FIBER OPTIC COMPONENT DESIGN, FABRICATION, TESTING, OPERATION, RELIABILITY AND MAINTAINABILITY

by

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Foreword

This book provides a thorough analysis of the currently available information on fiber optic reliability, maintainability and supportability. It covers the full range of fiber optic technology, from component fabrication, screening and accelerated testing, to failure mechanisms and modes, to maintenance philosophy and logistics considerations. It focuses on major components of fiber optic systems which include fiber and cable (transmission medium); connectors and splices (physical interconnecting devices); emitters, transmitters, detectors, and receivers (electro-optic and opto-electronic conversion devices); couplers, multiplexers/demultiplexers, and switches (signal combining and routing devices); and enclosures, splice trays, and organizers (ancillary items). Specifically excluded from consideration are those items which are predominantly non-fiber optic, such as bus interface units and telephone or video signal multiplexer/demultiplexer units. In addition to the primary fiber optic components, military fiber optic systems are addressed. These include the Communication, Navigation and Interrogation (CNI) system on the AV-8B Harrier fighter aircraft, the Fiber Optic Transmission System-Long Haul (FOTS-LH) field deployable communications link, and the AN/FAC-2 and 3 fixed communications link.

The approach taken was three-fold. First, voluminous amounts of technical data were gathered from many sources using a variety of techniques. Second, as the information was obtained, analysis was performed to ascertain whether it was current and relevant to the study. At this point, the data was cataloged for easy retrieval. This provided a baseline from which recommendations and guidelines were developed for system designers and planners based on engineering analysis.

The qualitative information was used to develop considerations which address the many phases of fiber optic component design, fabrication, testing, and operation which are important in the component selection process. In addition, considerations were developed for system installation, check-out, environmental factors, maintenance and physical lay-out. The quantitative data received from the results of laboratory research and from deployed systems were used to calculate component lifetimes and failure rates.

The book also contains a significant amount of information on the fundamentals of fiber optic component design, construction and operation. This provides the background necessary to understand the detailed reliability concepts which are presented, thus making the book useful as a fiber optics training aid.

The availability of Reliability, Maintainability and Logistic (R,M&L) data on fiber optic components and systems was limited, if not non-existent, in military data collection activities. Also, many military systems were billed as being "fiber optic systems" when in reality they were still in the conceptual design phase, development phase, or were simply one-time demonstrations. However, in several cases the lack of information on military systems indicated that there simply were no operational failures to report. For some of the components, the populations on which data were available were not large and/or the actual number of elapsed operating hours was low. These

conditions make it necessary to exercise caution when using the resulting calculations. That is, they should not be used in detailed design analysis, but they are appropriate for use in narrowing the wide range of component types to those that are suitable for a given application. Once the device type is selected, its reliability and failure characteristics presented in the book can be studied. This will tell the designer which features of the intended application are prone to impact the component the most.

The R,M&L recommendations and guidelines put forth in this study provide the reliability and maintainability engineer with the necessary direction to enhance system design. Also,those wishing to acquire an understanding of the basic fiber optic discipline can benefit by studying this document.

The information in the book is from *Impact of Fiber Optics on System Reliability and Maintainability,* prepared by N.L. Christian and L.K. Passauer of Vitro Corporation for the U.S. Department of Defense Rome Air Development Center, June 1988.

The table of contents is organized in such a way as to serve as a subject index and provides easy access to the information contained in the book.

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NOTICE

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Introduction

Photonics is the technology that deals with the manipulation and transfer of photons, packets of electromagnetic radiation with frequencies in the optical range. Although the term "photonics" is relatively new, the field of study encompassed by photonics is not. It is a wide-ranging technology with applications in military, industrial, and consumer markets. Photonics is much more pervasive than we may realize. Compact disk players, the current rage in stereo equipment, use lasers to read the information stored on the disk. Wireless remote controls for TV and stereo equipment use infrared signals to transmit the control information. Infrared light is also used in security systems for motion and intrusion detection. Most modern grocery stores have laser scanners at the checkout line to read the bar code information printed on the packages. Infrared radar systems and laser guided missiles are just two military applications of photonics. Some portions of photonic technology are well developed and understood, as evidenced by those systems listed above. Other areas of the technology are the subject of intense research and development efforts. Work is underway now to develop photonic logic gates and switching devices and all-optical computers. These will lead to new products and applications of photonics unheard of even a few years ago.

One segment of photonics that has experienced tremendous growth and extensive change over the last twenty years is the field of fiber optics. Fiber optics involves the transmission of information, in the form of optical signals, over optical waveguides or fibers. The concept of using light to carry information is not new. In the 1870s Alexander Graham Bell proposed a "photophone" in which sunlight would be used as a carrier, modulated by audio or voice signals. A contemporary version of Bell's idea can be seen in free space infrared optical links used in many urban areas, where running cables may not be cost effective and the use of microwaves may not be permitted for safety reasons.

