Appendix D

Case Study: The Fiber Optics Industry

CONTENTS

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Note: This case study, along with those in Appendixes E and F, was presented in condensed form in chapter 9 of the main report, Holding the Edge.

INTRODUCTION

Not until 1963 did Corning Glass Works, Bell Laboratories, and Standard Telecommunications Laboratories recognize the possibility that glass fibers could be used to transmit information from one place to another. In that year, all three groups initiated research on guided-wave optical communications.[1] In 1970, Corning demonstrated the necessary breakthrough by achieving a radiation loss of 20 dB/km, using a vapor deposition process.[2] It was not until 1977 that the state of the art had advanced sufficiently for AT&T and GTE to install the first commercial fiber optics systems. Since then, fiber optics technology and the extensive international industrial structure that supports it have matured at a dizzying pace, causing one of its early inventors to observe that "fiber optics went much faster from research to use than any big project ever before."[3] By 1988, the U.S. fiber optics and optoelectronic industries included about 700 firms and had reached an annual volume of sales in fiber optics systems of approximately $568 million.[4]

Fiber optics has realized exponential growth, not only in production and sales, but also in the potential scope of the technology itself. It has been defined, broadened, and redefined variously over the past several years. A recent study by the National Research Council included fiber optics as a subset of a larger field called photonics. That report described photonics as a "critical, emerging technology . . . [that] has been building a technological armamentarium of proven science and advanced technology throughout the past three decades." It focused broadly on telecommunications, information processing, optical storage and display, and optical sensors-four "technical areas where the overall worldwide market for equipment approaches $400 billion per year."[5]

This perspective echoes the assessment of independent analysts who believe that fiber optics and related optical disciplines will eventually exert an impact on the world economy comparable to that of electronics in the 1970s and 1980s. They expect intense international competition, with governments designating the new technologies as necessary national assets. This may well involve strategies for economic defense of photonics-related industries, similar to those that Japan and some European Community member states have already installed for optical fiber and optoelectronic devices.

OTA is examining fiber optics as a dual-use technology, from the perspective of its contribution to defense needs in the United States. It is important to note, however, that fiber optics technology is far more widely used in the civilian sector than it is in the military. While significant research is taking place in the military sector, few fiber optic systems have been fielded to date. The rule of thumb is that fiber and optoelectronic devices are installed only when no other adequate solution to a problem exists.

Fiber optics is a vital technology that has strong implications for national security, as well as for economic competitiveness. A primary purpose of this case study is to assess the availability of fiber

[1]This initial corporate interest in fiber optics was sparked by the path-breaking work of Elias Snitzer, first published in 1961. Trudy E. Bell, *IEEE Spectrum*, Special Issue, vol. 25, No. 11, pp. 97-98.

[2]F.P. Kapron, D.B. Keck, and R.D. Maurer, "Radiation Loss in Glass Optical Waveguide," *Applied Physics Letter*, Vol. 17, 1970, pp. 423.

[3]Bell, op, cit., footnote 1, p. 102.

[4]U.S. Department of Commerce, "U.S. Industrial Outlook 1988—Communications Equipment," 1988, pp. 31-36. It is important to note, however, that the U.S. optical fiber industry is extremely concentrated, with two firms—Corning Glass Works and AT&T—accounting for over 80 percent of fiber production. See, for example, U.S. International Trade Commission, "U.S. Global Competitiveness: Optical Fibers, Technology and Equipment," USITC publication 2054, January 1988, p. xii.

[5]National Research Council, *Photonics: Maintaining Competitiveness in the Information Era* (Washington, DC: National Academy Press, 1988), pp. vii, 1.

optics technology developed in the civilian sector for military use. For this reason, this appendix focuses on commercially available optical technologies for which there is demonstrated military need. It concentrates on fiber optic communications systems, including the fiber itself, cables, and related optoelectronic devices (transmitters, connectors, switches, repeaters, and receivers). Because of their many military applications, fiber optic sensors are also discussed.

This case study is designed to address three central questions: First are the civilian fiber optics and optoelectronics industries—especially those that are critical to the military-eroding in the United States? Second, do military applications of fiber optics technologies diverge significantly from their dual-use counterparts in the civilian sector of the economy? And third, what are the principal barriers, both technical and institutional, that inhibit military access to civilian fiber optics technology and vice versa? Each of these areas is addressed in a separate section below. The last section concludes ‘with a summary of policy problems specific to fiber optics technology.

GLOBAL FIBER OPTICS MARKETS AND THE HEALTH OF THE U.S. INDUSTRY

The first major boost to the fiber market came in the late 1970s when the regional Bell Telephone operating companies ran into problems pulling more copper wire through already established conduits. Because of this congestion, they had to choose between building more ducts or substituting fiber for copper. Thus, interoffice trunking became the first large market for fiber optics in the United States. A second big boost for fiber extended from 1983 through 1986, as long haul fiber trunks were installed across the United States. With deregulation of the telecommunications industry and competition for long distance carriage, demand for fiber increased by 100 percent per year and its cost dropped precipitously. By 1985, U.S. telephone companies had installed more than 2 million kilometers of fiber. Between 1986 and 1988, the price of fiber cable decreased 70 percent. The completion of these large-scale projects caused worldwide sales of fiber optics to stabilize, and has encouraged major fiber makers to look for new markets for their products.

