networks and Lucent Technologies announce partnership to deliver unified solutions for service providers*", May 5, 2003, and "*Lucent Technologies and Movaz Networks announce agreement to develop next-generation metro optical solutions*", February 24, 2004

[41] Ed Gubbins, Telephony, March 8, 2004; "Vendors continue partnering wile cutting deep into R&D; with far less internal development, vendors face M&A choices"

overcome Ciena's lackluster research efforts. Nortel on the other hand is using the cooperation and join development activities similar to Lucent. Nortel's R&D was cut by 12% in the year 2003, and to overcome this hurdle it has joined partnership agreements with Avici, Calix networks, and ECI Telecom.

4.5 Commoditization & De-Commoditization:

In the fiber optics in particular, and communications in general, products become obsolete with an ever increasing rate. As product obsolescence pulls profits away by reducing cost of network operators, they find it essential to lower both their OPEX and CAPEX. This reduction of costs is essential for longevity. Operators deploying fiber optic networks have been suffering financial pressures for some time as evident in Figure 4-13.

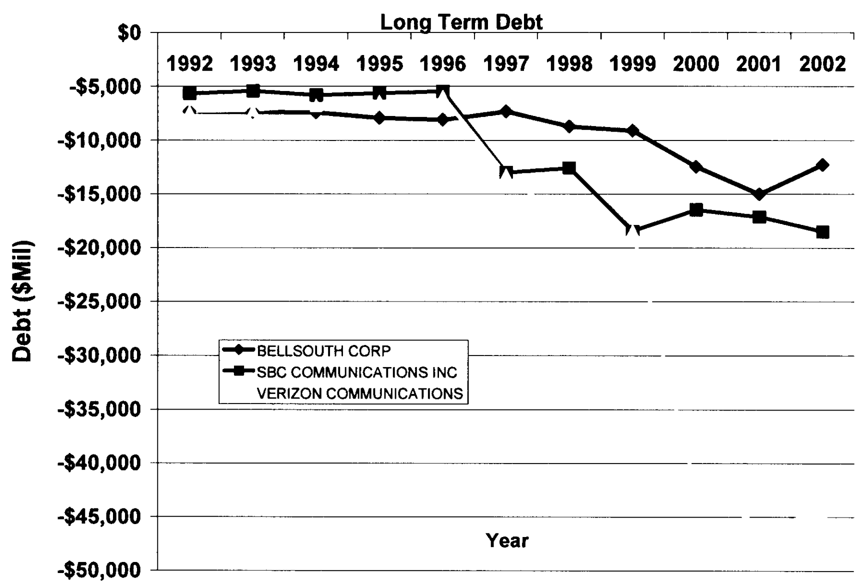

Figure 4-13: Service Provider Debt

The financial pressure along with technological advancements, drive product prices down while keeping required product functions the same or better in order to continue to serve their existing customer. As product differentiation becomes harder, and communication equipment becomes more of a commodity, network equipment companies seek to provide services to augment their product strategy. These companies are focusing on providing a better way for their customers, the service providers, to conduct business. This they do by helping their customers operate their own equipment, and in some cases taking over network management and operations altogether.

Today Qualcomm through its subsidiary network operations (Qualcomm Network Operations) is providing services to network operator Cardio Net. Using its own CDMA based networks, Qualcomm is providing all matters of operating their networks through its QChannel product line[42]. Also, Cisco as early as 1999 offered complete network solution to its Swedish customer Telia. With this deal Cisco would take over all aspect of operations, monitoring and provisioning of Telia's IP based network to provide a turn key solution. The equipment Cisco sold to Telia was finaniced by Cisco's Capital group. Clearly, both Qualcomm and Cisco are aware of their own industry dynamics and are fighting the forces of commoditization through moving higher in the value chain. Granted Qualcomm is not in the fiber optics industry, but they are part of the trends in the overall communication industry. This is an example that will find its way in the fiber optics industry. Cisco on the other hand is a clearer example of a fiber optics company moving up the value chain.

4.6 Summary:

Product Category	Fluid	Transition	Specific
Fiber	1970-1990	1990-2001	Today
Lasers			
Transmitter and Receiver	1985-1995	1995-2001	Today
Transceiver	1987-1998	1998-2001	Today
Transponders	1998-2001	2001-Present	Future
Optical Systems (DWDM)	1990-2001	2001-Present	Future

Table 4-3: Summary of Evolutions in Fiber Optics

In the recent years the fiber optic communication industry has undergone transitional phases in its life cycle. Not every part of the industry underwent through the cycle at the same time; as shown in the Table 4-3. Different segments of the value chain have undergone and continue to undergo these transitions; none has been immune. This chapter described the phases of life cycle of these segments. In addition to review of new entrants and exits, opportunity and appropriability regimes were used to identify the transition points of each phase. Examining the industry at the firm level showed the years 1998 and 2001 to be crucial years overall. This is an issue to be viewed in the next chapter.

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[42] Company press release: "QUALCOMM and CardioNet Partner to Deliver Wireless Data Monitoring Service to Cardiac Health Care Providers", August 11, 2003

5 Discussion:

In the rapidly changing field of technology a company's value is predicated by the choices it makes in pursuit of various technical paths. How a company innovates, the product strategy it chooses, and how these strategies are implemented determine the success of the company. Like an acrobat every move of every second develops the whole of the act; nothing suffices but all the right moves.

For assessing the dynamics of innovation in fiber optics industry, and deriving strategies for success in similar industries, current studies in management serve as a great yard stick. Technology strategies may be viewed based on the theories of innovation life cycle, technological regimes, and analysis of the commoditization processes. That was the approach taken by this thesis, and the following reviews the findings from the study.

5.1 <u>Innovation Life Cycle:</u>

Fiber optics industry was historically part of the traditional communication firms such as AT&T and Northern Telecom. These entities were closely tied to the high margin long distance telephony markets and as such had little concern for the dynamics of competitive markets (e.g., the present communication market). As usage of the long distance phone services increased - while prices decreased- fiber optic technologies were heralded as the technology of choice due to their high capacity to cost ratio. As described in Chapter 3, the widespread use of fiber optics was part of the larger industry dynamics of the communications value chain.

In communications as other industries where economies of scale have a significant affect on costs, utilization becomes an important factor of the firms' strategic intent. This is evident in the communication market where the main objective has simply been transport of data/voice. Low utilization rate in this type of industry is one of the key indicators of the systemic process of commoditization. Faced with lower than expected demand, communication service providers in the past years have been forced to improve their utilization rate either by lowering capacity, or increasing demand. Capacity reduction was not possible in most cases. Thus, in order to stimulate demand and increase their utilization rates the communication service providers started to either slash their prices or tried differentiating by offering new services.

Fiber optics sector, through its relation with communications industry, is also undergoing changes that have in turn lead to commoditization in several areas of its value chain as well. Firms in commoditized industries must innovate differently from those in non-commodity markets. The extent of innovations for these firms should be focused on advancements in processes suitable for widespread use and cost reduction. These process innovations are designed to lower the cost of producing or distributing products or services. Additionally, ubiquity and proliferation of goods and services in commoditized markets shift the nature of innovation to be more distributed and less central to the firm.

The success of firms is dependant on the focus of their innovation effort; if the dynamics of the innovation call for cost reduction by process improvement, any expense on mere product innovation will have less chance of success. In this process the vary nature of new product and service has changed from centralized research domain of larger firms to smaller more niche players, as evidenced in the case of AT&T Bell Labs.

Over the past decade there were a good number of entrants in the new fiber optics industry's value chain. These entrants joined the fray in the hopes of big payoffs for a market that did not quite materialize. The vulnerability of the suppliers throughout the communication value chain was amplified by choices and their focus in development of technologies. Based on the finding of this research, several indicators show that these new entrants had their timing wrong. The telecom industry cycle was on the downswing, as indicated by the system dynamics model, and thus new entrants faced a great deal of risks in innovating to the wrong cycle. According to the dynamics of the industry life cycle, innovations in the fiber optic industry during this period needed to focus much more on processes. This of course, was not the path they took. As outlined in chapter 4, most did not anticipate either the telecom downturn, nor did they realize the transition toward process innovation would come so quickly.

The trends of open innovations and networks clearly fit the facts of this industry as they unfolded in recent years. Lucent, the locus of innovations in the communications industry, was unable to hold on to its human capital. The mass exodus of the very engineers who were integral part of the optical communications group at Lucent helped create a much more distributed network of innovators in this field. The startups these engineers created were often clothed in a shroud of secrecy so to overcome the appropriability problem as shown by reduction in patent applications. This secrecy and lack of sharing of research led to a period of lull in the innovation output. The network that existed at Bell Labs was completely gutted. These innovators went off to create their own companies, and when the companies failed they did not go back to Lucent.

Take the case of Thomas Koch, and Joseph Ford. Tom was the Chief Technical Office of Lucent's optoelectronics division who recently became a professor at Lehigh University after leaving Lucent. Joe was a senior scientist with Lucent who moved west to be part of the startup Optical Micro Machines. After his company closed down, Joe went off to be a professor at University of California, San Diego.

In general, the fiber optic communication market has undergone two of the three identifiable phase shifts of the industry life cycle. During the late 1970's to the mid 1990's the industry underwent it fluid phase. This was evidenced by increase in the number of entrants and patent applications as implied by innovation regimes. During this transitional phase the industry development costs became the main stimulator of the innovation activities of successful firms. What was considerably a long fluid phase (close to 25 years) shifted to transitional phase rather quickly. By all accounts this transition phase too seems to be shifting to a specific phase very rapidly.

5.2 Key Findings:

This research showed two important points about fiber optic communications industry:

A. There was a relatively a long fluid phase in introduction of this innovation to mainstream applications. It took close to 30 years from the time that the disruptive nature of fiber optics was known and widely publicized to the time it took for new entrant firms to start to innovate more products.

B. The industry underwent a relatively short transitional phase. From the mid 1990's to the early 2000's a significant number of new entrants came to market with many product ideas. During the early 2000's to now most of these firms have exited the market. Furthermore, the companies that started the industry in its early phase did not benefit from their innovations.

C. Only a few innovators have remained after the industry shakeup, however, they are either service focused or are focused in reducing costs and product specification. They make products that are "good enough"; not over-engineered, nor extensively sophisticated. Some of the new entrants who had both large funding and a leading management team were able to survive the downturn, but not all of them. When the money ran out and prospects of new customers were reduced for the short term, they simply shut down. Most of the remaining players have very little centralized R&D. Their intellectual properties come from others either through acquisition or licensing arrangements.

What could explain this? The innovation / industry life cycle model provides some clues. Adding to this is the opening of innovation networks; a sort of democratization through the entry of venture capital and wider access to engineers in the innovation network. Let's look at these in some details.

5.2.1 Long Fluid Phase:

The long fluid phase in an industry like telecommunication may be due to the infrastructure issues. The telecom networks are extremely capital intensive to setup and operate. To implement a change in the network structure requires a financial commitment that monolithic company like AT&T was not willing to take on. Without any external drivers to the need to rapidly implement these changes was not fully justified.

As the telecommunication markets opened up by the process of divestiture and entrants of other carriers like MCI and Sprint, AT&T's commitment to fiber optics grew. Also, the advances in fiber cable and lasers reached an advanced point, and the deployment of fiber optics in the communication networks started to show their technical superiority then. The technical challenges in advancing of the fiber cable and the laser took over several years to go transition from laboratory setting to the manufacturing process.

5.2.2 Short Transitional Phase:

Proliferation of Internet and the resulting changes in traffic patterns of the networks created an environment where real innovations were needed in the communication structure. Internet type traffic required a network architecture that was markedly different from voice centric networks. Packet based traffic requires a distributed architecture whose propensity needed fiber optics at its base. They also seemed to require an endless supply of capacity which optical networks were known to be able to support. This pushed network related companies such as Ciena and Cisco to out-innovate the incumbents like Lucent and Nortel whose focus remained on voice. Drivers of innovations in the fiber optics were based on the architecture and capacity requirements of internet.

Combined with this was the abundance and accessibility of finance. Most companies formed in this time on the notion of having an 'optical' idea which could quench the thirst for huge bandwidth. Thrown in the mix was the liberalization of the telecommunication service industry by act of the federal government of U.S. Thus, allowing for a large number of companies to join the fray to compete for network equipment and optical gears. Rapid commoditization due to high capacity and low utilization rate set in, and caused further reduction in this phase of innovation life cycle.

In addition to these two forces, there were macro effects that have changed the very nature of innovation. In our era, research and development are not processes at the core of a few long established firms. Research in today's technology centric world means a network of ideas and innovations that are highly transferable. The notion of licensing and sale of rights to patents has become a serious business. Trading of innovations is at the core of what this thesis refers to as open innovation.

For the many startups formed during this fluid phase the end came suddenly. Like a plague it debilitated many of these new companies and left the industry in ruins. The symptoms were mass exits and terrific financial losses all across the value chain. The diagnosis was the effect of the larger market dynamics of the telecom. Companies innovated in the wrong cycle and with ill timing. While the cyclic telecom industry was in one of the worst downturn experienced, these new suppliers to the communication value chain were devastated. The transition phase ended very quickly; the transitional phase spanned from the mid to late 1990's to early 2001.