In the early 1970s, with the advent of relatively low-loss optical fibers, it became feasible to utilize the high bandwidth capacity of an optical carrier in a guided or confined transmission medium. Since that time, the use of fiber optics has been explosive. Today, networks of optical fibers crisscross the world. Optical fibers compete with satellites and terrestrial microwave links for the transmission of long distance telephone calls and they are used to tie together computers in office buildings and campuses.

The technical advantages of fiber optics, particularly those beneficial to the military, are numerous. First and foremost, fiber has an extremely high bandwidth. With the ever increasing reliance on computers in military systems, the need to move large volumes of data rapidly is increasing. Fiber offers a way to meet this need with a decrease in cabling volume and weight as compared to copper cables. Fiber is also non-conductive to electrical signals. This means that interconnected equipment can be electrically isolated and ground loop problems eliminated. In addition, electrical hazards, such as shock and arcing in explosive environments, are also eliminated by the use of fiber. Fiber is immune to electromagnetic interference and largely immune to permanent damage from the energy contained in electromagnetic pulses. Fiber cables need not be shielded when routed in electrically noisy areas nor be protected from electronic countermeasures. Fiber is very difficult to tap, especially in a non-invasive manner, which means that it can be used to enhance system security. Finally, fiber has a very low signal attenuation, enabling long, repeaterless links to be built with optical fibers.

Potential military applications for fiber optic technology abound. The military, however, has lagged behind the commercial world in using fiber optics. One reason for this has been a lack of definitive information regarding the reliability of fiber optic components and systems and the related issues of maintainability and logistics support. The information contained in this report will allow reliability engineers to address these technical issues in greater detail than has been conveniently possible before.

Considering the large amount of information contained in this report, it was important that the contents be formatted in a manner which makes the information easy to locate. This was accomplished in part by making the first two sections summaries.

Section I, RECOMMENDATIONS AND GUIDELINES, is a synopsis of the technical issues impacting R,M,&L that need to be considered by systems designers and planners. Most of the considerations are broken down into three items: 1) each issue is stated, 2) it is then followed by a statement of the possible cause(s) in the case of a problem, and 3) where known, a method of preventing the problem is given. These issues are organized in an easy-to-use fashion which gives the reader the ability to quickly find the information he needs on a specific design consideration. These guidelines are divided into the following areas of interest: environmental, physical lay-out and installation, operational/optical requirements, manufacturing, logistics, and maintenance. Page numbers to the associated chapters in the report are referenced so further information can be found.

Section II, NUMERICAL RELIABILITY SUMMARY, contains the reliability parameters calculated for each of the components and systems discussed in the individual chapters. Where applicable, these parameters are given for different component constructions. Again, references point the reader to more detailed information in the associated chapters.

Section III, COMPONENTS, contains seven chapters on the fundamental fiber optic components. These are FIBER AND CABLE; CONNECTORS AND SPLICES; EMITTERS AND TRANSMITTERS; DETECTORS AND RECEIVERS; COUPLERS, MULTIPLEXERS AND DEMULTIPLEXERS; SWITCHES; and ENCLOSURES/SPLICE TRAYS AND ORGANIZERS. Each chapter contains detailed information on the component's design and operation, and a thorough discussion on the failure modes and mechanisms of that component. Also, an explanation is given regarding the reliability data obtained and any calculations performed to develop reliability parameters from that data. Any assumptions that were made are clearly stated. Maintenance and logistics information pertinent to each component is also included.

Section IV, SYSTEMS, contains three chapters each of which discusses a military system which uses fiber optics. These systems are the AN/FAC-2 and 3 fixed communications set, the Communication, Navigation and Interrogation System on the AV-8B Harrier fighter aircraft, and the Fiber Optic Transmission System-Long Haul (FOTS-LH) field deployable communications link. The FOTS-LH is a system which is still in the development stage. These chapters describe the systems, their design, construction, operation and exhibited performance.

Section V, TESTING, contains chapters on the two prevalent methods used to test fiber optic systems: the optical source/power meter test set, and the Optical Time Domain Reflectometer (OTDRs). The operation of the test equipment and how that test equipment is used in system testing is addressed. Information received from manufacturers regarding repair, predominant failures, storage and operating conditions, and anticipated lifetimes is also included.

Section VI, SUMMARY, concludes the report and provides recommendations for future activity based on our experiences and the information obtained during the course of this study.

This report can be used in four ways. First, it can be used as a quick reference guide for determining those R,M&L areas which need to be considered when planning a fiber optic system. Section I provides the necessary information for this purpose. Second, it can be used to quickly determine the lifetime of the fiber optic components addressed. Section II would be used to find these values. Third, detailed information on the R,M&L issues associated with each component can be studied in the individual chapters. And fourth, the information found throughout the report on the basics of these fiber optic components can be used in teaching those who are unfamiliar with the technology.

These applications of this report provide a substantial start to understanding and improving fiber optic system reliability, maintainability and supportability.

Section I

Recommendations and Guidelines