The U.S. market for fiber optics is the largest and most open in the world, accounting for over 50 percent of world consumption in 1984.[6] Over the past four years, however, the relative size of the U.S. market has decreased; it is forecast to drop to between 35 and 40 percent of the world market by 1989. Near-term installation of fiberoptic systems in Japan and Western Europe is expected to exceed that of North America. At the same time, overall world consumption of fiber optic systems is expected to increase by a factor of four by the year 2000.[7] The major market for fiber optics has been, and continues to be, the supply of fiber and optoelectronic devices for telecommunications systems. Although flat, this market could expand dramatically if financial and regulatory barriers to bringing fiber to the home are removed. While potentially substantial, military markets are not expected to mature until the middle 1990s—and even then, DoD technology planners and the U.S. Congress would have to designate and support fiber optics as a critical military technology. This scenario is by no means assured, given the imperative to reduce budget deficits and the continued strong competition within the Department of Defense (DoD) for a decreasing pool of funds.

Telecommunications applications now account for as much as 90 percent of the world market for fiber optic components and cables by some estimates. The U.S. consumed about 1.6 million kilometers of fiber in 1987, while the world market reached approximately 3 million kilometers. Europe comprises about a third of the market, with Japan and Korea accounting for about 16 percent. The overall international market for fiber grew about 20 percent in 1987,8 North America and the Far East are net exporters of optical fiber, while Europe is a net importer. The difference between production and consumption of fiber is not large in any region.

Since the end of the long haul market boom, the worldwide fiber optic industry has been characterized by overcapacity and intense competition, with

[6] U.S. Department of Commerce, International Trade Administration, “A Competitive Assessment of the U.S. Fiber Optics Industry,” September 1984, p. 32.

[7] U.S. Department of Commerce, International Trade Administration, “International Competitiveness Study: The Fiber Optics Industry,” September, 1988, pp. 24.

[8] Figures provided by Corning Glass Works.

most Organization for Economic Cooperation and Development (OECD) countries designating fiber optics as an essential national capability. By 1980, a pattern had begun to emerge in the way that OECD member governments and their corresponding industries would respond to the strong growth potential of the fiber optics markets. In the United States, large, vertically integrated firms like ITT and AT&T began to invest heavily in fiberoptic R&D. Corning Glass Works, which held many of the important patents in the field, established an early lead in fiber development. Major cable companies became takeover targets by firms that had not been principally associated with the telecommunications industry, and that now sought to position themselves for future fiber optics business.[9]

In Japan, NTT, MITI, and KDD (the Japanese international communications agency) initiated a carefully orchestrated campaign. NTT (then an official government agency) led the effort, conducting and promoting fiber optics and optoelectronics research. At the same time, KDD initiated a long-term program to develop all aspects of technology necessary for submarine fiber optic systems. And MITI[10] initiated two substantial research projects, the Hi-OVIS program and the Optical Measurement and Control System R&D program.[11] Most European countries generally appeared to take a middle ground, with the national PTTs (state-run public telecommunications monopolies) establishing R&D programs (such as BIGFON in West Germany) and actively seeking to promote the interests of their domestic industries. In Sweden and the Netherlands, the private sector appears to have taken a stronger role.[12] The differences in the development of fiber optics industrial structure and markets in the three regions require further explanation.

In Europe, most European Community (EC) member states have designated fiber optics as a critically important technology, and the national PTTs have tended to favor a few domestic suppliers of equipment and cable. More importantly, because the PTTs provide centralized planning and control of the telephone networks, they can (and do) support the introduction of new technology into those networks by arranging for trials and demonstration projects. This has resulted in highly fragmented national markets. Nevertheless, Corning Glass Works, an American firm, has been able to penetrate European markets by entering into joint ventures and licensing agreements-usually with cable manufactures, who then sell to the PTT monopoly buyer. Other companies, including the Japanese, participate in joint ventures with European firms to establish a presence in a changing market environment,

Concern over the anticompetitive aspects of centrally planned and regulated domestic markets has led EC officials to create programs designed to help European industry keep pace with innovative U.S. and Japanese industries. They believe that the eventual merging of communication and information technologies will require dynamic changes in the structure of the independent and isolated national industries and markets. With an eye to Europe's 1992 unification. they have instituted such programs as RACE (Research in Advanced Communication in Europe) and ESPRIT (European Strategic Plan for Research and Development in Information Technologies).[13] While representatives of large U.S. fiber optics companies believe that European markets are essentially open to all, they are concerned about the possible consequences of a pan-European policy.

In fiber optics and optoelectronics, the Japanese government has pursued a strategy of sponsoring a domestic industry, insulating home markets from foreign competition, building up a highly capable, vertically integrated industry with significant overcapacity, and encouraging export of quality systems to Europe and the United States. By the late 1970s, Coming and AT&T had established strong positions in world markets, due to the advanced state of the U.S. technology and to Corning's ownership of the major fiber optics patents. At that time, MITI identified optoelectronics as a key technology for Japan, and was very active in focusing the industry and getting development started. Specifically, NTT was tasked with designating industrial partners and

[9] Organization for Economic Co-Operation and Development, *Telecommunications: Pressures and Policies for Change* (Paris: OECD, 1983), pp. 117-118.

[10] Nippon Telephone and Telegraph, Ministry of International Trade and Industry, and Kokusai Denshin Denwa.

[11] OECD, op. cit., footnote 9, p. 120.

[12] Ibid., p. 124.

[13] U.S. International Trade Commission, op. cit., footnote 4, pp. 10.2-10.5.

forming a consortium to conduct the R&D work necessary to develop a domestic optoelectronics industry.[14]

In close consultation with MITI officials, NTT selected three major companies, Sumitomo, Furukawa, and Fujikura, essentially picking winners from among a larger pool.[15] While NTT provided some R&D funds, the most significant funding was invested by the companies themselves. What NTT did was to guarantee that it would purchase the fiber that was produced at over twice the world market price, and in proportion to the investment that each company made.[16] By guaranteeing a market, and by discriminating against companies like Coming and Siecor,[17] NTT effectively eliminated risk for the three companies as well as for the financial institutions that backed them. By the middle 1980s, the Japanese optoelectronics companies had developed technology on a par with the best in the world. and had established a major position in world markets for fiber optic systems.[18] Indeed, their ability to produce total fiber optic systems has led some analysts to suggest that they will soon achieve a strong-and perhaps dominant-position when fiber reaches into the local area network and into the home.