5.2.3 Specific Phase:

As the fiber optic industry has already entered its specific phase suppliers are attacking the market from different angles. Some have convinced their investors to keep funding them through another cycle. Some have decided to go back to drawing board and to innovate new products. Few have left the communication markets and modified their solutions for other industries like the military, health, and consumer markets. Yet fewer are focusing on production techniques to lower costs, they are convinced that in a commoditized market they will have the edge. Some firms have also found ways to provide services like design and tests, instead of products.

Today several Asian suppliers have entered the market with focus on only producing transponders based on standard MSA specifications. Their attention is cost reduction through volume manufacturing, they also benefit from geographic vicinity to their customers. As we enter the commoditization phase it seems that cost improvement and focus on process innovation may be the way forward. It also means that suppliers who know the value of de-commoditization can hold on to their markets. This they do by supporting their customers through outsourcing of their operations, helping with design process, and finding other ways to create trust and bond with their customers.

5.3 Future Direction:

Looking ahead, the future of fiber optic communication industry is very uncertain. Trends in this industry are not readily discernable. The complexity is due to dynamics of the communications as related to macroeconomics conditions. In lieu of the uncertainty present, interpretation of current trends allows for some forecasting of the industry and can support speculation of the future direction for fiber optic market. This section aims to provide some possible future directions for this industry by review of dynamics introduced throughout this thesis. The extrapolation of these trends is done with the risk of being wrong; any prediction of the future direction of this complexity cannot be fully accurate[43].

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[43] This is further complicated with the advent of changes in regulatory rulings of the Federal Communications Commission, and the possible change of the administrative policies surrounding financial markets.

As indicated in previous chapters, most companies in the fiber optics value chain missed the window of opportunity and innovated to the wrong cycle of the industry dynamic. This happened due to unexpectedly short transition phase of the market; product innovations did not cease even when the time had come for process innovation. Following this trend, companies in existence today are either focusing on process innovation, or will undoubtedly face extinction.

Additionally, as described in the past chapter, the number of suppliers of fiber optic components and equipment manufacturers has remained relatively high, while the number of service providers has substantially gone down. There are too many hardware suppliers going after too little network operators. The network operators will continue to drive costs down by pressing their suppliers to lower prices. In this market the buyers have substantial power. It is also probable that consolidation will continue to take place in various aspects of the value chain as well. Companies that cannot face margin pressures will give away to those who perfect their process innovations to drive down the cost curve.

The rapid rate of investment in technological innovations was extremely rapid in the years leading up to 2001. This rate has decreased drastically and will not recover to its previous levels anytime soon. This is due to two forces: A) The larger dynamics of the communications market continue to focus on ease and reduced cost of deployment of replacement technologies (such as wireless), B) Funding of new ventures in the fiber optics domain is focusing on cross-over applications in other adjacent markets. These two forces combined will continue to cause unfavorable conditions for entrepreneurs in the communications market with the sole focus in fiber optics. There will be little opportunities in the long haul (WAN) fiber optics communications segment, as most product innovations have already created unfilled capacity. Other areas of communications such as access and storage (MAN, and SAN respectively) may utilize fiber as one of the means of fulfilling growth[44]. However, fiber optics will not be the only solution for these applications as wireless technologies in unlicensed spectrum will fill some of these needs.

5.3.1 Advent of Lower Cost Technologies:

The communication industry will continue to evolve around the concept of commoditization. To this effect the network operations will slowly disengage from services and content, cost and

[44] See Lightwave, *Carriers profit from 'SAN-in-MAN' managed storage services*, Jan2004, Vol. 21, pg. 1

value of seamless communications will become the key marker for this evolution. Each part of this future value chain infrastructure will focus its efforts in reducing operational costs and risks. The network operators' value proposition will become their ability to transfer content (voice, data or video) from any available network technology to another; this means handing off calls from the wireline networks to wireless without any dropped calls. The future network will have to be an amalgamation of various technologies as services will need to be further removed from the network operations and technologies[45].

In this view, fiber optic communications' core value will be in its ability to carry a large aggregate capacity at relatively low costs. As this new infrastructure of communications appears, there will be an extended period of time where there is little incentive to invest in the fiber optics value chain. Wireless technology's advantage will continue to be its mobility and ubiquity. Faced with this competition, future innovations in fiber optics will be valuable only if they can provide higher capacity and capability at substantially lower costs and with more ease. Fiber infrastructure expansion continues to be expensive due to its prohibitive deployment cost and installation. Wireless services have an advantage in this case, especially unlicensed wireless networks that do away with costs associated with buying scarcity of allocated wireless spectrum[46]. The excess of investments in fiber optics seen in years prior to 2001 is no longer justifiable.

Future suppliers of key technologies such as transceivers will have to work on unique pricing models. As the cost of new fiber deployment remains high, these components will become the key upgradeable parts of the fiber optic networks. This is due to their relatively lower cost when compared to fiber cable installation. Thus, these components will continue to see most demand and requirements for process innovations. Pricing models should encourage replacements by network operators. Economies of scale will be the key drivers of this pricing model; suppliers with higher production volumes will be in favorable cost position. In order to achieve these economies of scale, fiber optic transceivers must be on par with wireless transceivers of lower capacity.

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[45] See WSJ; *Cisco Wi-Fi Switch Helps Blend Wireless, Hard-Wire Networks*, May 5, 2004, Pg. C14
[46] Variations of IEEE 802.11, 802.16, and 802.20; and the advent of UWB and 1394b use unlicensed spectrum. This allows them to be extremely cost effective and widely deployable. These networks continue to evolve in their capabilities and have the potential of becoming a replacement for licensed spectrum cellular networks such as CDMA, GSM and UMTS.

5.3.2 Adjacent Markets and Applications:

New ventures and research areas for fiber optic communications are being created in other industries outside of traditional network applications. Fiber optic communication carriers will enter new markets such as video[47] in order to fill their excess capacity. Additionally, fiber optics will also be used in various computational applications for imaging and data mining within high speed networks[48].

These new innovations are aimed at the cross-roads between computing and communications (voice, video and data). As processor speed increases so does the rate of interconnections between it and the bus. Currently bus architectures are designed to handle several hundred megabits per second. In the future bus structures, such as InfiniBand and video display interconnects, will push beyond this limit and will use fiber optics[49]. Fiber optics will be seen in automotive and avionic applications[50]. The most suitable alternative to copper based wires in high-speed interconnect applications will be fiber optics (cost remains an issue).

In the future optical components will be built using semiconductors based on Silicon and CMOS processes. Thus enabling these devices (such as lasers, modulators and photo-detectors) to be integrated on the same substrate with advanced electronics and with the same price points. By enabling optical functions to proximate electronic intelligence, designers will be able to adapt optics into computers and consumer applications[51].

5.4 <u>Further Research:</u>

As indicated in chapter 4, the measures of appropriability are not limited to the number of patents. In the research of communications industry one can expand this search by further investigation of the number of industry and academic research initiatives. Additionally, number of publications and conferences can be good indicators of industry's market dynamics for new

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[47] See Telephony; *Level 3, Broadwing tune in to video market*, Pg. 16, April 19, 2004
[48] See Communications of the ACM; *The OptIPuter*, Nov2003, Vol. 46 Issue 11, p58
[49] See Electronic Engineering Times; *Infiniband deal spells out 10- and 30-Gbit links*, 6/16/2003 Issue 1274, p38
[50] See Communications News; *Plastic Optical Fiber*, Volume 36, Pg. 10.
[51] See Electronic News (North America); *Intel Making Silicon Work for Optoelectronics,* March 2004, Vol. 50, Issue 9

entrants. The appropriability in the high tech industry also includes brand name, market share and system lock-in (such as Wintel alliance). These measures will become more significant in the future of the fiber optic communications industry as it reaches a higher level of maturity in the coming few years. To continue this research one can look for ways that firms have been able to increase their longevity. Additionally, further research could look at global indicators such as the evaluation of currencies and labor arbitrage.

5.5 Recommended Readings:

For more on trends and patterns emerging from R&D read:

Changes in the strategic management of technology: results of a global benchmarking study; Jakob Edler, Frieder Meyer-Krahmer and Guido Reger, R&D Management 32, 2, 2002

The author provides a very comprehensive outline of generalized models of R&D management over the past several decades. Included are classification of three generations of management models and their evolution. The authors' benchmark study provides an analysis and outlook of what they refer to as fourth generation management model. In this study they found that location of where innovation occurs is global, pointing to an internationalization and notion of "pockets of innovation". Successful companies place responsibility of innovation resources to be strategically linked to both corporate and business unit levels.

For detailed analysis of the technologies in the fiber optic communication industry see:

Optical fiber telecommunications III / edited by Ivan P. Kaminow, Thomas L. Koch.

The volume identifies key advances in areas of the telecommunication networks based on fiber optic innovations. In this collection authors describe topics as broad as architectural design of fiber based networks, to basics properties of materials with suitable optical properties. The editors were researchers at Bell Labs with authoritative qualification in addressing the dynamic technologies of fiber optics.

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Appendix:

Fiber-Optic Chronology

By Jeff Hecht

Circa **2500 B.C.**: Earliest known glass

Roman Times: Glass is drawn into fibers

1713: Rene de Reaumur makes spun glass fibers

1790s: Claude Chappe invents 'optical telegraph' in France

1841: Daniel Colladon demonstrates light guiding in jet of water Geneva

1842: Jacques Babinet reports light guiding in water jets and bent glass rods Paris

1853: Paris Opera uses Colladon's water jet in the opera Faust

1854: John Tyndall demonstrates light guiding in water jets, duplicating but not acknowledging Colladon

1873: Jules de Brunfaut makes glass fibers that can be woven into cloth

1880: Alexander Graham Bell invents Photophone, Washington

1880: William Wheeler invents system of light pipes to illuminate homes from an electric arc lamp in basement, Concord, Mass.

1884: International Health Exhibition in South Kensington district of London has first fountains with illuminated water jets, designed by Sir Francis Bolton

1887: Charles Vernon Boys draws quartz fibers for mechanical measurements

1887: Royal Jubilee Exhibition in Manchester has illuminated "Fairy Fountains" designed by W. and J. Galloway and Sons

1888: Illuminated fountains at Glasgow and Barcelona fairs

1888: Dr. Roth and Prof. Reuss of Vienna use bent glass rods to illuminate body cavities

1889: Universal Exhibition in Paris shows refined illuminated fountains designed by G. Bechmann

1895: Henry C. Saint-Rene designs a system of bent glass rods for guiding light in an early television scheme (Crezancy, France)

1892: Herman Hammesfahr shows glass dress at Chicago World's Fair

April 25, 1898: David D. Smith of Indianapolis applies for patent on bent glass rod as a surgical lamp

1920s: Bent glass rods used for microscope illumination

June 2, 1926: C. Francis Jenkins applies for U.S. patent on a mechanical television receiver in which light passes along quartz rods in a rotating drum to form an image.

Oct. 15, 1926: John Logie Baird applies for British patent on an array of parallel glass rods or hollow tubes to carry image in a mechanical television. He later built an array of hollow tubes.

December 30, 1926: Clarence W. Hansell outlines principles of the fiber-optic imaging bundle in his notebook at the RCA Rocky Point Laboratory on Long Island. RCA files for U.S. patent Aug. 13, 1927, and later files for British patent.

1930: Heinrich Lamm, a medical student, assembles first bundle of transparent fibers to carry an image (of an electric lamp filament) in Munich. His effort to file a patent is denied because of Hansell's British patent.

December 1931: Owens-Illinois devises method to mass-produce glass fibers for Fiberglas.

1937: Armand Lamesch of Germany applies for U.S. patent on two-layer glass fiber (non-optical)

1939: Curvlite Sales offers illuminated tongue depressor and dental illuminators made of Lucite, a transparent plastic invented by DuPont.

Circa 1949: Holger Moller Hansen in Denmark and Abraham C. S. Van Heel at the Technical University of Delft begin investigating image transmission through bundles of parallel glass fibers.

April 11, 1951: Holger Moller Hansen applies for a Danish patent on fiber-optic imaging in which he proposes cladding glass or plastic fibers with a transparent low-index material. Patent claim is denied because of Hansell patent.

October 1951: Brian O'Brien (University of Rochester) suggests to Abraham C. S. Van Heel (Technical University of Delft) that applying a transparent cladding would improve transmission of fibers in his imaging bundle.

July 1952: Harold Horace Hopkins applies for a grant from the Royal Society to develop bundles of glass fibers for use as an endoscope at Imperial College of Science and Technology. Hires Narinder S. Kapany as an assistant when he receives grant.

Spring 1953: Hopkins tell Fritz Zernicke his idea of fiber bundles; Zernicke tells van Heel, who decides to publish quickly

June 12, 1953: van Heel publishes first report of clad fiber in Dutch-language weekly De Ingeneur after submitting brief paper to Nature.

