RF PHOTONIC TECHNOLOGY IN OPTICAL FIBER LINKS

In many applications, radio-frequency (RF) signals need to be transmitted and processed without being digitalized. These analog applications include CATV, antenna remoting, phased array antenna and radar amongst others. Optical fiber provides a transmission medium in which RF modulated optical carriers can be transmitted and distributed with very low loss. With modulation and demodulation of the optical carrier at the sending and receiving ends, the optical fiber system functions like a low-loss analog RF transmission, distribution, and signal processing system. RF photonic fiber technology has particular advantages in that it is more efficient, less complex, and less costly than conventional electronic systems, especially at high microwave and millimeter wave frequencies. Analog signal processing of RF signals can be achieved optically while the signal is being transmitted along the optical carrier. Examples of such processing techniques include up- and down-conversion of RF frequencies, true time delay of RF signals, and optical distribution of RF clocks.

This volume presents a review of RF photonic components, transmission systems, and signal processing examples in optical fibers from the leading academic, government, and industry scientists working in this field. It discusses important concepts such as RF efficiency, nonlinear distortion, spurious free dynamic range, and noise figures. This is followed by an introduction to various related technologies such as direct modulation of laser sources, external modulation techniques (including lithium niobate modulators, polymer modulators and semiconductor electroabsorption modulators), and detectors. In addition, several examples of RF photonic signal processing technology, such as the phased array, the optoelectronic oscillator, and up and down RF frequency conversion and mixing, are presented. These will stimulate new ideas for applications in RF photonic signal processing.

RF Photonic Technology in Optical Fiber Links will be a valuable reference source for professionals and academics engaged in the research and development of optical fibers and analog RF applications. The text is aimed at engineers and scientists with a graduate-school education in physics or engineering. With an emphasis on design, performance, and practical application, this book will be of particular interest to those developing novel systems based on this technology.

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Introduction and preface

RF technology is at the heart of our information and electronic technology. Traditionally, RF signals are transmitted and distributed electronically, via electrical cables and waveguides. Optical fiber systems have now replaced electrical systems in telecommunications. In telecommunication, RF signals are digitalized, the on/off digitally modulated optical carriers are then transmitted and distributed via optical fibers. However, RF signals often need to be transmitted, distributed and processed, directly, without going through the digital encoding process. RF photonic technology provides such an alternative. It will transmit and distribute RF signals (including microwave and millimeter wave signals) at low cost, over long distance and at low attenuation.

RF photonic links contain, typically, optical carriers modulated, in an analog manner, by RF subcarriers. After transmission and distribution, these modulated optical carriers are detected and demodulated at a receiver in order to recover the RF signals. The transmission characteristics of RF photonic links must compete directly with traditional electrical transmission and distribution systems. Therefore the performance of an RF photonic transmission or distribution system should be evaluated in terms of its efficiency, dynamic range and its signal-to-noise ratio.

RF photonic links are attractive in three types of applications. (1) In commercial communication applications, hybrid fiber coax (HFC) systems, including both the broadcast and switched networks, provide the low cost network for distribution of RF signals to and from users. RF photonic technology has already replaced cables in commercial applications such as CATV. (2) At high frequencies, traditional microwave and millimeter wave transmission systems, using coaxial cables and metallic waveguides, have extremely large attenuation. Electrical systems are also complex and expensive. Other advantages of RF photonic methods include small weight and size, and immunity to electromagnetic disturbances. RF photonic systems offer an attractive alternative to traditional electrical systems at high frequencies. However, much of the RF technology for high frequency application is

still in the research and development stage. It is important to understand the operation of each new development and to assess the implication of each new component before any application of the photonic link. (3) Once the RF signal is carried on an optical carrier, photonic techniques may be used to process the RF signals. An obvious example is the frequency up- or down- conversion of the RF signal. Therefore, photonic RF signal processing represents a potential attractive application area for new applications. However, in photonic RF signal processing, the system performance will have additional requirements than just the requirements for bandwidth, efficiency and dynamic range. For example, the phase noise of the RF signal becomes an important consideration in sensor applications.

System design consideration and the choice of the technologies and components to be used in RF photonic links, as well as the evaluation of their performance characteristics, are very different for analog links than for digital optical fiber links. For example, the "on–off" threshold switching voltage of a modulator is important for digital communication systems while the slope efficiency is the important figure of merit for analog modulation. A thorough understanding of the analog system issues and component requirements is necessary for a successful system design.

This monograph describes, in detail, the various key components and technologies that are important in analog RF links. The components are evaluated in terms of their potential contributions to the RF links, such as RF efficiency, bandwidth, dynamic range and signal-to-noise ratio. Since the modulation of an optical carrier is much smaller than its bias for analog links, a special feature of the analyses presented in this book is the use of small signal approximations with emphasis on the reduction of nonlinear distortions.

The objectives of this book are: (1) to present to the reader various key technologies that may be used in RF photonic links: (2) to assess the significant aspects of various technologies; (3) to explore extant and potential applications of such technologies; (4) to illustrate specific applications of RF photonic links.

The analyses of basic RF photonic links are presented in Chapter 1. The analyses show clearly the important figures of merit of various components and the system objectives of analog RF photonic links. Chapter 2 describes the role of RF subcarrier links in commercial local access networks. Modulation and detection techniques are of particular importance in RF photonic links, because they determine the nonlinear distortion, the bandwidth, the efficiency, and, in certain cases, the noise of such links. Chapters 3 to 7 describe various modulation techniques, including the direct modulation of semiconductor lasers, the $LiNbO_3$ external modulators, the traveling wave modulator, the polymer modulator and the electroabsorption semiconductor modulator. The basic materials and principles of operation, the performance expectation and the advantages and limitations of each modulation technique are presented. In Chapter 8, a description of the key features of various detectors is

presented. In the next three chapters, Chapters 9 to 11, three novel techniques, photonic frequency up- and down-conversion, integration of antenna and modulators at high millimeter wave frequency and optical generation of high RF frequency oscillation are discussed. They may offer hitherto unavailable opportunities for applications of RF photonic technology. Since RF modulation of optical carriers can be transmitted via fibers over long distance and with true delay, RF photonic technology can be used for antenna remoting and RF signal processing. Chapter 12 illustrates an important application of RF photonic technique to antenna remoting and to the phased array antennas.

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