One pervasive effect of these differences in policy and approach is that U.S. firms must face stiff competition at home, while they are effectively breed from substantial penetration of some foreign markets. Nevertheless, U.S. fiber makers believe that they lead the world competition across a number of vital areas. Product performance for U.S. fiber makers is presently superior to that of Japan and the major EC member states (including France, Great Britain, and the FRG), and is superior to that of Korea and ether producers such as Australia. American fiber companies assert that for fiber, the U.S. leads the world in R&D and innovation, and that major new advances are in the offing. The cost to manufacture fiber is lowest in the U. S., but Japanese and some European producers are narrowing the gap hem. Many representatives of American fiber and optoelectronic companies believe that the U.S. presently maintains a technological lead in virtually every area of fiber optics, but that this lead is eroding.[19] The American position was established and is still based on intense competition for sales to American telephone companies. Many believe that the industry is robust, and that for this reason, official Washington should stay on the sidelines and allow market forces to favor an industry in which the U.S. has already proven itself to be particularly sturdy and capable.

Others are less sanguine about the future competitive status of the fiber optics and optoelectronics industries in the United States. A 1984 Commerce Department assessment predicted that although the U.S. fiber optics industry "urrently enjoys a significant competitive advantage, the limited access of U.S. firms to markets in Japan and Western Europe will adversely affect the performance of these firms in the future"[20] Four years later, a second Commerce Department report provided a somewhat more so-

[14]NTT has played a similar role in telecommunications as well as, in electronics: "In essence, NTT's industrial policy role has enabled favored Japanese telecommunications-computer-semiconductor companies to develop and commercialize new technologies in a protected and subsidized, risk-minimized way. The resulting equipment has been procured in high volume at premium prices until quality and cost have reached world levels, enabling rapid competitive penetrations of world markets by major Japanese firms". Michael Borrus et al., "How Government Policies Shape High Technology Trade," BRIE Working Paper #3, October 1984, pp. 68-69.

[15]Each of the "winners" knew that NTT officials expected first-rate performance, and that they were prepared to pick other players in the event that the three companies did not deliver. This posture on the part of Japanese government officials helped to generate intense competition, not only between the three winners, but also with a larger group of second-tier companies working with optoelectronic technologies.

[16]Clyde V. Prestowitz, Jr., *Trading Places: How We Allowed Japan to Take the* Lead (New York, NY: Basic Books, 1988), pp. 131-135.

[17]For reasons that are difficult to pin down, Corning's patent applications in Japan were not processed for 6 years on average. The Japanese patent office took 11 years to grant exclusive rights for Corning's basic patent, retarding the initial stages of that company's market development in Japan. In addition, the system of Japanese standards promulgated by NTT effectively excluded much of the foreign competition, even though the U.S. companies were able to offer NTT superior products at a much lower price than the three Japanese companies.

[18]When Sumitomo attempted to enter the U.S. market, however, Corning challenged them in court for patent infringement and won, closing Sumitomo's American production facility. It is likely, however, that Japanese industry will renew its efforts to produce in the U.S., as Corning's patents expire over the next several years.

[19]This view was not reflected in the finding of the U.S. International Trade Commission: "Japan is generally regarded as the leader in applied research and product development of certain optoelectronic components and systems that drive optical fiber lightwave systems . . . .Japanese producers have also gained more experience than U.S. or Western European firms in the mass production and commercialization of certain optoelectronic devices. Included in these are compact disk systems that many industry experts believe will be transferable in the near future to optical fiber transmission systems, especially those used in local area networks and subscriber links to the home". U.S. International Trade Commission, op. cit., footnote 4, p. xvi.

[20]U.S Department of Commerce, International Trade Administration, op. cit., footnote 6, p. ix.

bering view. It concluded that the future competitiveness of the U.S. fiber optics industry is by no means assured, but instead will hinge on a variety of critical factors, a view strongly endorsed by the U.S. International Trade Commission in a recent report.[21] An OTA workshop held in Washington on July 25, 1988 reflected these, as well as other, concerns, the most important of which are summarized below.[22]

The future health of the U.S. fiber optics industry depends largely on its ability to sell fiber and optoelectronic devices to the telecommunications companies, and this in turn depends on the development of a fiber-to-the-home market in the U.S. Legislators and regulators have tended to shift responsibility for the development of the national telecommunications infrastructure to market forces and the courts. And the courts have established a regulatory regime that effectively separates telephone and television delivery systems and inhibits the spread of telematic (online) services. The Bell operating companies are limited to providing local exchange communications and to permitting access to long-distance (or interexchange) companies. They may not provide additional information services or manufacture telecommunications equipment.[23] While AT&T and the other long-distance carriers are not restricted in manufacturing, they depend on the local Bell networks to access individual homes. Accordingly, there is little economic incentive for either the local Bell operating companies or for the long distance carrier/manufacturers to invest in fiber-to-the-home networks. This situation may retard the development of the optoelectronics industry in the United States. At the same time, large Japanese and European firms are gaining experience in the development, production, and commercialization of overall fiber optic systems in their home markets.