January 2, 1954: Hopkins and Kapany and van Heel publish separate papers in Nature. Hopkins and Kapany report imaging bundles of unclad fibers; van Heel reports simple bundles of clad fibers.

1954: Basil Hirschowitz visits Hopkins and Kapany in London from the University of Michigan

September 1954: American Optical hires Will Hicks to implement develop fiber-optic image scramblers, an idea O'Brien proposed to the Central Intelligence Agency

Summer 1955: Kapany completes doctoral thesis on fiber optics under Hopkins, moves to University of Rochester.

Summer 1955: Hirschowitz and C. Wilbur Peters hire undergraduate student Larry Curtiss to work on their fiber-optic endoscope project.

Summer 1956: Curtiss suggests making glass clad fibers by melting a tube onto a rod of higher-index glass

December 8, 1956: Curtiss makes first glass-clad fibers by rod-in-tube method.

February 1957: Hirschowitz is first to test fiber-optic endoscope in a patient.

1957: Image scrambler project ends after Hicks tells CIA the code is easy to break.

1958: Hicks, Paul Kiritsy and Chet Thompson leave American Optical to form Mosaic Fabrications in Southbridge, Mass., the first fiber-optics company.

1958: Alec Reeves begins investigating optical communications at Standard Telecommunication Laboratories

1959: Working with Hicks, American Optical draws fibers so fine they transmit only a single mode of light. Elias Snitzer recognizes the fibers as single-mode waveguides.

May 16, 1960: Theodore Maiman demonstrates first laser at Hughes Research Laboratories in Malibu.

December 1960: Ali Javan makes first helium-neon laser at Bell Labs, the first laser to emit a steady beam.

Circa 1960: George Goubau at Army Electronics Command Laboratory, Bell Telephone Laboratories and Standard Telecommunication Laboratories begin investigating hollow optical waveguides with regularly spaced lenses

January 1961: Charles C. Eaglesfield proposes hollow optical pipeline made of reflective pipes

May 1961: Elias Snitzer of American Optical publishes theoretical description of single-mode fibers.

1962-63: Alec Reeves at Standard Telecommunications Laboratories in Harlow, UK, commissions a group to study optical waveguide communications under Antoni E. Karbowiak. One system they study is optical fiber.

Autumn 1962: Four groups nearly simultaneously make first semiconductor diode lasers, but they operate only pulsed at liquid-nitrogen temperature. Robert N. Hall's group at General Electric is first.

1963: Karbowiak proposes flexible thin-film waveguide.

December 1964: Charles K. Kao takes over STL optical communication program when Karbowiak leaves to become chair of electrical engineering at the University of New South Wales. Kao and George Hockham soon abandon Karbowiak's thin-film waveguide in favor of single-mode optical fiber.

January 1966: Kao tells Institution of Electrical Engineers in London that fiber loss could be reduced below 20 decibels per kilometer for inter-office communications.

Early 1966: F. F. Roberts starts fiber-optic communications research at British Post Office Research Laboratories

July 1966: Kao and Hockham publish paper outlining their proposal in the Proceedings of the Institution of Electrical Engineers.

July 1966: John Galt at Bell Labs asks Mort Panish and Izuo Hayashi to figure out why diode lasers have high thresholds at room temperature.

September 1966: Alain Werts, a young engineer at CSF in France, publishes proposal similar to Kao's in French-language journal L'Onde Electronique, but CSF does nothing further for lack of funding.

1966: Roberts tells William Shaver, a visitor from the Corning Glass Works, about interest in fiber communications. This leads Robert Maurer to start a small research project on fused-silica fibers.

1966: Kao travels to America early in year, but fails to interest Bell Labs. He later finds more interest in Japan.

Early 1967: British Post Office allocates an extra 12 million pounds to research; some goes to fiber optics.

Early 1967: Shojiro Kawakami of Tohoku University in Japan proposes graded-index optical fibers.

Summer 1967: Corning summer intern Cliff Fonstad makes fibers. Loss is high, but Maurer decides to continue the research using titania-doped cores and pure-silica cladding.

October 1967: Clarence Hansell dies at 68.

Late 1967: Maurer recruits Peter Schultz from Corning's glass chemistry department to help making pure glasses.

January 1968: Donald Keck starts work for Maurer as the first full-time fiber developer at Corning. The team also includes Frank Zimar, who draws fiber in a high-temperature furnace he built

1968: Kao and M. W. Jones measure intrinsic loss of bulk fused silica at 4 decibels per kilometer, the first evidence of ultratransparent glass, prompting Bell Labs to seriously consider fiber optics.

August 1968: Dick Dyott of British Post Office picks up suggestion for pulling clad optical fibers from molten glass in a double crucible.

1969: Martin Chown of STL demonstrates fiber-optic repeater at Physical Society exhibition.

April 1970: STL demonstrates fiber optic transmission at Physics Exhibition in London.

Spring 1970: First continuous-wave room-temperature semiconductor lasers made in early May by Zhores Alferov's group at the Ioffe Physical Institute in Leningrad (now St. Petersburg) and on June 1 by Mort Panish and Izuo Hayashi at Bell Labs.

June 30, 1970: AT&T introduces Picturephone in Pittsburgh. The telephone monopoly plans to install millimeter waveguides to provide the needed extra capacity.

Summer 1970: Maurer, Donald Keck, Peter Schultz, and Frank Zimar at Corning develop a single-mode fiber with loss of 17 dB/km at 633 nanometers by doping titanium into fiber core.

September 30, 1970: Maurer announces results at London conference devoted mainly to progress in millimeter waveguides.

November 1970: Measurements at British Post Office and STL confirm Corning results.

Late Fall 1970: Charles Kao leaves STL to teach at Chinese University of Hong Kong; Murray Ramsay heads STL fiber group.

1970-1971: Dick Dyott at Post Office and Felix Kapron of Corning separately find pulse spreading is lowest at 1.2 to 1.3 micrometers.

May 1971: Murray Ramsay of Standard Telecommunication Labs demonstrates digital video over fiber to Queen Elizabeth at the Centenary of the Institution of Electrical Engineers.

October 13, 1971: Alec Reeves dies in London.

1971-1972: Unable to duplicate Corning's low loss, Bell Labs, the University of Southampton, and CSIRO in Australia experiment with liquid-core fibers.

1971-1972: Focus shifts to graded-index fibers because single-mode offers few advantages and many problems at 850 nanometers.

June 1972: Maurer, Keck and Schultz make multimode germania-doped fiber with 4 decibel per kilometer loss and much greater strength than titania-doped fiber.

Late 1972: STL modulates diode laser at 1 Gbit/s; Bell Labs stops its last work on hollow light pipes.

December 1972: John Fulenwider proposes a fiber-optic communication network to carry video and other signals to homes at International Wire and Cable Symposium.

1973: John MacChesney develops modified chemical vapor deposition process for fiber manufacture at Bell Labs.

Mid-1973: Diode laser lifetime reaches 1000 hours at Bell Labs.

Spring 1974: Bell Labs settles on graded-index fibers with 50- to 100 micrometer cores.

December 7, 1974: Heinrich Lamm dies at 66

February 1975: Bell completes installation of 14 kilometers of millimeter waveguide in New Jersey. After tests, Bell declares victory and abandons the technology.

June 1975: First commercial continuous-wave semiconductor laser operating at room temperature offered by Laser Diode Labs.

September 1975: First non-experimental fiber-optic link installed by Dorset (UK) police after lightning knocks out their communication system

October 1975: British Post Office begins tests of millimeter waveguide; like Bell it declares the tests successful, but never installs any.

1975: Dave Payne and Alex Gambling at University of Southampton calculate pulse spreading should be zero at 1.27 micrometers.

January 13, 1976: Bell Labs starts tests of graded-index fiber-optic system transmitting 45 million bits per second at its Norcross, Georgia plant. Laser lifetime is main problem.

Early 1976: Valtec launches Communications Fiberoptics division.

Early 1976: Masaharu Horiguchi (NTT Ibaraki Lab) and Hiroshi Osanai (Fujikura Cable) make first fibers with low loss -- 0.47 decibel per kilometer -- at long wavelengths, 1.2 micrometers.

March 1976: Japan's Ministry for International Trade and Industry announces plans for Hi-OVIS fiber-optic "wired city" experiment involving 150 homes.

Spring 1976: Lifetime of best laboratory lasers at Bell Labs reaches 100,000 hours (10 years) at room temperature.

Summer 1976: Horiguchi and Osanai open third window at 1.55 micrometers.

July 1976: Corning sues ITT alleging infringement of American patents on communication fibers.

Late 1976: J. Jim Hsieh makes InGaAsP lasers emitting continuously at 1.25 micrometers.

Spring 1977: F. F. Roberts reaches mandatory retirement age of 60; John Midwinter becomes head of fiber-optic group at British Post Office.

April 1, 1977: AT&T sends first test signals through field test system in Chicago's Loop district.

April 22, 1977: General Telephone and Electronics sends first live telephone traffic through fiber optics, 6 Mbit/s, in Long Beach, California.

May 1977: Bell System starts sending live telephone traffic through fibers at 45 Mbit/s fiber link in downtown Chicago.

June 1977: British Post Office begins sending live telephone traffic through fibers in underground ducts near Martlesham Heath.

June 29, 1977: Bell Labs announces one-million hours (100-year) extrapolated lifetime for diode lasers.

Summer 1977: F. F. Roberts dies of heart attack.

October 1977: Valtec "acquires" Comm/Scope, but Comm/Scope owners soon gain control of Valtec.

Late 1977: AT&T and other telephone companies settle on 850 nanometer gallium arsenide light sources and graded-index fibers for commercial systems operating at 45 million bits per second.

1977-1978: Low loss at long wavelengths renews research interest in single-mode fiber.

May 22-23, 1978: Fiber Optic Con, first fiber-optic trade show, held in Boston.

July 1978: Optical fibers begin carrying signals to homes in Japan's Hi OVIS project.

August 1978: NTT transmits 32 million bits per second through a record 53 kilometers of graded-index fiber at 1.3 micrometers.

September 1978: Richard Epworth reports modal noise problems in graded-index fibers.

September 1978: France Telecom announces plans for fiber to the home demonstration in Biarritz, connecting 1500 homes in early 1983.

1978: AT&T, British Post Office and STL commit to developing a single mode transatlantic fiber cable, using the new 1.3-micrometer window, to be operational by 1988. By the end of the year, Bell Labs abandons development of new coaxial cables for submarine systems.

Late 1978: NTT Ibaraki lab makes single-mode fiber with record 0.2 decibel per kilometer loss at 1.55 micrometers.

January 1980: AT&T asks Federal Communications Commission to approve Northeast Corridor system from Boston to Washington, designed to carry three different wavelengths through graded-index fiber at 45 Mbit/s.

Winter 1980: Graded-index fiber system carries video signals for 1980 Winter Olympics in Lake Placid, New York, at 850 nanometers.

February 1980: STL and British Post Office lay 9.5 km submarine cable in Loch Fyne, Scotland, including single-mode and graded-idex fibers

1980: Bell Labs publicly commits to single-mode 1.3-micrometer technology for the first transatlantic fiber-optic cable, TAT-8.

September 1980: With fiber optics hot on the stock market, M/A Com buys Valtec for $224 million in stock.

July 27, 1981: ITT signs consent agreement to pay Corning and license Corning communication fiber patents.

1981: Commercial second-generation systems emerge, operating at 1.3 micrometers through graded-index fibers.

1981: British Telecom transmits 140 million bits per second through 49 kilometers of single-mode fiber at 1.3 micrometers, starts shifting to single-mode.

Late 1981: Canada begins trial of fiber optics to homes in Elie, Manitoba.

1982: British Telecom performs field trial of single-mode fiber, changes plans abandoning graded-index in favor of single-mode.

December 1982: MCI leases right of way to install single-mode fiber from New York to Washington. The system will operate at 400 million bits per second at 1.3 micrometers. This starts the shift to single-mode fiber in America.

Late 1983: Stew Miller retires as head of Bell Labs fiber development group.

January 1, 1984: AT&T undergoes first divestiture, splitting off its seven regional operating companies, but keeping long-distance transmission and equipment manufacture.

1984: British Telecom lays first submarine fiber to carry regular traffic, to the Isle of Wight.

1985: Single-mode fiber spreads across America to carry long-distance telephone signals at 400 million bits per second and up.

Summer 1986: All 1500 homes connected to Biarritz fiber to the home system.

October 30, 1986: First fiber-optic cable across the English Channel begins service.

1986: AT&T sends 1.7 billion bits per second through single-mode fibers originally installed to carry 400 million bits per second.

1987: Dave Payne at University of Southampton develops erbium-doped fiber amplifier operating at 1.55 micrometers.

1988: Linn Mollenauer of Bell Labs demonstrates soliton transmission through 4000 kilometers of single-mode fiber.

December 1988: TAT-8 begins service, first transatlantic fiber-optic cable, using 1.3-micrometer lasers and single-mode fiber.

February 1991: Masataka Nakazawa of NTT reports sending soliton signals through a million kilometers of fiber.

