Optics in Data Processing and Data Transmission

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Abstract - **Today optical systems are more and more important in data communications (optical fibers) and are also becoming important in data processing (optical and quantum computing) allowing for a fully optical communication network where all signals will be processed and transmitted in the optical domain. This paper gives an overview of optical fiber communications and analyses some optical devices and applications such as optical computing, holographic memory and optical pattern recognition.**

Keywords: Optical Fibers, NLO, Soliton, Optical Computing.

1 INTRODUCTION

Optical technology is capable of providing the required information capacity for the rapidly increasing demand in data transmission and processing.

Optics is of greatest importance in telecommunications due to the high bandwidth and lower attenuation obtained in optical fibers. In addition it begins to be implemented in real information processing as pattern recognition using optical computing.

In future is desirable that all processes involved in data networks, such as amplification, multiplexing, de-multiplexing, switching and signal processing take place in the optical domain which can be more efficient than electrical signal processing and avoids bottlenecks of electrical to optical and optical to electrical conversions [1-5].

2 OPTICAL FIBER COMMUNICATIONS

In figure 1 is shown a state of the art wavelength division multiplexing (WDM) optical fiber system used for long-distance, high-bandwidth telecommunication. The different elements that are part of this system, the performance and limitations are analysed.

2.1 Optical fiber characterisation and elements

In this optical fiber system the emitter consists of *n* independent optical beams coming from *n* laser sources with proper λ_i wavelength individually modulated by *n* electrical signals. The external modulation employing electro-optic materials is much faster than direct modulation of laser output power. The different modulated λ_i laser beams are coupled (Mixer Coupler) in the same optical fiber. In long distance fibers the optical amplifier allows signals to be regenerated without the use of electro-optical converters. Erbium-doped fiber amplifiers (EDFA) pumped usually by diode lasers are used. In WDM or dense wavelength division multiplexing (DWDM) systems in order to separate closed spaced wavelengths ($<$ 0.8 nm) fiber Bragg gratings are used. For optical detection the most commonly used are the PIN or avalanche photodiodes (APD).

2.2 Optical fiber limitations

The most import limitations in single mode fibers are the attenuation due to material absorption, linear dispersion due to the variation of refractive index as a function of wavelength causing the pulses to broaden (limiting the overall bandwidth) and Rayleigh scattering (or elastic scattering) due to random fluctuations of the refractive of the refractive index on a scale smaller than the optical wavelength.

All previous processes described are linear or intensity-independent, but in single mode fibers with high light intensity, due to the small cross section inside the fiber, another type of intensity-dependent processes occurs. These nonlinear effects are described by nonlinear optics (NLO). In optical fibers the NLO effects can be divided in nonlinear refractive processes and inelastic scattering phenomena.

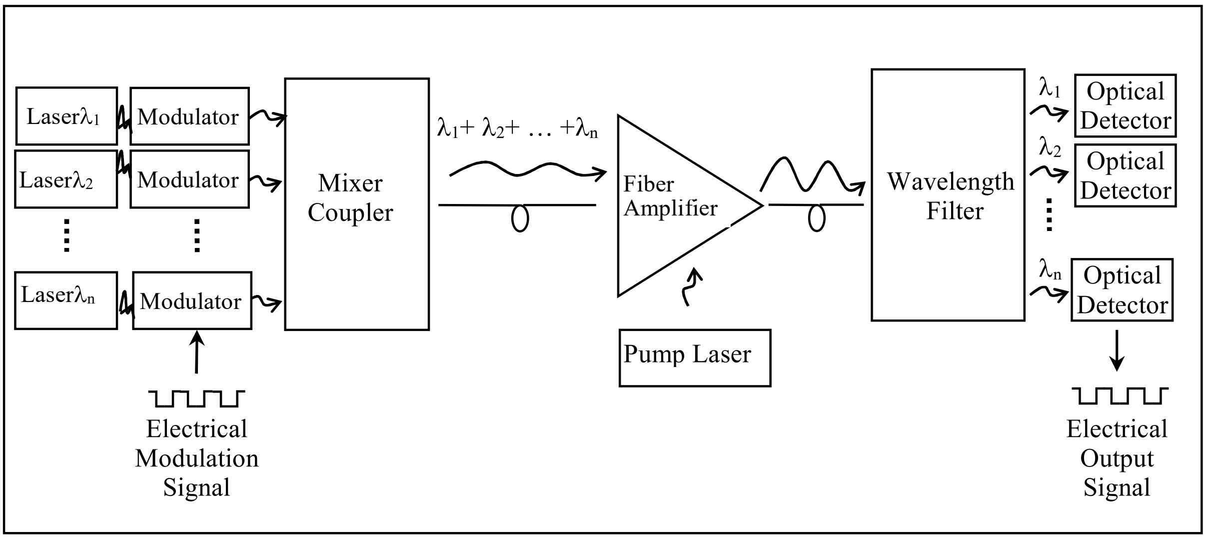

Fig. 1. *Typical wavelength-division multiplexing-fiber optic communication system.*

Nonlinear refractive change includes: Self-phase modulation (SPM) related to changes of refractive index caused by variation in signal intensity and resulting in a temporary varying phase change that leads to additional dispersion; Cross-phase modulation (CPM) related to change of refractive index of an optical beam produced by the intensity of that beam and the intensity of other beams co-propagating in the same optical fiber; Four-wave mixing (FWM) process originated from 3rd order susceptibility ($\chi^{(3)}$) resulting in a fourth frequency ω_4 related to ω_1, ω_2 and ω_3 frequencies which co-propagate simultaneously inside a fiber by $\omega_4 = \omega_1 \pm \omega_2 \pm \omega_3$.

If the light intensity in the optical fiber exceeds a certain threshold value the inelastic scattering light grows exponentially. Contrary to elastic scattering, the frequency of scattered light is red-shifted during inelastic scattering and can induce stimulated effects such as stimulated Brillouin-scattering (SBS) and stimulated Raman-scattering (SRS).

All these linear and nonlinear processes in general result in degrading the overall performance of an optical fiber telecommunication system but in certain situations can interact positively. An example is the effects of linear and SPM dispersions that can be compensated mutually by proper choice of light pulse shape and the power carried by the pulse. In such situation the pulse would propagate undistorted and is called soliton with applications in high bandwidth optical communication systems [6].

3 OPTICAL DATA PROCESSING

We can divide optical computing in digital and analogue processes. Digital optical computing employs optical gates and switches. The main technical difficulty remains in the creation of large high-density arrays of fast optical gates.

The principle of analogue optical computing is based in the property of the lens which perform in their back focal plane the Fourier transform of a 2D image located in their front focal plane [7]. The inherent parallel processing is one of the key advantages of optical processing compared to electronic processing that is mostly serial. Optical analogue processing is useful when the information is optical and no electronics to optical transducers are needed.

In a parallel optical computer, a parallel access optical memory is required as for example 3D optical holographic memories using different materials such as photorefractive crystals.

Actually the optical computers were not able to compete with the electronic computers essentially due to the lack of appropriate optical components, but in the future the employment of nanotechnologies can change this situation [8].

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