Many analysts expect that the future demand will be for fiber optic systems, not for fiber or isolated devices. Some believe that firms that sell systems may be willing to give away the fiber in order to obtain the contract. They believe that such a demand structure would tend to favor companies that are vertically integrated.[24] At present the only U.S. firm that can produce whole systems is AT&T. As many as six Japanese firms are thought to have this capability. Unless the structure of the industry is dramatically altered, U.S. companies will have to cooperate with other suppliers to be able to construct entire systems. Some foreign firms-which lead in an overall systems approach—have even developed large-scale integration through government-supported demonstration projects, moving farther "down the learning curve" in integrating their products into functioning systems. When North American markets for local area networks and subscriber loops do open in the 1990s, it is likely that vertically integrated foreign firms will have significant experience and a comparative advantage as suppliers.

A second area of concern focuses on the lack of international standards for fiber optic systems and associated optoelectronic devices. While international standards are developing, especially for integrated system digital networks (ISDN), progress in this area is very slow and cumbersome in an industry that is innovating quickly. Different countries have tended to adopt different standards, and standards have sometimes been used as non-tariff barriers to protect home markets for developing industries. Some industry representatives believe that Japan and the European nations are more advanced in setting standards than the United States, and that this will give them a developmental advantage. They believe that U.S. firms are reluctant to make extensive capital investments in optoelectronic devices that may be obsolete before they can be installed. Large firms that can offer complete fiber optic systems are at a distinct advantage in this respect. With well-developed national standards, large, vertically integrated Japanese firms may be

[21] U.S. Department of Commerce, International Trade Administration, op. cit., footnote 7, pp. xiv-xv.

[22] "Workshop on the Relationship between Military and Civilian Fiber Optics," Office of Technology Assessment, Washington, DC, Jul. 25, 1988. See *Holding the Edge*, p. vi, for a list of workshop participants.

[23] These prohibitions are contained in the Modified Final Judgment. See "United States v. Western Electric Co., Inc., et al. Notice of Entry of Final Judgment," 47 Fed. Reg. 40392-40394 (Sept. 13, 1982).

[24] Globalization and vertical integration are powerful trends in the field of telecommunications equipment generally. "In the next decade or so the global telecommunications equipment market will come to be dominated by about six Western players: two in Europe, two in North America, and two in the Far East . . . .Building the next generation of optical super-switches and super-computers will require enormous concentrations of capital, talent, and sustained engineering effort. The stakes are huge, not just for individual companies but for entire nations. This is not a market that the largest players enter lightly, or that smaller players enter at all". U.S. Department of Justice, Antitrust Division, "The Geodesic Network: 1987 Report on Competition in the Telephone Industry," January 1987, p. 1.13.

able to set *de facto* world standards, thus forcing U.S. and other component makers to meet those standards if they wish to Participate.

Third, foreign markets-especially in Japan but also in some EC member states-still present significant barriers to American firms. This disadvantage to U.S. companies is compounded because future expanded demand for fiber optic systems is expected to occur first in foreign markets, where domestic manufacture are favored. At the same time, the U.S. market remains wide open to all suppliers, and U.S.-based companies face intense competition for their share. As the U.S. market for fiber optics shrinks in relation to the world market, so too will the proportionate share of world sales for U.S. firms. As the market for fiber optic systems expands in the future, foreign firms may achieve large market shares and realize economies of scale unavailable to the American competition.

Fourth, most European producer nations and the Japanese government have designated fiber optics as an essential technology of the future, and subsidize research and development in the optoelectronics field. In the U. S., government assistance has been largely confined to the military, and U.S. companies have tended to pursue such R&Don an ad hoc basis. American firms lack the subsidies, the protectionist trade policies, the experience developed from demonstration projects, and the government-led standard-setting that their foreign competitors enjoy. On the other hand, U.S. firms have benefited from early and extensive patent acquisition, superior R&D, and the largest domestic market for fiber optic products in the world. However, these advantages appear to be eroding, and some will expire shortly. For example, some of the key patents held by Coming Glass Works will expire in the next several years, threatening the American position in both the domestic and international fiber optics markets.[25] Already, a number of foreign fins-especially French and Japanese—have had considerable success in the American market. The leading American companies, AT&T and Corning Glass, face considerably greater obstacles in attempting to penetrate foreign markets.

And finally, the U.S. continues to maintain a regime of export controls for fiber optics that is more restrictive than that of its CoCom partners and non-CoCom nations such as Sweden and Finland. The result is that U.S. companies often experience unnecessary delays, and have even been barred from exporting products that can easily be obtained through the European and Asian competition. For this reason, some executives of foreign companies have instructed their managers not to include American-made parts in their systems on the basis that supply may be unreliable in the future.

CONVERGENCE/DIVERGENCE OF CIVILIAN AND MILITARY FIBER OPTICS TECHNOLOGY

Military planners recognize a number of advantages inherent in deploying fiber optic systems in a military environment. Fiber optic systems are immune to electromagnetic interference, including the electromagnetic pulse that would emanate from a nuclear blast. They are considerably more secure from eavesdropping than traditional electron-based communications systems. It is comparatively easy to determine if a listening device has been attached to a fiberoptic system, and fiber itself has no electronic signature. Communication systems that use fiber can span longer distances without repeaters than can a twisted copper wire or coaxial cable. In addition, fiber optic systems are much lighter and far less voluminous. This is of extreme importance, for example, in Army tactical communications that must be strung out over a large area in a matter of hours or minutes, and in the Navy's ships, where weight and volume are especially critical factors. Fiber optic systems can function in intense heat and are able to withstand severe vibration, shock, and other mechanical stresses. Extensive testing by all three Services indicates that under most battlefield conditions, optical fiber systems are superior. It is a technology that appears to be inherently better suited to military environments than the technologies presently employed.[26]

Shipboard application demonstrates these points well. When the *U.S.S. Stark was* struck by missiles in the Persian Gulf last year, the communications

[25]Some industry representatives argue, however, that expiration of these patents may stimulate the U.S. fiber optics industry. They maintain that a "patent umbrella" has resulted in stifling domestic competition in a critical technology and has placed enormous marketing power in the hands of two companies, AT&T and Corning. They argue that it is not in the national interest for a key technology to reside in such a limited sphere.