February 1993: Nakazawa sends soliton signals 180 million kilometers, claiming "soliton transmission over unlimited distances."

February 1993: Linn Mollenauer of Bell Labs sends 10 billion bits through 20,000 kilometers of fibers using a simpler soliton system.

February 1996: Fujitsu, NTT Labs, and Bell Labs all report sending one trillion bits per second through single optical fibers in separate experiments using different techniques.

Privately Funded Fiber Optic Companies (1995 to 2004)

Company Name	City	State	Country	Current Situation	Company Founding Date	Business Description	Total Number of Company Investors	Total Known Amt Invested in Co. ($000)	Investors (Firms)
Aerie Networks, Inc.	Denver	CO	United States	Active Investment	1999	Builds a national fiber optics telecommunications network. The Company builds and operates a broadband technology and business platform designed to host an infinite number of new networks with high bandwidth capacity. Aerie Networks, Inc. has shifted its focus toward acquiring and consolidating networks in order to provide managed network services. The company acquired the Ricochet wireless data network from bankrupt Metricom in 2001; it operates primarily under the Ricochet brand. network fiber optic communications telecommunications	28	$113,400	Adams Capital Management, Inc.,Advent International Corporation,Apax Partners, Inc. (FKA: Patricof & Co. Ventures, Inc.),BancBoston Capital/BancBoston Ventures,Bessemer Venture Partners,Global Technology Group Ventures (FKA: DAMAC Ventures),Lockheed Corporation,Meritech Capital Partners,Oak Investment Partners,TeleSoft Partners,Undisclosed Venture Firm,Wilson, Sonsini, Goodrich & Rosati (AKA: WS Investments),Worldview Technology Partners
Alliance Fiber Optics Products, Inc.	Sunnyvale	CA	United States	Went Public	1996	Designs, manufactures and markets high performance fiber optic components and integrated modules for the optical network equipment market. The Company's products enable emerging and leading communications equipment manufacturers to deliver optical networking systems to the rapidly growing long-haul, metropolitan and last-mile access segments of the communications network. The broad product line of passive optical components includes interconnect systems, couplers and splitters, thin film DWDM components and modules, fixed and variable optical attenuators, and depolarizers. WDM WMS fiber optics DWDM splitters couplers optical network integrated modules	28	$76,000	Cedar Fund,Cedar Grove Investments,Cedar Ventures, LLC,GE Equity (FKA: GE Capital Equity Capital Group),Gilde Investment Management,Giza Venture Capital (FKA: Giza Investment Management),Index Ventures Management SA,Morgan Stanley Venture Partners (AKA: MSDW),SSM Ventures,SoundView Ventures,U.S. Bancorp Piper Jaffray Private Capital,Undisclosed Corporate Investor,Undisclosed Venture Firm,VantagePoint Venture Partners

American Fiber Systems, Inc.	Rochester	NY	United States	Active Investment	1999	Develops and constructs local fiber optic communications systems. The Company is organized as an infrastructure provider for ELECs and BLECs. American Fiber Systems is a developer of high-capacity, dark fiber optic networks in second-and third-tier American cities. Customers, such as CLECs, ISPs, and others, then lease the company's networks on the basis of long-term "indefeasible" rights of use. communications fiber optic system	12	$58,370	Crescendo Venture Management LLC,Hotung International Company, Ltd.,Individuals,InveStar Capital, Inc.,Undisclosed Non Venture Firm,Undisclosed Venture Firm,Worldview Technology Partners
Auxora, Inc. (FKA: NexWave)	Baldwin Park	CA	United States	Active Investment	2000	Manufactures five types of precision optical filters for fiber optic communication applications. Auxora develops deposition technologies that produce thin films with consistent and predictable properties and with thickness controls precise to the molecular level. Auxora engineers thin film materials that have extremely low absorption and scattering loss, as well as the appropriate thermal-mechanical properties that ensure easy fabrication and environmental and thermal stability. fiber optics	21	$56,250	AIG Global Investment Corporation,AIG Investment Corp (Asia) Ltd,Apax Partners Ventures (Israel) Ltd (AKA: Apax Israel),Apax Partners, Inc. (FKA: Patricof & Co. Ventures, Inc.),CIBC Wood Gundy Capital,Eurofund LP,Genesis Partners,Geneva Merchant Banking Partners,Israel Seed Partners,KTB Network Company, Ltd.(FKA:Korea Technology Banking Corp),KTB Ventures (FKA: KTB Venture Capital),Undisclosed Venture Firm
BigBear Networks, Inc.	Sunnyvale	CA	United States	Active Investment	2000	Develops subsystems for fiber optic networking applications. The Company is focused on designing and manufacturing highly integrated, opto-electronic interface solutions for next generation high-speed optical transmission operating at rates from 10Gb/s to greater than 40Gb/s. 40G network communications optic network signal processing (DSP) 2.5G 10Gb/s	41	$175,850	Atlas Venture,BCI Partners,Boston University Community Technology Fund ,Comcast Interactive Capital ,Dain Rauscher Corporation,Individuals,J.P. Morgan Capital Corporation,Lazard Technology Partners,Morgan Stanley Private Equity ,New Enterprise Associates,Pequot Capital Management, Inc.,Texas Pacific Group,Undisclosed Non Venture Firm,Undisclosed Venture Firm,Wachovia Corporation (FKA:First Union Capital Partners)

Brocade Communications Systems, Inc.	San Jose	CA	United States	Went Public	1995	Manufactures data communication equipment and Fiber Channel switching solutions. The Company offers a line of intelligent storage networking products and storage area network (SAN) management software that enables companies to implement highly available, scalable, manageable and secure environments for data storage applications. Brocade products and services are marketed, sold and supported worldwide to end users through distribution partners, including original equipment manufacturer (OEM) partners, value-added distributors, systems integrators and value-added resellers (VARs). data communication equipment fiber channel data backbone design	11	$51,000	CSFB Private Equity (AKA: Credit Suisse First Boston),Lexington Ventures,Montgomery & Co. (FKA: Digital Coast Partners),Redpoint Ventures,TL Ventures (FKA: Radnor Venture Partners),Undisclosed Non Venture Firm,Undisclosed Venture Firm
BTI Photonics, Inc.	Ottawa	ON	Canada	Active Investment	2000	Designs, develops and integrates flexible amplification, signal conditioning and performance monitoring for intelligent optical networks. The companys network-ready Optical Link System (OLS) provides OEMs, system integrators and service providers with a fully-scalable, cost-effective solution to extend the reach of optical networks. fiber optics dense wavelength-multiplexing	16	$50,000	Agilent Ventures,Carolinas Capital Investment Corp.,Individuals,Intel Capital,Intersouth Partners,J&W Seligman & Company,J.P. Morgan Partners (FKA: Chase Capital Partners),Undisclosed Non Venture Firm,Wakefield Group
C Speed Corporation	Santa Clara	CA	United States	Active Investment	1997	Delivers scalable optical switching subsystems to Systems Integrators building optical networks. The company's subsystem architecture combines optical packaging and MEMS designs with control and network interface software that can be easily designed into core, metro, access, and edge network infrastructure. fiber optics optics optical switches	8	$31,300	Boulder Ventures, Ltd.,Kinetic Ventures LLC,New Enterprise Associates,Optical Capital Group ,Sprout Group,Undisclosed Venture Firm,Vertex Management Pte, Ltd.

Calient Networks (FKA: ChromiSys, Inc.)	San Jose	CA	United States	Active Investment	1999	Develops intelligent, all-photonic switching systems and software that help service providers scale their networks for explosive bandwidth demands and deliver a new generationb of wavelength services. The Company's DiamondWave system will provide a foundation for rapid innovation and service delivery needed for revenue growth, while significantly reducing network operating costs by eliminating the need for opto-electronic conversion. fiber optics networking Optical Layers Service Providers systems	8	$24,250	LLR Partners, Inc.,Liberty Venture Partners, Inc.,Mellon Ventures, Inc.,Undisclosed Non Venture Firm,Updata Venture Partners
CENiX, Inc.	Allentown	PA	United States	Defunct	2000	Designs and manufactures high-speed optoelectronic subsystems for DWDM and TDM SONET/SDH and 10 Gigabit Ethernet based transmission systems. The Company makes optoelectronic subsystems that translate electrical signals, sent from standard networks over copper lines, into light that travels on fiber-optic lines. CENiX's products bear the UNiPAK, ULTRAPAK, and TETRAPAK brand names and combine optical transmitters, receivers, and serializers/deserializers into a single unit. The Company is also banking on the interest of other manufacturers in its method for automating the production of these devices; many optical products are built by hand. optoelectronic interface bandwidth optical networking application	21	$62,849	Anschutz Investment Company,ComVentures (AKA: Communications Ventures),Crosspoint Venture Partners,J.P. Morgan Partners (FKA: Chase Capital Partners),JVP (FKA: Jerusalem Venture Partners),Lucent Venture Partners, Inc.,Soros Fund Management (AKA: Soros Private Equity Partners),Tamir Fishman Ventures,Undisclosed Venture Firm
Centerpoint Broadband Technologies, Inc.	San Jose	CA	United States	Defunct	1999	Develops infrastructure equipment for optical fiber networks. The Company's technology aggregates and transports multi-service traffic within optical networks at rates above 10 Gbps. Also, The Company's solutions are designed to expand throughput of broadband wireless networks. optical fiber communications network wireless wired network high speed modem	10	$109,500	Apax Partners & Co. Ventures Ltd (AKA: Apax UK),Individuals,Marconi Ventures,Merrill Lynch Capital Partners,RS Investments (AKA: Robertson Stephens & Company, LLC),TA Associates, Inc.,Undisclosed Non Venture Firm

Ceyba, Inc. (FKA: Solinet Systems, Inc.)	Ottawa	ON	Canada	Defunct	2000	Develops fiber optic transmission systems for telecommunications carriers. The Company delivers network solutions that enable service providers to realize cost effective, all optical core networks. A full suite of network and service management products enable simplified network installation & operation and high service velocity and reliability. fiber optics telecommunications transmissions systems	25	$42,851	Baker Capital Corp.,Banexi Ventures Partners,CDC Equity Capital (CDC IXIS Private Equity),CDC IXIS Innovation,CSFB Private Equity (AKA: Credit Suisse First Boston),Hillman Company,Individuals,Innovacom,Lightspeed Venture Partners (FKA: Weiss, Peck & Greer),Schneider Electric Ventures,Siparex Group (FKA: Siparex Provinces de France-Suddinova),Undisclosed Investor,Undisclosed Non Venture Firm,Undisclosed Venture Firm
Chorum Technologies, Inc. (FKA: Macro-Vision)	Richardson	TX	United States	Active Investment	1996	Develops optical switching components and subsystems for communications equipment. The Company designs products with the mission of boosting capacity and flexibility fiber-optic networks. optical switching components optical technologies optical networks communications equipment	8	$24,125	DynaFund Ventures LLC,InveStar Capital, Inc.,Undisclosed Venture Firm
Chromatis Networks, Inc.	Bethesda	MD	United States	Acquisition	1997	Develops a multi-service aggregation and switching platform for optics-based communications and content delivery in metropolitan areas. The Company combines packet, cell, and TDM switching into an integrated optical bandwidth. optical networking communications fiber optics	26	$271,000	American Express (AKA: Shearson Lehman/American Express),Amerindo Investment Advisors, Inc.,BlueStream Ventures,Cayuga Venture Fund ,Enterprise Partners Venture Capital (AKA: EPVC),Greylock,INVESCO Private Capital (FKA: Chancellor),J&W Seligman & Company,Juniper Networks,Marconi Ventures,ONI Systems Corporation (AKA:Optical Networks, Inc.),Sofinnova Ventures,Storm Ventures,TeleSoft Partners,Tellabs Inc.,Undisclosed Venture Firm,Van Wagoner Capital Management
Cidra Corporation	Wallingford	CT	United States	Active Investment	1996	Designs and manufactures high-precision optical components, modules and subsystem products for next-generation optical networks. The Company's components are used for dynamic routing, monitoring and conditioning of optical signals to provide cost-effective wavelength management solutions. fiber optic instruments network oil and gas communicationa multiplexing wavelength division	9	$30,999	Intel Capital,Investor AB,Investor Growth Capital, Inc.,Novak Biddle Venture Partners, L.P.,St. Paul Venture Capital, Inc.,Technology Venture Partners