[26]Army briefing to OTA on fiber optics, Jun. 29, 1988.

systems were immediately disabled. The electrical wire physically melted in the ship. Wire that was run on the deck melted in place. Under these conditions, a fiber system would be far more likely to survive. Experimental data have shown that fiber will continue to transmit information when it is heated up to 1200 degrees Centigrade, a temperature at which copper or aluminum would long since have disintegrated. There are other advantages. The Navy indicates that for one of its ships, 47 copper wire cables could be replaced with one glass fiber cable, which would weigh 15 pounds as opposed to 14,000 pounds, and could be installed at a cost of $30,000 instead of $1 M, the cost to install the copper cable.[27] Despite all these advantages, it is still the case that no ship in the U.S. Navy presently employs a shipwide fiber optic communications system.

In approaching the question of the extent of divergence between military and civilian applications of fiberoptic technology, it is perhaps useful to distinguish between tactical and fixed-plant fiber optic systems. The Army has provided information that directly addresses this problem. Tactical systems require rapid mobility. Approximately 50 percent of mobile communications would be operating in place for only ten hours. Although fixed-plant systems are installed directly in the ground or in conduits, most tactical systems must be placed on the ground or strung above the ground. While there are no significant limitations on cable length for fixed systems, tactical systems must be configured so that they can be set up and retrieved quickly. In addition, cable used in tactical communications must be more flexible and durable than in fixed-plant systems because it is handled frequently and under conditions that may not be optimal. Cable and repeaters for fixed facilities are usually protected from extreme variations in climate; whereas tactical systems may have to face a temperature range of between -55 and +160 Fahrenheit. While optical splicing may be used for many fixed applications, connectors are necessary due to requirements for mobility in a tactical environment. And finally, batteries or other sources of local power are usually required to drive sources and repeaters in tactical systems.[28]

There are also some important military applications of fiber optic technologies that do not have civilian analogs. One example is the use of fiber optic guidance systems in tactical missiles. The fiber configuration must be light, strong, and able to pay out quickly even after years of storage on a coil. The Fiber Optic Guided Missile (FOG-M), now in full scale engineering development, pays out an optical fiber from a bobbin, like a fishing reel, enabling the battlefield operator to target the missile with a real-time video image emanating from a camera in the nose of the missile. This makes it possible to hit targets that are not in the operator's line of sight, while the operator is at a sheltered location.[29] It requires many special parts that are not typically produced for civilian purposes. In addition, there are a number of fiber optic sensing devices now in research and development, such as the Navy Ariadne system, for which there are no obvious civilian applications.

But do such differences in application really translate into differences in the technology itself or in the way that R&D for fiber optics must be conducted? Here, the answer is a qualified "No." For fixed-plant systems, the requirements would differ only marginally, if at all, from those used in private sector businesses or for local area subscriber networks. The need for secure lines might, in some cases, entail a requirement for special hardware to monitor the system to ensure that security was not compromised. But such measures might also be necessary to safeguard proprietary information of businesses as well as the communications of banks and other financial institutions. For a large percentage of military applications[30]—wiring the Pentagon, the DoD laboratories and R&D facilities, and the military bases-the technology is broadly available from the civilian sector. This is also true for the long distance trunk lines used to connect military facilities with one another and with commercial communications systems. In addition, fiber optic systems deployed on ships would be similar to local area

[27] Navy briefing to OTA on fiber optics, Jun. 23, 1988.

[28] Army briefing to OTA on fiber optics, Jun. 29, 1988.

[29] Although the current military market for fiber is small, if this weapon system were put into full-scale production, the military demand for fiber optic cable would increase dramatically.

[30] Of principal fiber optics programs in the Army, for example, seven were categorized as fixed plant, two as tactical, and one was the FOG-M missile. (Army briefing to OTA on fiber optics, Jun. 29, 1988).

networks now undergoing trials in the private sector in Japan and the United States.

In both sectors of the economy, sensors have enormous potential in a wide range of applications. Many of the major sensors used by the military are analogous to those used in the civilian sector. Radar and sonar probably diverge the most from civilian products, but sonar is used to locate and harvest fish in the open sea as well as in logging and oil exploration operations. The oil industry employs a cable that is inserted into wells, using optical gyros, which is subjected to more severe environments than would be encountered in a military context, and which is used over and over again. For this reason, it is not accurate to say that fiber optic sensor technologies that are employed for military purposes diverge significantly from those used in the civilian sector. Nevertheless, some sensors are absolutely unique to combat environments.

One fiber optics group in the Navy has designated 54 different types of sensors that could be applied to a wide variety of military systems. Most would be benign and passive in all the environments for which they are designed. The group has tested a great many sensors developed for civilian purposes and found that most of them did not perform adequately in a military context. Their conclusion, however, was not that the civilian sensors should be discarded and replaced by sensors built to military specification. (After all, most such specifications do not yet exist, and the process of writing them and getting them approved will take years.) Instead, the group took the approach of addressing military requirements by attempting to modify commercial products so that they are suitable for the particular military needs.

The group's objective is to use the technology that is out there-technology which, they believe, is far more capable than the Services are currently capable of employing. Industry already has endoscopic devices used to look into machinery and into places where electronics cannot be inserted. None of these things is new or radical; each represents basic technology with different applications. In this view, the job at DoD is to figure out how to take the technology that is available-not a radical departure from it—and adapt it to a military setting. This synergistic approach is especially interesting, because sensing technology is probably the only area of fiber optics technology where the military leads the civilian sector.

Despite the decidedly military character of the FOG-M missile, its designers indicate that the Army has been able, for the most part, to use optical fiber that can be produced on modified commercial manufacturing equipment. The fiber companies have entered into earnest discussion with the FOG-M program because they anticipate a run of fiber that might reach 2 million kilometers. There are differences in the way that the fiber is wound on the spool. in the cladding that must surround it, and in the materials that are used to attach the fiber to the spool. But these do not translate into large technical differences, nor do they require large differences in the way that R&D is carried out. What is needed is the civilian industry and technology base to develop the modification.

BARRIERS TO MILITARY ACCESS TO CIVILIAN FIBER OPTICS TECHNOLOGY AND VICE VERSA

The issue of using civilian products for military purposes is not new. It is at least as old as the recognition that the costs for the military to develop its own technologies are extensive and, in some cases, prohibitive. The Packard Commission recommendations addressed the question of commercial versus developmental items in strong language: "Rather than relying on excessively rigid military specifications, DoD should make much greater use of components, systems, and services available 'off-the-shelf. ' It should develop new or custom-made items only when it has been established that those readily available are clearly inadequate to meet military requirements."[31]

The Commission's statement builds on a long line of legislative provisions, presidential directives, and cabinet-level memoranda since 1972 that have suggested a preference for commercially available products in government procurement. Nevertheless, the substitution of civilian products for military standard items remains the exception rather that the rule, and nothing less than a "specific and enforceable statutory directive [from Congress] in favor of the acquisition of commercial products" is likely to

[31] *An Interim Report to the President by the President's Blue Ribbon Commission on Defense Management*, Feb. 28, 1986. p. 17.

make a difference.[32] The wisdom or unwisdom of such a mandate is a matter of heated debate; but there is, nevertheless, considerable consensus that much excellent technology exists in the civilian sector, and that the military must surmount enormous barriers to acquire it.

Perhaps the greatest structural impediment that the military faces in drawing on the civilian technology base is that the business practices of the government diverge so radically from those of the private sector.[33] Like other industries, fiber optics companies have found it necessary to create a separate corporate division in order to do any substantial amount of business with the Department of Defense. In *order* to meet government regulations and specifications, fiber optics businesses must organize many of their principal functions differently-including accounting, personnel, auditing, R&D, production, advertising, marketing, and management information systems.

They must also adjust their business psychology and profit orientation. Successful fiber optics and optoelectronics companies invest heavily in research, develop a superior product, realize large profits, and plow their earnings back into the R&D effort. This business environment contrasts sharply with government-subsidized research and regulated profit margins. While all firms that seek defense contracts must face these facts, it is particularly difficult for high technology companies whose products and technologies were born in the civilian sector. In many cases, fiber optics and optoelectronics companies are unable or unwilling to make the required investments and adjustments.

The Problem of Specifiations and Standards

The question of how to specify fiber optic systems and devices for the military poses what amounts to a paradox, both for the industry and for the government. The problem is that optoelectronic and fiber optic technologies are changing so rapidly that no one can agree on standards. Part of the reluctance to adopt worldwide standards is based on the competitive postures of different national industries. If a company or group of companies could set standards *de facto*, forcing the rest of the industry go along, the originators would enjoy a strong comparative advantage. But equally important, there are some fields in which settling on a particular set of standards is not possible because the technology never stabilizes. Fiber optics has been such a field. and standards officials expect that it will remain in flux for the foreseeable future. Faced with such volatility, DoD has been unable, thus far, to write specifications for fiber optics fast enough to enable it to procure many of the items that it needs.

DoD is confronted with the problem that, by picking a standard, it may lock itself into an obsolete technology or an application that no one in the civilian sector is willing to build at a reasonable cost. This is because the military wants to nail down prescriptive standards[34] in a field that is changing from month to month. The alternative is to adopt performance standards specifying, in a general way. the characteristics that a part or component must meet, and then leave it to industry to figure out the specifics. Performance standards may make more sense for fiber optics technology in the present situation, but they raise problems of enforcement and lack of uniformity among testing measurements. Nevertheless, the rate of technological change in the industry makes prescriptive standards virtually impossible to use.[35]

Industry executives suggest that, in general. the military does not recognize the capabilities of the commercial sector. From the industrial perspective this is due to "the momentum factor" and "cultural

32"A Quest for Excellence: Final Report to the Presdent," by the President's Blue Ribbon Commission on Defense Management, June 1986-Appendix H: "Expanding the Use of Commercial Products and 'Commercial-Style' Acquisition Techniques in Defense Procurement: A Proposed Legal Framework," pp. 95, 103-105.

33This was a principal conclusion of the 1986 Defense Science Board Summer Study: "'Commercial practices used to procure commercial products are sufficiently different from DoD practices (because of history, regulations, and statutes) that the expanded use of commercial products in DoD systems will be inhibited until the differences are reduced". Defense Science Board, Report of the Defense Science Board 1986 Summer Study on Use of Commercial Components in Military Equipment. prepared for the Office of the Under Secretary for Research and Engineering, January 1987, p. vii.

34In general, "prescriptive standards" specify how something is to be made or what it is to be made from. For example, a prescriptive standard might specify the material to be used for the protective jacket of an optical fiber. In contrast. "performance standards" specify only the resulting capability or performance level to be achieved. For example, a performance standard might specify the tensile stress that a jacketed fiber must withstand without damage.