Ciena Corporation (FKA: HydraLite Corporation)	Linthicum Heights	MD	United States	Went Public	1992	Manufactures dense wavelength division multiplexing systems used in fiberoptic telecommunications networks. The Company produces products that alleviates bandwidth constraints in high traffic fiberoptic routes which eliminates the need for new fiber installations. wavelength fiber optic inter-exchange carrier market	9	$75,733	Bank One Equity Investors, Inc.,Nortel Networks Corporation,Penny Lane Partners,Signal Equity Management Corp.,Trident Capital,Undisclosed Venture Firm,Wachovia Capital Associates, Inc. (WCA)
Cierra Photonics, Inc.	Santa Rosa	CA	United States	Acquisition	2000	Develops fiber optic communication components derived from wafer scale integration. The Company is relying initially on its newly developed Advanced Energetic Deposition process. First products are optical add-drop multiplexor (OADM) filters. They form the basic building blocks for a wide range of optical filtering products for DWDM systems. DWDM fiber optics wafer scale integration communications networks	5	$18,000	Highland Capital Partners,JVP (FKA: Jerusalem Venture Partners),Undisclosed Investor
Circadiant Systems, Inc.	Allentown	PA	United States	Active Investment	2000	Provides optical component and network equipment testing systems. The Company is introducing a new class of testing equipment that offers standardization, automation and scalability and compliance testing in a system built to meet the needs of the current and future optical networking market. Circadiant fills the gap in optical testing equipments and is positioning itself to seize a significant portion of the testing market. optical testing fiber optics optical components	10	$36,585	Bay Partners,Comerica Ventures (FKA: Imperial Ventures, Inc.),Crosspoint Venture Partners,Globespan Capital Partners (FKA: JAFCO America Ventures),Individuals,J.F. Shea & Company,LSI Logic Corporation,Lightspeed Venture Partners (FKA: Weiss, Peck & Greer),Mohr Davidow Ventures,Norwest Venture Partners (FKA: Norwest Equity Partners),Undisclosed Non Venture Firm,Undisclosed Venture Firm

Cirrex, Inc.	Alpharetta	GA	United States	Active Investment	1996	Develops and commercializes optical technology and products for optical communications networks. The Company's OCHIPTM (Optical Communication Hybrid Integration Platform) technology is the first in the industry to combine active and passive optics using planar lightguide circuits (PLCs) and electronics in a single, compact package. The OCHIP product suite includes 100 GHz channel spacing transceivers with options for integrated channel filtering and Variable Optical Attenuators. The cost-effective introduction of DWDM technology in the metro/access market enables widespread high-speed Internet access and new bandwidth-intensive applications such as audio and video streaming. optical networking communications	22	$67,950	Anthem Venture Partners,CDIB Venture Management,CE Unterberg Towbin (FKA:Unterberg Harris Capital Partners),Fortune Venture Investment Group (AKA:Fortune Consulting),Infineon Ventures GmbH,Intel Capital,J.F. Shea & Company,Ridgewood Capital Management, LLC,Undisclosed Investor,Undisclosed Venture Firm,Walden International
CityNet Telecommunications, Inc.	Silver Spring	MD	United States	Acquisition	1999	Operates a telecommunications and broadband infrastructure company that builds dark fiber, carrier-class, and all optical high speed networks in high-growth metropolitan areas. The Company deploys its metropolitan networks using a deployment methodology. The Company provides its local carrier customers with a broadband fiber optic network that connects directly into commercial and residential multi-tenant buildings. intra-city fiber networks broadband connectivity bandwidth	21	$40,627	Bessemer Venture Partners,Charles River Ventures,Gibraltar Trust,Globespan Capital Partners (FKA: JAFCO America Ventures),InterWest Partners,Kinetic Ventures LLC,Lightspeed Venture Partners (FKA: Weiss, Peck & Greer),SG Cowen Private Equity Group,STAR Ventures ,Sevin Rosen Funds (AKA: Sevin Rosen Management Co.),Vanguard Ventures
CitySignal Communications, Inc.	Malvern	PA	United States	Active Investment	1999	Develops flexible multi-ring metro dark fiber solutions that help communications providers deliver high capacity broadband applications to the consumer. The Company's metro dark fiber infrastructure is located in key Mid-Atlantic and Mid-West markets of the United States. The Company's strategy is to establish their networks into the suburban landscape targeting those areas lacking a dark fiber infrastructure. dark fiber communications	11	$42,325	Adams Capital Management, Inc.,Enterprise Partners Venture Capital (AKA: EPVC),Sierra Ventures,TeleSoft Partners,Undisclosed Venture Firm,Windsor

Clerios, Inc. (FKA: IOA Corporation)	Sunnyvale	CA	United States	Acquisition	2001	Designs and manufactures a family of optical sub-systems. The Company's sub-systems are targeted at optical system manufacturers in the metro, long haul and ultra-long haul markets. fiber optics communications optical sub-sytems	8	$36,000	Individuals,JK&B Capital,Mitsubishi Corporation,Mohr Davidow Ventures,Spectrum Equity Investors,Undisclosed Venture Firm
CodeStream Technologies Corp. (FKA: Commercial Technologies)	Richardson	TX	United States	Defunct	1996	Develops advanced fiber optic telecommunications products. The Company's products, based on its patented OCDMA technology, are geared towards public telecommunications carriers serving metropolitan markets and help reduce the cost and complexity of running broadband networks. fiber optic telecommunications	1	$1,500	Abell Venture Fund
CoreTek, Inc.	Wilmington	MA	United States	Acquisition	1994	Develops microelectromechanical (MEMs) devices for applications in wavelength division multiplexed communication systems. The Company is manufacturing the next generation of tunable photonic devices for the fiberoptic communications industry.	20	$35,600	Boulder Ventures, Ltd.,Core Capital Partners,Davenport Capital Ventures,Draper Atlantic Venture Fund, L.P.,EDB Investments Pte Ltd.,Grosvenor Funds, The,Intersouth Partners,Kinetic Ventures LLC,Optical Capital Group ,Riggs Capital Partners,Undisclosed Venture Firm
Coriolis Networks, Inc.	Boxborough	MA	United States	Defunct	1999	Develops metro optical products that speed the transmission of data. The Company targets the network service provider community on a global basis. Coriolis Networks has developed an architecture for the next-generation metropolitan optical network that effectively combines LAN and WAN technologies in a flexible, scalable, low-cost solution. Coriolis' Optical Spatial Division Multiplexing (OSDM) architecture applies optical technology to both access and transport functions, enabling service providers to cost-effectively deliver traditional TDM and emerging data services from the long-haul optical network to enterprises connected to the edge of the metro network. Coriolis' mission is to develop and deliver metro optical network through our OptiFlow Network solution. WAN data transmission fiber optics optical products LAN software development	13	$34,776	Acorn Ventures, Inc.,CMEA Ventures (FKA:Chemicals & Materials Enterprise Associa),Lightspeed Venture Partners (FKA: Weiss, Peck & Greer),New Enterprise Associates,Texas Pacific Group,Transpac Capital Pte, Ltd.,Undisclosed Corporate Investor,Undisclosed Non Venture Firm,Undisclosed Venture Firm

Corvis Corporation (FKA: Nova Telecommunications)	Columbia	MD	United States	Went Public	1997	Designs, manufactures and markets all-optical network solutions. The Company designs solutions that enable telecommunication service providers to construct high-capacity, all-optical, ultra long-haul backbone networks. The Company's product lines include electrical/optical and all-optical switching products, terrestrial and subsea ultra-long-haul and point-to-point optical transport systems and network management software that enables seamless end-to-end network management. This range of product lines enables the Company to provide carriers with solutions for their SONET (synchronous optical network technologies)/SDH (synchronous digital hierarchy) ring networks, as well as their electrical/optical and all-optical mesh networks. communications data flow telecommunications optical fiber optic DWDM	6	$29,100	Cisco Systems, Inc.,Goldman, Sachs & Co.,Mohr Davidow Ventures,Photonics Fund
Cube Optics AG (AKA: CUBO)	Mainz	ZF	Germany	Active Investment	2000	Designs an assembly platform for data and telecommunications networks. The Company has developed an advanced assembly and manufacturing platform that enables the mass-manufacture of low-cost miniaturized products for data and telecommunications networks. The Company's platform is based upon proprietary sub-components that combine automated manufacturing processes, such as polymer injection molding, with high-precision optical design. electronics components fiber optics	43	$187,069	Azure Capital Partners,CSFB Private Equity (AKA: Credit Suisse First Boston),GE Equity (FKA: GE Capital Equity Capital Group),Menlo Ventures,Mitsubishi International Corp.,Mitsui & Co. Venture Partners (MCVP),New Enterprise Associates,Siemens Corporation,Siemens Venture Capital GmbH (AKA: SVC),Storm Ventures,U.S. Venture Partners,Undisclosed Investor,Undisclosed Non Venture Firm,Undisclosed Venture Firm,W.R. Hambrecht & Co., LLC,Wheatley Partners,Zero Gravity Internet Group, Inc.

Digital Optics Corporation	Charlotte	NC	United States	Active Investment	1992	Develops and manufactures integrated micro-optical systems. The Company designs, develops, manufactures, and markets wafer-based micro-optics and wafer-based integration of PHOTONIC CHIP optical sub-assemblies (OSAs) and AURORA illumination solutions. PHOTONIC CHIP OSAs integrate passive optical components (silicon bench, diffractives, refractives, mirrors, etc.) with active components (lasers, detectors and electronics) at the wafer level to create a scaleable and cost-effective module platform, enabling telecom and datacom applications across the communications spectrum. optic stores retail wafer-based manufacturing fiber optics	4	$10,100	Advanced Technology Ventures (AKA: ATV),BA Venture Partners (AKA: BankAmerica Ventures),Polaris Venture Partners,Spectrum Equity Investors
E2O Communications, Inc.	Calabasas	CA	United States	Active Investment	1998	Develops fiber optic subsystems for computer storage and transceivers. The Company develops and manufactures multi-gigabit rate fiber optic subsystems for the computer storage, Internetworking and telecommunications markets. The Company is in accelerated development of 10 Gbps long wavelength VCSELs, DFB Lasers, and 10 Gbps to 40 Gbps EA modulators, to create high performance fiber optic building blocks, which will satisfy the ever-increasing bandwidth needs of enterprise networks and service providers. A 10 Gbps transceiver and transponder product family, based upon its proprietary LW-VCSEL technology for 10 Gbps Ethernet and OIF OC192 applications is in final development and will be offered in 300 pin Transponder, XENPAK and XGP multisource agreement (MSA) form factors. transceivers communications components fiber optics	6	$246,000	Darby Asia Investors Ltd. (FKA: Prumerica),H&Q Asia Pacific, Ltd.,J.P. Morgan Partners (FKA: Chase Capital Partners),PAMA Group Inc. (FKA:Prudential Asset Management Asia),Undisclosed Investor

Enterprise Networks (FKA: GNG Networks, Inc.)	Seoul	ZF	South Korea	Active Investment	1996	Owns and operates fiber-optic network acting as a carrier's carrier to provide limited private line services. The Company is a backbone telecommunication infrastructure carrier. Enterprise Networks has established a national fiber optic network that stretches up to 15,000km and MANs (Metropolitan Area Network) along the subway system in 6 large cities including Seoul. It has also set up a 320 Gbps high-speed communication network using DWDM that covers low-speed transmission to Gbps-scale transmission. backbone telecommunication fiber optic network	7	$31,100	Battery Ventures, L.P.,Mayfield Fund,Oak Investment Partners,Undisclosed Venture Firm,VantagePoint Venture Partners
Eolring	Caen	1	France	Defunct	1997	Develops high availability access switches. The Company's product is dedicated to multi-service fiber-based networks, supporting real-time and data-centric applications. access switches ATM switch	7	$19,500	CEI Ventures, Inc. (AKA: CVI) ,North Atlantic Capital Corporation,Sierra Ventures,Undisclosed Venture Firm
E-tek.com	San Jose	CA	United States	Went Public	1983	Manufactures and designs telecommunications fiber optic components and equipment including optical isolators, couplers, and wavelength division multiplexers. telecommunications couplers multiplexers fiber optics optical isolators	26	$161,225	Amerindo Investment Advisors, Inc.,Axiom Venture Partners, L.P.,Cisco Systems, Inc.,Connecticut Innovations, Inc.,First Reserve Corporation,Global Technology Group Ventures (FKA: DAMAC Ventures),HRLD Venture Partners,MSD Capital L.P.,Morgan Stanley Private Equity ,Putnam Management,Undisclosed Corporate Investor,Undisclosed Non Venture Firm,Undisclosed Venture Firm

Fiber Optic Network Solutions Corporation	Northborough	MA	United States	Active Investment	1992	Manufactures passive optical components and fiber optic cable packaging, distribution and connectivity products for voice, video and data applications. The Company designs and manufactures a complete line of passive fiber optic components including connectors, cable assemblies, enclosures, frames, as well as fused and micro-optic technology based optical components and modules, for single-mode and multimode applications. Its broad range of products include cable assemblies, connectors, adapters, patch panels, attenuators, fiber distributing frames, wall mounted enclosures, as well as optical components including splitters, taps, WDMs and DWDMs. ISO-9001 fiber optics splitters filter-based DWDM optical components OEM Market	12	$46,000	Enterprise Partners Venture Capital (AKA: EPVC),Individuals,Ridgewood Capital Management, LLC,Undisclosed Corporate Investor,Undisclosed Investor,Undisclosed Non Venture Firm,Undisclosed Venture Firm,Walden International
FiberNet Telecom Group, Inc.	New York	NY	United States	Went Public		Provides optical fiber network inside class-A commercial buildings. FiberNet solves metropolitan bottleneck problems by offering telecom carriers access to a 100% fiber optic network that runs horizontally through the streets and vertically to every floor of major carrier hotels and select Class A commercial office buildings. FiberNet's network enables carriers to connect directly with one another. optical fiber network commercial buildings local exchange	7	$50,700	J.P. Morgan Partners (FKA: Chase Capital Partners),Mayfield Fund,RWI Group,Soros Fund Management (AKA: Soros Private Equity Partners),Undisclosed Venture Firm,Worldview Technology Partners
Fiberspace, Inc.	Woodland Hills	CA	United States	Defunct	1998	Develops fiber optical networking products for telecom and cable systems. The Company develops a family of optical networking products to increase fiber capacity and system performance at minimum cost. fiber optics communications architectuure Internet communications infrastrucure communications	3	$18,000	Goldman, Sachs & Co.,Novare Kapital AB,Spectrum Equity Investors