35Some observers argue that DoD has been slow to develop prescriptive standards for fiber optics largely because there was no compelling advantage to adopting fiber optics for many applications. There is evidence to suggest that the Defense Department has moved to develop such standards when no non-fiber alternative was available. Examples would include underwater fiber sensing systems, fiber optic gyros and fiber guided missiles.

conservatism" in the military, two substantial barriers to the large-scale introduction of fiber optics technology. The first idea holds that the Services have committed themselves to older communications and sensing technologies, many of which are not compatible with fiber optic systems. In this view, the military is constrained to maintain an evolutionary approach, working gradually away from systems that already exist in the field. Converting the older systems over to fiber optics would introduce enormous costs that simply cannot be justified in most cases. While fiber optics technologists in the Services are anxious to retrofit ships and other platforms with fiber systems, they encounter a pervasive willingness to get along with older and less capable technology. Indeed, fiber optics technology seems to be advancing rapidly toward the field only in those applications, such as sensors, where there is a significant new capability and no existing alternative.

In addition, there are many new weapons systems in advanced development that have not been designed to take advantage of fiber optics technology. While military planners and technicians at all levels recognize the overall superiority of fiber optics, they must work against a strong and unabating cultural conservatism within the procurement system that tends to mitigate against the introduction of fiber optics. There is little incentive for program managers to seek out a new technology and put it into a weapon system, particularly if the technology is changing rapidly and proposed parts or components are not fully specified. Here, the specification would act as a buffer between the program manager and possible failure or delay associated with a new fiber optic device. Faced with possible career damage and an administrative structure that does not reward the successful introduction of a new technology, the officer in charge is likely to avoid risk and to make do with coaxial cable or a twisted copper pair and associated electronic components.

The lack of industry standards exacerbates this already difficult internal problem. From the DoD perspective there is no way that acquisition managers can make mass scale purchases from civilian industry-and this is where the technology is found-in the absence of performance, design, and testing specifications. From their perspective, such specifications are essential to the acquisition process. So there is an impasse. DoD can acquire optoelectronic technology and products only in the presence of mature specifications (or at the very least, a ruggedized civilian standard). But the technology is developing so rapidly that temporary or firm-generated standards are insufficient to meet DoD's unstated requirements.

There are also circumstances-and these may be more numerous-in which the existence of specifications creates barriers to the introduction of a new technology into the military. This problem can occur, for example, when a large civilian-sector company attempts to install a standard fiber optic telecommunications system for a military base. DoD could procure regular commercial fiber optic products because there are no special requirements. These might be systems already developed to supply businesses or subscriber networks in the civilian sector. But it is very difficult to install such a system on a base, because the company must comply with unnecessary and unreasonable specifications that are costly and unrelated to performance.

In this kind of situation, there are commercial specifications that would meet the needs of the base. In many cases, though, the military people do not pick up on the commercial standards, insisting instead on a great many complex, and sometimes contradictory, specifications that may have little to do with the way in which the telecommunications system is supposed to perform. The key obstacle here is the military specifications that are already written for the procurement of communications systems. They tend to be design-based instead of performance-based, making it difficult to substitute a newer, more capable technology for an older one.[36]

One key missing element in getting civilian technologies into the military is the lack of a commercial standard for ruggedized fiber optic cables and components. If there were a standard, the military would buy substantially more fiber. Without one, commercial technologies must be tested individually. For its part, the industry would be willing to produce to military specifications, but they do not yet exist. Military procurement officials

36It is, of course, still possible for DoD to acquire these systems; it is just difficult and costly. The Navy, for example, has installed a fiber optics-based communication system at its weapons testing center at China Lake, California and also plans to use fiber optics in a local area network for the U.S. Naval Academy in Annapolis, Maryland. The fiber in the backbone of this network "will be able to support future 100-megabit/sec data transmission based on the specifications being developed for fiber-distributed data interface networks". *Government Comparer News, Oct.* 24, 1988, p. 37.

reported that they are using as much civilian technology as they can, but that they need standards to promote consistency in design, facilitate procurement, assure inter-operability, ease maintenance, and reduce cost. On the other hand they recognize that the military specifications process for fiber optics should be performance-based and will have to be synchronized with the pace of technological development.[37]

Is Government an Undesirable Customer?

In general, DoD-mandated business procedures bias the system toward large prime contractors. From the military's perspective, these companies minimize the risks associated with performance, cost and scheduling. Large companies generally establish separate divisions to handle the military side of the business, a costly option that would be prohibitive for most smaller companies. In comparison to the civilian economy, the military industrial sector is extremely concentrated. A relative handful of large firms account for a large portion of the annual defense business. These circumstances have led some analysts to conjecture that the single most important capacity of the large primes is the ability to obtain and administer government contracts. The structure of these firms enables them to deal with the sometimes awesome requirements of DoD; it is a structure that simply cannot be emulated by most high technology firms operating in the civilian sector of the economy.

Industry executives and analysts cite several reasons for the difficulties some optoelectronics and fiber optics firms have experienced in selling to DoD, and why others are reluctant to do business with DoD at all.[38] Among these reasons are: (1) DoD cannot guarantee firms that funding will be available for authorized projects; (2) DoD seeks to acquire data rights that would compromise large R&D investments; and (3) to do business with DoD, a firm must fundamentally alter its corporate structure, policies, and overall intentions. Each of these problems is discussed below.