Finisar Corporation	Sunnyvale	CA	United States	Went Public	1988	Provides fiber optic subsystems and network performance test systems which enable high-speed data communications over local area networks, or LANs, and storage area networks, or SANs. The Company is focused on providing high-performance, reliable, value-added optical subsystems for networking and storage equipment manufacturers that develop and market systems based on Gigabit Ethernet and Fibre Channel protocols. The Company develops novel lazer diode transmitter technologies in the area of optics, packaging, control, and modulation. They also manufacture low cost transmitters and receivers that transmit data at rates up to 2 Gigabites per second. The Company is also a leading supplier of Fiber Channel test equipment. data communications components SAN storage area networks local area networks LAN networks fiber optics transmitter receivers	1	$6,500	Sierra Ventures
FONS Corporation	Northborough	MA	United States	Active Investment	1992	Focuses solely on fiber optic technology and products. The Company manufactures of passive optical components and fiber optic cable packaging, distribution and connectivity solutions.	10	$54,675	Battery Ventures, L.P.,Corning Innovation Ventures,Dominion Ventures, Inc.,Lee Munder Venture Partners,TPG Ventures ,Undisclosed Venture Firm
Genoa Corporation	Fremont	CA	United States	Acquisition	1998	Designs and manufactures active, semiconductor based optical components for communications networks. The Company's core technology is a single chip linear optical amplifier (LOA) - a small, cost-effective semiconductor device capable of amplifying light in the optical Designs and manufactures active, semiconductor based optical components for communications network Dense Wave Division Multiplexing (DWDM) applications. optical amplifiers fiber optics optical network	19	$84,500	Fortune International Limited,Fortune Venture Investment Group (AKA:Fortune Consulting),Lehman Brothers,New Enterprise Associates,PTI Ventures ,Smart Technology Ventures,SunAmerica Ventures,Undisclosed Corporate Investor,Undisclosed Investor,Undisclosed Venture Firm,Vitesse Semiconductor Corporation,Windward Ventures

Gigabit Optics Corporation	Sunnyvale	CA	United States	Active Investment	2000	Develops and manufactures high-speed fiber-optic communications equipment utilizing their Optical Engine technologies. The Company develops a micro-optical platform that enables a variety of optical networking products with substantially smaller form factor and lower cost. Its micro-optical subassemblies are targeted to OEMs who manufacture optical networking subsystems, and those who require small, reliable parts for line card integration. optical networking micro-optical communications equipment high-speed fiber optic	18	$118,000	Advanced Technology Ventures (AKA: ATV),AsiaVest Partners, TCW/YFY Ltd. (FKA: TCW/YFY Investment),Azure Capital Partners,BA Venture Partners (AKA: BankAmerica Ventures),Deutsche Venture Capital GmbH (DVCG),Essex Investment Management Company, LLC,JK&B Capital,Merrill Lynch Capital Partners,Undisclosed Investor,Undisclosed Venture Firm
InLight Communications, Inc.	Fremont	CA	United States	Bankruptcy - Chapter 7		Develops fiber-optic transceivers for high capacity broadband applications. The Company's low-phase noise fiber-optic transceivers enables the efficient delivery of integrated services over hybrid/coax networks.	39	$119,175	China Development Industrial Bank (CDIB),Corvis Corporation (FKA: Nova Telecommunications),Goldman, Sachs & Co.,Inco Venture Capital Management,Individuals,J&W Seligman & Company,Lucent Venture Partners, Inc.,Mayfield Fund,NEC Corporation,NIF Ventures USA, Inc.,Newbury Ventures,STAR Ventures ,Sumitomo Corporation,Thomas Weisel Partners, LLC,Undisclosed Venture Firm
Inplane Photonics, Inc. (FKA: Key Optics)	South Plainfield	NJ	United States	Active Investment	2000	Manufactures integrated optical component subsystems using their proprietary planar optics technology. The Company's platforms will enable the large-scale deployment of 10 and 40 Gbps systems throughout the telecom and datacom networks. Planar Lightwave Circuits fiber optics silicon optical bench optical components	6	$11,490	HIG Capital Management (AKA H.I.G. Ventures),Lucent Venture Partners, Inc.,Undisclosed Non Venture Firm,Undisclosed Venture Firm

IPG Photonics Corporation	Oxford	MA	United States	Active Investment	1990	Manufactures high-power fiber amplifiers and lasers. The Company designs, develops and manufactures fiber optic components, high performance fiber amplifiers and lasers, modules and subsystems to meet the growing demands of the communication, materials processing, test and measurement and research markets. IPG Photonics specializes in manufacturing critical modules and subsystems for fiber optic communication systems, terrestrial wireless optical networks and free-space communications. The Company also provides fiber lasers for such industrial applications as high-speed commercial printing, welding, drilling, micromachining, and medical imaging. Broadband light sources fiber optics Continuous wave lasers fiber communications fiber amplifier Diode laser systems test measurement Erbium amplifiers	10	$26,500	Adams Capital Management, Inc.,Apax Partners, Inc. (FKA: Patricof & Co. Ventures, Inc.),Broadview Associates,Hillman Ventures, Inc.,JK&B Capital,Oak Investment Partners
K2 Optronics	Sunnyvale	CA	United States	Active Investment	1999	Develops optical cross connect subsystems and tunable lasers. The Company manufactures components and subsystems for fibre optic telecommunications equipment. fiber optic equiptment tunable lasers Internet communications	4	$14,000	Individuals,JVP (FKA: Jerusalem Venture Partners),Worldview Technology Partners

Kodeos Communications, Inc.	South Plainfield	NJ	United States	Active Investment	2001	Develops systems and equipment for fiber optic communications networks. The Company seeks to improve the transmission quality of compliant WDM signals using proprietary electronics and off the shelf components. Kodeos has developed a family of transmitter-side signal processing algorithms, built on a flexible hardware platform, that spectrally shape the light as it is transmitted into the fiber in such a way that transmission that can reach from 80 km up to 200 km without requiring dispersion compensation modules (DCMs) or forward error correction (FEC) and is received by standard optical receivers. Kodeos next generation platform utilizes the Double Reac algorithm that achieves superior performance beyond 40 km when compared with the industry's general accepted long-reach (LR) 10 Gbps transponders for both receiver sensitivity and optical signal-to-noise specifications. opitcal networks fiber optic WDM Signals communication network	11	$15,077	Carlyle Group, The,Sevin Rosen Funds (AKA: Sevin Rosen Management Co.),Target Partners GmbH,Undisclosed Venture Firm,tbg Technologie-Beteiligungsgesellschaft mbH
Larscom (FKA:NetEdge Systems, Inc.)	Morrisville	NC	United States	Acquisition	1994	Manufactures fiber optic communications and data transmission systems. The Company's products include transceivers, an Ethernet system, an interfacility communications link and FDDI bridges. The Company produces a system which is a fiber optic implementation of Ethernet with enhanced capabilities. They also produces asychronous transfer mode (ATM) network edge routers.	4	$8,995	Kline Hawkes & Co.,Undisclosed Investor,Undisclosed Venture Firm
LaserComm, Inc.	Plano	TX	United States	Defunct	1998	Develops photonic components for fiber optic networks. The Company's Hi-Mode DMD product line applies breakthrough physics to allow optical networks to carry more data, faster and farther, more economically. The Hi-Mode DMD precisely manages chromatic dispersion and dispersion slope for any fiber type, continuously across the entire C-band or L-band.	26	$79,000	Ampersand Ventures,Cisco Systems, Inc.,Corning Innovation Ventures,Rho Ventures (AKA: RHO Management),Sevin Rosen Funds (AKA: Sevin Rosen Management Co.),Telecom Partners (FKA:Telecom Management LLC),Undisclosed Corporate Investor,Undisclosed Investor,Undisclosed Venture Firm,Wellesley Venture Partners

						photonic components optical components broadband fiber optics			
Lightbit Corporation	Mountain View	CA	United States	Active Investment	2000	Develops optical communications technology. The Company is bringing to market a family of optical components for next-generation telecommunications systems, based on a disruptive and revolutionary patented technology developed at Stanford University. optical communications communications components fiber optics	14	$15,545	Accel Partners,Mayfield Fund,Undisclosed Investor,Undisclosed Non Venture Firm,Undisclosed Venture Firm,Wilson, Sonsini, Goodrich & Rosati (AKA: WS Investments)
LightChip, Inc.	Salem	NH	United States	Defunct	1997	Provides DWDM-based optical networking products for management of optical networks. The Company's flagship product is comprised of three network-ready system components: a wavelength router, an optical add/drop node metropolitan unit, and an optical performance management system. multiplexers optic network transport DWDM fiber wavelength	16	$23,529	Advent International Corporation,Argentum Group, The ,First Analysis Corp.,Menlo Ventures,Merrill, Pickard, Anderson & Eyre,North Carolina Enterprise Fund, L.P., The,TA Associates, Inc.
LIGHTCONNECT, Inc.	Newark	CA	United States	Active Investment	1999	Develops MEMS (micro electro-mechanical systems) components for dynamically configurable optical networks.The Company's components will include optical cross-connects, switches, VOAs, gain equalizers, channel equalizers, tunable lasers, tunable filters, and optical add-drop multiplexers. fiber optic components communications MEMS micro electro-mechanical	12	$21,540	Columbia Capital LLC,Envest Ventures,Gryphon Capital Partners,Novak Biddle Venture Partners, L.P.,SoundView Ventures,Undisclosed Investor,Undisclosed Venture Firm

LightLogic, Inc.	Newark	CA	United States	Acquisition	1998	Develops optoelectronic components and subsystems for high speed (10 Gb/s and up) and Dense Wavelength Division Multiplexing (DWDM) fiber optics telecommunications equipment. The Company also develops optical data networking hardware. optoelectronics fiber optics WDN lighting products telecommunication	39	$143,241	Boston Millennia Partners,CORAL Ventures,Cisco Systems, Inc.,Comdisco Ventures,Concord Financial Company, Ltd.,Concord Ventures (FKA: Nitzanim),Corning Innovation Ventures,Dain Rauscher Corporation,HIG Capital Management (AKA H.I.G. Ventures),Individuals,Intel Capital,Menlo Ventures,Minnesota Investment Network Corporation,Sprout Group,St. Paul Venture Capital, Inc.,TechnoPlus Ventures,Triumph Capital Group, Inc.,Undisclosed Venture Firm
LightPointe Communications	San Diego	CA	United States	Active Investment	1998	Designs and manufactures carrier-class optical transmission equipment using Free-Space Optical (FSO) technology that delivers high-speed communications solutions to enterprise and service provider customers who want to address the connectivity bottleneck in the metro optical networks. The Company addresses needs of both carriers and enterprise customers through a host of bandwidth options that provide the freedom to extend the reach of optical networks. LightPointe's FSO Products are Fast because they operate at speeds of 10 Mbps up to 2.5 Gbps at wavelengths of 850nm and 1550nm. Product installation is simple, and connections of varying distances are available, based on bandwidth and environmental considerations. laser optics optoelectronics FSO fiber optic networks	20	$156,925	Collaborative Capital,Gleacher & Co.,Nortel Networks Corporation,Tyco Capital (FKA: CIT Group),Undisclosed Corporate Investor,Undisclosed Non Venture Firm,Undisclosed Venture Firm,VantagePoint Venture Partners,Wolf Ventures (AKA: Wolf Asset Management Corp.)

Lumera, Inc.	Bothell	WA	United States	Active Investment		Providies polymer innovations targeting optical and wireless systems, semiconductor markets, as well as bioarray applications. The Company's new devices and materials are expected to improve performance and reduce costs of electro-optic components for telecommunications, phased array antenna systems, optical computing, optical signal processing and optical interconnects. The properties of these materials are also expected to enable new applications in other technologies such as organic light emitting diode displays, low k dielectrics and coating materials. Lumera expects to be able to sell and license its technology in a variety of forms, including custom polymer materials, coated wafers, and discrete and integrated component devices, both packaged and unpackaged. Electro-Optics networking components optical networking RF Electronics Coatings	2	$120,001	Summit Partners,Undisclosed Non Venture Firm
Luna Technologies, Inc. (AKA: Luna Innovations)	Blacksburg	VA	United States	Active Investment	1990	Develops and commercializes emerging fiber optic sensing, fiber optic component and advanced material technologies. The Company's goal is to become a premier supplier of test instrumentation for optical component developers and producers worldwide, eventually broadening their product line for additional applications and markets. fiber optics	13	$24,000	Individuals,Israel Seed Partners,Lucent Venture Partners, Inc.,Oak Investment Partners,Redwood Venture Partners,Undisclosed Corporate Investor,Undisclosed Non Venture Firm

LuxN, Inc.	Sunnyvale	CA	United States	Acquisition	1998	Develops optical access network platforms for local service providers and high-bandwidth data communications applications. The Company offers products designed to allow clients to network data centers, web sites, storage area networks, or other server intensive applications together over fiber more economically and effectively than with conventional SONET services. optical networking solutions networking bandwidth backbone dark fiber data communications	61	$215,497	Amerindo Investment Advisors, Inc.,Austin Ventures, L.P.,Azure Capital Partners,Bowman Capital,CenterPoint Venture Partners,Crown Advisors International, Ltd.,Dain Rauscher Corporation,Equitek Capital,Fidelity Investments,Individuals,InterWest Partners,J&W Seligman & Company,Octane Capital Management,Rho Ventures (AKA: RHO Management),STAR Ventures ,Scudder Kemper Investments E-Cubator Group,Sevin Rosen Funds (AKA: Sevin Rosen Management Co.),Sycamore Ventures,Undisclosed Non Venture Firm,Undisclosed Venture Firm,Wheatley Partners,Zurich Scudder Investments (FKA: Scudder Kemper Investments)
Memlink, Ltd.	Herzliya	ZF	Israel	Defunct	1999	Develops a scalable approach for directly switching optical signals. The Company's products are based on MEMS technology. The Company's optical cross connect should serve as the core switching fabric for optical cross connects that require at least an 8x8 switch. photonic switching switching components fiber optics optical networks MEMS	14	$52,100	Bessemer Venture Partners,Columbia Capital LLC,Comdisco Ventures,Globespan Capital Partners (FKA: JAFCO America Ventures),Highland Capital Partners,Undisclosed Venture Firm
METRObility Optical Solutions, Inc. (FKA: Aura Networks)	Merrimack	NH	United States	Active Investment	1981	Delivers Ethernet-based optical access platforms to service providers. The Company delivers fiber optic connectivity; distance, speed and media solutions; and unique fiber optic access solutions that are manageable, flexible, reliable and scalable. software fiber optics network management communications	3	$12,500	Mayfield Fund,U.S. Venture Partners,Undisclosed Venture Firm
Network Technologies Group, Inc. The	Baltimore	MD	United States	Active Investment	1998	Develops network integration services. The Company provides a full range of voice and data network integration capabilities including maintenance and support for all levels of desktop computers and printers, providing solutions for fiber optic applications, and network engineering.	2	$12,100	J.P. Morgan Capital Corporation,Morgenthaler Ventures

Nex-i.com	Princeton	NJ	United States	Active Investment	1999	Provides small business with an integrated package of Internet network and data services. The Company's services are deliver over fiber optic network that is installed in the client's building. Internet networks Network Solutions	13	$11,926	Agilent Ventures,EnerTech Capital (FKA: EnerTech Capital Partners, L.P.),Finaventures,ITU Ventures,TL Ventures (FKA: Radnor Venture Partners),Wilson, Sonsini, Goodrich & Rosati (AKA: WS Investments)
Nova Crystals, Inc.	San Jose	CA	United States	Active Investment	1998	Develops and manufactures fiber-optic data/telecommunications components. The Company develops and manufactures high-end fiber-optic data and telecommunications components based on its proprietary semiconductor technologies. Nova Crystals was founded by leading fiber-optic researchers at Cornell University. It manufactures VCSELS (Vertical Cavity Surface Emitting Lasers) for optical telecom applications. fiber-optic optical telecom telecommunications components optical networks	27	$67,000	Advanced Technology Ventures (AKA: ATV),Armada Venture Group LLC ,Lucent Venture Partners, Inc.,Mellon Ventures, Inc.,Morgenthaler Ventures,Noro-Moseley Partners,Oak Investment Partners
Novera Optics, Inc. (FKA:Ultraband Fiber Optics)	Palo Alto	CA	United States	Active Investment	1999	Develops, markets and supports fiber optic components. The Company provides a revolutionary technology for dynamic filtering of optical transmission signals. Dynamic optical filtering will be an essential ingredient in high-speed optical networks over the next decade. fiber optic filters enabling infrastructure	5	$31,050	JVP (FKA: Jerusalem Venture Partners),Morgenthaler Ventures
NP Photonics, Inc.	Tucson	AZ	United States	Active Investment	1998	Develops components based on proprietary glass fiber technology. The Company is developing fiber optic components using glass fiber and wave guide technology for customers building metro optical networks and dense wavelength division multiplexing systems. The Company's products include tunable filters, OSA engines, fiber lasers, ASE sources and amplifiers. wave guide amplifier optical components fiber optics	8	$16,000	EnerTech Capital (FKA: EnerTech Capital Partners, L.P.),Individuals,PA Early Stage (AKA: Pennsylvania Early Stage Partners),TL Ventures (FKA: Radnor Venture Partners),Undisclosed Venture Firm

Nuera Communications, Inc.	San Diego	CA	United States	Active Investment	1993	Provides voice-over-Internet Protocol (VoIP) solutions for all mediums (cable, wireless, Copper, fiber).The Company is a provider of high-quality packet Voice-over-Internet Protocol (VoIP) infrastructure and technology for voice/fax/data/video networking over frame relay, IP and circuit-switched networks. The Company's Open, Reliable Communications Architecture (ORCA) product portfolio helps carriers worldwide migrate from legacy networks to next-generation VoIP networks. Voice-over-Internet Protocol VoIP software packet voice communication networking voice	8	$26,700	Acorn Ventures, Inc.,Barksdale Group, The,Cisco Systems, Inc.,Individuals,Undisclosed Investor,Undisclosed Venture Firm,WRF Capital
Ocular Networks, Inc.	Reston	VA	United States	Acquisition	1999	Provides optical edge products and services to offer high-density voice and data. The Company uses its single-switch architecture to deliver its services to customers on and off the fiber network.	5	$18,200	CenterPoint Venture Partners,InterWest Partners,Undisclosed Venture Firm
OEpic, Inc.	Sunnyvale	CA	United States	Active Investment	2000	Develops and manufactures high-speed opto-electronic integrated circuits (OEICs) and devices for next generation fiber-optic telecommunications. The company's products are high-speed optical transceiver components that are based on integrated circuits that are build on InP wafers. OEICs opto-electronic circuits	14	$30,378	BB&T Capital Partners, LLC,Banc of America Capital Investors (FKA:NationsBanc Capital),Chestnut Street Partners, Inc.,Individuals,M/C Venture Partners (AKA: Media/Communications Partners),MC Capital, Inc.
OEwaves, Inc.	Pasadena	CA	United States	Active Investment		Develops integrated optical components using technology originally developed by Cal-Tech's Jet Propulsion Laboratory. The Company offers ultra-low phase noise, high frequency signal sources up to 40 GHz and beyond that target test and radar equipment, as well as other defense and commercial communication applications where unprecedented performance is a requirement. OEwave's novel signal source architecture enables ultra-low phase noise without frequency dependence, low sensitivity to acceleration and vibration, low power consumption, and a product roadmap directed toward size reduction and	10	$20,495	DynaFund Ventures LLC,Hoya Corporation,Individuals,Smart Technology Ventures,Tech Coast Angels (AKA: TCA)

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OnePath Networks, Ltd. (FKA: Foxcom.com)	Jerusalem	ZF	Israel	Active Investment	1993	Develops high-speed fiber-optic backbones for cellular networks. The Company designs, manufactures and markets high performance broadband and fiber optic transmission systems for the convergence, DBS, SatCom and MDU markets. The Company supports the delivery of multiple communications services over a single infrastructure. cellular network fiber-optic broadband optical networking	5	$42,500	Intel Capital,Morgenthaler Ventures,Oak Investment Partners
Onix Microsystems, Inc.	Fremont	CA	United States	Defunct	1998	Develops and manufactures optical transparent switching engines for enable their customers to provide high-value, scalable, reliable systems to manage, test and protect fiber optic networks. The Company's products leverage MEMS technologies to communications networks. The products cover the entire spectrum of optical switching needs, including network protection, optical add/drop multiplexing and optical cross connects. fiber optic communications optical switching	16	$17,902	AGF Private Equity,AXA Private Equity,CDC IXIS Innovation,Canada Development Corp.,China Development Corporation,Credit Lyonnais Private Equity (FKA: CLAM Private Equity),Innovacom,Partech International,SPEF Developpement (AKA SPEF Banques Populaires),Undisclosed Venture Firm
Oplink Communications, Inc.	San Jose	CA	United States	Went Public		Designs, manufactures and provides a support services for a broad range of fiberoptic component applications.	15	$44,100	Baystar Capital, LLC,East River Ventures, L.P.,Lucent Venture Partners, Inc.,North Atlantic Capital Corporation,Sierra Ventures,Undisclosed Investor,Undisclosed Venture Firm

Optical Integrated Circuits, Inc.	Mountain View	CA	United States	Active Investment	1997	Develops fiber optic transmitter/receiver systems for the regional telecommunications market.	18	$33,400	Intel Capital,Morgenthaler Ventures,Optical Capital Group ,Sevin Rosen Funds (AKA: Sevin Rosen Management Co.),U.S. Venture Partners,US Trust Private Equity,Undisclosed Investor,Undisclosed Venture Firm,iNCUBIC
Optical Solutions, Inc.	Minneapolis	MN	United States	Active Investment	1994	Designs, manufactures and markets Fiber-To-The-Home (FTTH) and Fiber-To-The-Business (FTTB) passive optical networks for voice, video and data to service providers worldwide. The Company designs its products to enable transmission of data, video and telephone services over the same fiber line by a single service provider. Fiber-To-The-Home fiber optic communications product	29	$307,207	Arete Corporation,Cisco Systems, Inc.,Gilbert Global Equity Capital, L.L.C.,Individuals,Integral Capital Partners,Kinetic Ventures LLC,Kleiner Perkins Caufield & Byers,Meritech Capital Partners,Merrill Lynch Investment Managers,New Enterprise Associates,Teknoinvest Management AS,Undisclosed Non Venture Firm,Undisclosed Venture Firm,Worldview Technology Partners
OptiMight Communications, Inc.	San Jose	CA	United States	Defunct	1998	Develops Coherence Division Multiplexing (CDM) optical transport systems for sale carriers. The Company's CDM products enable carriers to substantially increase the throughput capability of their fiber networks. CDM optical transport system	17	$51,000	Bessemer Venture Partners,Cisco Systems, Inc.,Dassault Developpement,HRLD Venture Partners,Infineon Ventures GmbH,Infinity Capital LLC,Information Technology Ventures,Lightspeed Venture Partners (FKA: Weiss, Peck & Greer),Siemens Venture Capital GmbH (AKA: SVC),Undisclosed Venture Firm,Viventures Partners,Western Technology Investment
Optinetrics, Inc. (FKA: Optical Technology Solutions Corp.)	Torrance	CA	United States	Active Investment	2000	Develops passive and active integrated, optical telecommunication devices. The Company's silica-based waveguide integrated devices and specialized optical glass materials are used in a variety of commercial and aerospace applications. The Company's glass platform technology facilitates the integration of active and passive components on a single optical chip with advanced functionalities. This technology radically reduces the complexity to manufacture optical components by eliminating the costly standard deposition and etching methods. telecommunications optics optic devices	30	$91,025	ABS Ventures,Bay Partners,Comcast Interactive Capital ,Cox Enterprises, Inc.,Gleacher & Co.,Goldman, Sachs & Co.,HarbourVest Partners LLC,J.F. Shea & Company,Motorola Ventures,SAIC Venture Capital Corporation,Sandler Capital Management,Telesystem-Argo Global Capital (AKA: Argo Global Capital),Undisclosed Investor,Undisclosed Non Venture Firm,Undisclosed Venture Firm,Venture Management Services Inc. (FKA: AT&T Ventures)