Somewhat ironically, a fiber optics company that licensed its technology from a DoD-funded university program is now unwilling to do business with the government. It is a small, highly profitable company that is limited as to the money and technology it can leverage for any given purpose. Executives must see a payoff down the road or they cannot commit in that area. They are very reluctant to take contracts with DoD because they cannot support the cost of research and gearing up for production unless there is a definite market for the product in question. Accordingly, they avoid military contracts because they are unwilling to assume the risk or even the uncertainties that go with year-to-year funding.

A related problem pertains to the turnover and reliability of government acquisition managers. In the civil sector, a company can develop long-term relationships with buyers in other firms, with a reasonable expectation that they will be around to honor their commitments. With DoD, it is less certain that the people and the program will last, and that they will end up with the final contract authority. Large defense-oriented firms undertake extensive lobbying and specialized political intelligence operations to address this problem. Fiber suppliers may also gear up for a large production run, only to have the government recompete the contract and award it to a firm submitting a lower bid-even if the firm cannot deliver the same product within the specified time.

A second major problem cited by some industry analysts is that government procurement officers and regulations do not recognize the extent to which fiber optics and optoelectronics are technologies driven by R&D. Government agents tend to demand as many data rights as they can get in a given contract, because they are under a fiduciary obligation to protect the interests of the government and get as much for the taxpayers' dollars as possible. Most fiber optics firms are unwilling to share their data because they believe that such data can be used to reveal a core of proprietary product or process information. In some cases, fiber optics companies invest tens of millions of dollars to develop a product or process. The knowledge gained is vital to the company. They know that, sooner or later, govern-

[37] There is, for example, an effort under way in the Navy to harmonize the military's proposed Safenet standards with the commercial FDDI (Fiber Data Distribution Interface) standards, but progress has been slow, since the proposed standards deal with low data rate systems which mayor may not be useful in the future.

[38] On the other hand, many technologists and procurement officers in the Services observe that civilian-sector companies are unwilling to invest their own funds to satisfy the needs of Dod. They point out that many civilian items—including fiber optic products-must be adapted, repackaged. and tested before they arc suitable for military applications.

ment may share the data, perhaps even setting a competitor up in business. They are particularly concerned that military procurement is oriented toward developing multiple sources for any given commodity, product, or process. Standard requirements in government R&D and production contracts may obligate the initial contractor to share information with another firm or firms that DoD chooses to participate in the manufacturing process down the line.

For optoelectronics and fiber optics companies, the problem of protecting proprietary rights comes at the very beginning of a decision to take a government contract or not. Fiber optics companies generally rely on quite extensive patents. That is their bread and butter in the civilian sector. If the military segment of the business is small, or if the company usually does not do military business, executives may eschew government contracts because they are expected to sign away the patent rights. Some have argued for a more versatile mechanism that would enable government agents to write a contract that defines and splits the patent and proprietary rights in a more equitable reamer. This problem was underscored for some fiber makers when DoD contracted with a Japanese competitor, enabling the competitor to continue climbing up the learning curve, even after the courts had ruled that the Japanese firm had infringed patents held by an American company.

A third major impediment between DoD and civilian sector fiber optics firms is the perception on the part of industry executives that they are simply ill-equipped to do business with DoD. This is partly a consequence of the difference in business practices in the military and civilian sectors of the economy, and partly a result of inflexibility on the government's part.[39] Many optoelectronics firms in the United States are quite small and extremely entrepreneurial. They invest heavily in research and are in the business of making and selling products at a profit. To do substantial business with the government, these firms would have to adopt DoD's standard operating procedures. They would have to learn to live with and respond to regulatory, reporting, accounting, and auditing requirements that are largely incompatible with their own systems and make no sense in the context of civilian sector business. From their perspective, managers would have to accept pervasive government oversight and regulation, including the imposition of regulated profits.

To some extent, the Small Business Innovation and Research (SBIR) program helps to alleviate this problem. It has helped some smaller "fiber optics companies enter into the initial stages of development when they might not otherwise have been able to do so. But its critics complain that by the time the product gets to production, the SBIR supports are removed and competition to ensure multiple sources comes back into play. Larger companies accustomed to doing business with DoD can easily eliminate the smaller companies from the competition.

Easing the Barriers

There are some circumstances in which the various barriers, discussed above, are diminished or have been circumvented altogether. The FOG-M missile is an important case of cooperation between government and the civilian sector in the development of military applications for fiber. Fiber optics suppliers developed new techniques for coating fiber to strengthen it. The military provided precision winding that had been developed for the TOW missile, in return receiving the fiber optic data link necessary to target the missile. The key obstacle—both for the companies and for the Army-was the rapidly changing nature of fiber optic technologies. Nevertheless, the missile, which the U.S. Army Missile Command and several fiber optics companies jointly developed, will soon enter production. This path was highly unusual, because an Army laboratory functioned as a kind of prime contractor for the project.

A second area has to do with the highly classified, special access (or so-called "black") military programs. While it is not possible to provide a specific example, DoD fiber optics officials indicated that the best thing that could happen to a program manager would be for his or her program to receive a special access classification. As such, it would be exempted from many of the regulatory, legal, and administrative requirements that usually apply when government is doing business. In addition, the program would be largely exempt from Congressional oversight as well as from inquiries from the press and public interest groups. Some analysts

[39] Several groups within the Services have stated that the procurement process is the leading barrier when DoD attempts to access technology in the civil sector.

believe that, from a security perspective, there is little that goes on in the special access programs that does not go on in less highly classified programs. But because the number of black programs has expanded by a factor of eight in the past decade, these programs now constitute a second developmental track that weapons systems can follow. In this view, the special access classification is a fast track. It indicates that a program has been given high priority by top leadership and is being pushed along outside the system for that reason. If this is true, it is a significant comment on the impediments that exist in doing business with the government.