Optium, Inc.	Chalfont	PA	United States	Active Investment		Develops optical components for long-haul, fiber optic networks. The Company will produce module level solutions that will alter the economics of high-speed data transmission. fiber optics optical networks optical components	15	$63,700	Advent International Corporation,Amadeus Capital Partners Limited,Infrastructure Fund,InterWest Partners,MMC Capital, Inc (AKA: Marsh & McLennan Capital, Inc.),Quantum Capital Partners,Sevin Rosen Funds (AKA: Sevin Rosen Management Co.),Undisclosed Venture Firm
ParAcer, Inc.	Santa Clara	CA	United States	Acquisition	2000	Designs, manufactures and markets highly-integrated fiber optic transceiver products. The Company offers a family of products that serve including the optical backplanes, very-short-reach box-to-box interconnections (VSR-1 and VSR-3) as defined by the optical inter-networking forum (OIF) and emerging high speed server interconnections as defined in the Infiniband specifications. fiber optics parallel optics transceiver	7	$41,700	ComVentures (AKA: Communications Ventures),Photonics Fund,TL Ventures (FKA: Radnor Venture Partners),U.S. Venture Partners,Undisclosed Venture Firm
Phaethon Communications, Inc.	Fremont	CA	United States	Active Investment		Develops tunable, multichannel modules to address optical dispersion in OC-192 and networks. The Company is developing and manufacturing a comprehensive product suite to address the phenomenon of dispersion, or the degradation of optical signals over fiber that makes the signals' data difficult to interpret at the intended receiver. optical networking OC-192 OC-768 optical dispersion chromatic dispersion Fiber Optics	14	$95,900	August Capital Management,Bessemer Venture Partners,Global Crossing Ventures (FKA: Frontier Ventures),Investor AB,Levensohn Venture Partners LLC (FKA: Levensohn Capital Mgmt),Meritech Capital Partners,Oak Investment Partners,Undisclosed Venture Firm,WorldCom Ventures

PhotonEx Corporation	Maynard	MA	United States	Bankruptcy - Chapter 11	1999	Develops next generation long-haul transmission equipment. The Company provides 40 Gb/s and faster network-wide smart photonic systems that support the service providers goal of increased revenue and fiscal efficiency. The Company's PX-Ultra 4T is a core optical transport system that delivers high capacity (up to 3.2 Tb/s) and speed (40 Gb/s and faster) on todays embedded fiber without the need for a full network overbuild. The highly scalable, spectrally-efficient system delivers high-performance 40 Gb/s transmission using todays commercially available components, making the PX-Ultra 4T extremely cost competitive with available 10 Gb/s solutions. The PX-Ultra 4T is fully-integrated with the Company's IntelliCore system software and CorePilot EMS solution to enable accelerated services delivery and streamlined operations. photonic broadband communications service provider	23	$178,000	3i (US),Axxon Capital, LP,Boston Millennia Partners,Castile Ventures,Comdisco Ventures,Essex Investment Management Company, LLC,Intel Capital,J.P. Morgan Capital Corporation,Matrix Partners,North Bridge Venture Partners,North Hill Ventures,Oak Investment Partners,Photonics Fund,Silicon Valley BancVentures (FKA: Silicon Valley Bank)
Photonport Technologies, Inc.	Boulder	CO	United States	Active Investment	2000	Designs, develops, and manufactures liquid-crystal-based fiber-optic components and subsystems for telecommunication applications. fiber optic telecommunication subsystem	13	$108,000	Alta Partners,Bessemer Venture Partners,New Enterprise Associates,U.S. Venture Partners,Undisclosed Investor,Worldview Technology Partners
Photon-X, Inc.	Malvern	PA	United States	Active Investment	1998	Operates as an optical fiber and component developer. The Company's strengths are optical fiber and device design, optical fiber and waveguide fabrication and optical module design and prototyping.	15	$60,500	Athena Ventures,Cisco Systems, Inc.,Corning Innovation Ventures,Individuals,Kleiner Perkins Caufield & Byers,Optical Capital Group ,Undisclosed Corporate Investor,Undisclosed Investor,Undisclosed Venture Firm
Princeton Optronics, Inc. (Princeton Electronics Systems)	Mercerville	NJ	United States	Active Investment	1999	Provides low cost high performance communications services. The company engages in the development and manufacturing of advanced fiber optic component modules and integrated subassemblies for optical network solutions.	17	$46,125	Advent Venture Partners,Alloy Ventures,Bessemer Venture Partners,GATX Ventures (FKA: Meier Mitchell & Co.),Globespan Capital Partners (FKA: JAFCO America Ventures),Intel Capital,JAFCO Co., Ltd.,Photonics Fund,Storm Ventures,Sutter Hill Ventures,Undisclosed Investor,Undisclosed Venture Firm

Qeyton Systems	Hagersten	ZF	Sweden	Active Investment		Provides Dense Wave Division Multiplexing solutions for maximising fibre optic information carrying capacities and offering more economical and timely solutions than traditional alternatives while exploiting limited physical resources such as fibers, conduits and floorspace.	26	$79,432	Bessemer Venture Partners,Boston University Community Technology Fund ,Columbia Capital LLC,EnerTech Capital (FKA: EnerTech Capital Partners, L.P.),New Enterprise Associates,TL Ventures (FKA: Radnor Venture Partners),Undisclosed Venture Firm
Qtera Corporation	Boca Raton	FL	United States	Acquisition	1998	Develops fiber optic equipment. The Company focuses on ultra long-reach photonic transport systems for telecommunications service providers. Qtera is developing purely photonic network solutions for both new IP based carriers and long distance carriers. The Companys ultimate mission is to build a purely photonic backbone for the optical Internet - free of scalability restrictions and spatial boundaries. photonic transport systems telecommunications bandwidth	2	$3,200	Photonics Fund,VantagePoint Venture Partners
Quantum Bridge Communications, Inc. (FKA: MetroWeb Tech)	Andover	MA	United States	Active Investment	1998	Provides carrier class Fiber to the Premises (FTTP) equipment. The Company's optical access networking switches and connection terminals are designed to upgrade the telecommunications last mile (the section of network between a carrier's central office and the end user), which typically uses copper wire infrastructure. fiber access systems high speed bandwidth local loops optical networks	1	$10,000	Raza Venture Fund (FKA: Raza Foundries)
Quantum Photonics, Inc.	Jessup	MD	United States	Merger	1998	Develops optoelectronic components for use in fiber optic networks. The Company uses proprietary technology to produce lower-cost, higher-performance optoelectronic modules. optoelectronic fiber optics	28	$195,656	Amerindo Investment Advisors, Inc.,BancBoston Capital/BancBoston Ventures,Cisco Systems, Inc.,ComVentures (AKA: Communications Ventures),Essex Investment Management Company, LLC,J.P. Morgan Partners (FKA: Chase Capital Partners),Menlo Ventures,Pilgrim Baxter & Associates,U.S. Venture Partners,Undisclosed Investor,Undisclosed Non Venture Firm,Undisclosed Venture Firm,Viventures Partners

RedWave Networks	San Jose	CA	United States	Active Investment	2000	Develops a multiservice aggregation platform for the metro market for delivering fiberless solutions at multigigabit speeds aggregation platform	12	$27,400	Atlas Venture,Business Development Bank of Canada(AKA:BDC Venture Capital),HarbourVest Partners LLC,Individuals,North Bridge Venture Partners,Undisclosed Venture Firm,Ventures West Management, Inc.
Sabeus Photonics, Inc. (FKA: D-Star Technologies, Inc.)	Chatsworth	CA	United States	Active Investment	1998	Designs and manufactures high-concept optical devices for use throughout the optical communications network. The Company's high-concept mode-coupling technology, based upon the Company's unique understanding of the physics of light and materials, has enabled them to be the manufacturer of several high-precision, cost-effective, in-fiber optical components used by major optical equipment vendors. These products represent the first in a variety of the Company's high-concept devices that will continue to change the economics of the optical network. fiber bragg gratings optical networks	1	$3,000	Acorn Campus
Sedona Networks Corporation (FKA: NetPoint Communications)	Kanata	ON	Canada	Bankruptcy - Chapter 11	1998	Develops fiber optic access network infrastructure. The Company designs and manufactures mulit-services access network products designed to deliver integrated voice and data services over a single broadband connection. communications network solutions voice and data convergence infrastructure equipment	5	$14,020	Advent International Corporation,Individuals
Seneca Networks, Inc.	Rockville	MD	United States	Defunct	2000	Develops a fiber based network for telecom services and provides broadband service delivery. The Company's products and services are designed to develop next generation optical infrastructure platforms to enable rapid enable service providers to build intelligent metro optical core networks for broadband delivery at significantly reduced operational costs. Internet backbone infrastructure fiber optics communication systems	5	$42,500	Intel Capital,Morgenthaler Ventures,Oak Investment Partners

Southampton Photonics, Inc.	Southampton	ZF	United Kingdom	Active Investment	2000	Develops and manufactures in-fiber optical components and subsystems. The Company produces fiber optic components including precision optical filters for DWDM (Dense Wave Division Multiplexing), fibre grating, photon-powered laser arrays, and high-power, adaptive DWDM amplifiers. optical components optic networks laser arrays fiber optics	3	$36,485	Nautic Partners LLC ,Summit Partners,TA Associates, Inc.
StrataLight Communications, Inc.	Campbell	CA	United States	Active Investment		Develops Dense Wavelength Division Multiplexing fiber optic systems. The Company's products are designed to provide higher data rates and increased capacity for existing fiber networks. dense wave length division mulitplexing fiber optics fiber optic transmission fiber optic systems	16	$91,500	Berkeley International Capital Corp.,Individuals,J.P. Morgan Capital Corporation,Morgenthaler Ventures,Undisclosed Corporate Investor,Undisclosed Non Venture Firm,Venture Management Services Inc. (FKA: AT&T Ventures)
Teem Photonics	Meylan	17	France	Active Investment	1998	Manufactures active and passive optical waveguide components. The Company designs and manufactures new glass waveguide functions which is at the source of DWDM fiber network expansion. The Company has developed three categories of optical components based on its proprietary application of ion-exchange technology: optical amplifiers, interface components and signal distribution components. optical waveguide components DWDM optical splitter communication components fiber optic network	20	$60,740	Brentwood Venture Capital,Dali, Hook Partners,Lucent Venture Partners, Inc.,Meritech Capital Partners,Thomas Weisel Partners, LLC,Undisclosed Venture Firm,Venrock Associates,Vertex Management Pte, Ltd.,Worldview Technology Partners
Trillium Photonics, Inc.	Ottawa	ON	Canada	Defunct	2000	Develops fiber optic amplifiers designed specifically to handle optically switched communications traffic. The Companys optical system portfolio uses patented technology to achieve performance gains in optical networks. The family of intelligent optical amplifiers is positioned to make optical networks dramatically less costly, more scalable, and simpler. Internet infrastructure fiber optics communications systems	18	$83,000	Accel Partners,Agilent Ventures,Austin Ventures, L.P.,Menlo Ventures,Oak Investment Partners,Sequoia Capital,Undisclosed Venture Firm

Triton Network Systems, Inc.	Orlando	FL	United States	Defunct	1997	Provides broadband fixed wireless network products for local loop access. The Company offers an Invisible FiberTM high bandwidth broadband wireless network product line covers the 38 GHz, Local Multipoint Distribution Service (LMDS) and Local Multipoint Communication Systems (LMCS) markets, with functionality designed to fiber optic specifications. The Company's broadband fixed wireless Invisible FiberTM 155 Mbps SONET OC-3 and 100 Mbps Invisible Fiber Internet products are designed to provide telephony, data and Internet network solutions. wireless networks local loop access telecommunications mmWave	16	$21,990	BCE Capital,Individuals,Kodiak Venture Partners,Lucent Venture Partners, Inc.,Primaxis Technology Ventures Inc. ,Undisclosed Investor,Undisclosed Venture Firm,VenGrowth Capital Funds
Tsunami Optics	Mountain View	CA	United States	Acquisition	2000	Develops and manufactures fiber optic components and modules that are designed to enable the delivery of bandwidth in metro communication networks. The Company's products include coarse wavelength division multiplexing (CWDM) modules, micro-lithographic optics, and micro-optic components.	34	$296,400	Berkshire Partners LLC,CIBC Wood Gundy Capital,Carlyle Group, The,Crescendo Venture Management LLC,Great Hill Equity Partners, LLC,Individuals,Telecom Partners (FKA:Telecom Management LLC),Trimaran Capital Partners, LLC,Undisclosed Non Venture Firm,Undisclosed Venture Firm
Wave7 Optics, Inc.	Alpharetta	GA	United States	Active Investment	2000	Develops an optical access system for video, data and telephony services. The Company's end-to-end network develops a fiber-to-the-home and business (FTTX) optical access system for architecture effectively overcomes traditional cost and implementation barriers to the bandwidth capacity bottleneck in the last mile of communications networks. video, high-speed data and telephony services. fiber optics optical access telecommunications networks optical electronics	10	$64,000	Amerindo Investment Advisors, Inc.,Enterprise Partners Venture Capital (AKA: EPVC),Individuals,Intel Capital,KLM Capital Group,Meritech Capital Partners,Redpoint Ventures,Storm Ventures,Van Wagoner Capital Management
WaveSplitter Technologies, Inc. (FKA: Applied Fiber Optics)	San Jose	CA	United States	Active Investment	1996	Develops fiber optic devices for telecommunication systems. The Company sells these components, based upon proprietary technologies, into a variety of applications, including CATV, local area networks (LANs), optical fiber amplifiers, high speed short-haul and long-haul	6	$14,700	Individuals,Intel Capital,Rustic Canyon Ventures (FKA: TMCT Ventures, L.P.),Undisclosed Venture Firm

						telecommunications, as well as other fiber optic communications systems. fiber optic devices telecommunication local area network LAN cable			