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Fiber-based tunable dispersion compensation

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Abstract. Tunable dispersion has been implemented in various technology platforms, including fiber gratings, planar waveguides, thin film etalons, and bulk optic technologies. This paper will focus on fiber grating based tunable dispersion compensation, because fiber gratings are at present one of the best developed TDC technologies available. The paper is divided into three parts. In the first part we describe grating based TDC technologies and discuss their advantages and disadvantages. We focus on thermally tuned linearly chirped fiber gratings, as these have to date been the most successful grating technology for 40 Gbit/s. We also compare grating TDCs to two other prominent tunable dispersion technologies: thin film etalons and planar waveguide ring resonators. In the second section we describe the techniques used to fabricate high performance dispersion compensation gratings as well as the theory of the primary defect of fiber grating dispersion compensation: group delay ripple (GDR). In the third section we describe the telecom system related issues for tunable gratings, including characterization of grating performance, tunability requirements and results from actual system trials using tunable FBGs.

Introduction

Tunable dispersion compensation (TDC) refers to a range of optical technologies that allow for a controlled amount of chromatic dispersion to be added to a signal over a given bandwidth. Tunable dispersion can be distinguished from "adjustable" dispersion which requires switching and hence loss of data during the change in dispersion [1]. Tunability implies continuously variable chromatic dispersion that can be employed in feedback loops to stabilize high bit rate channels or compensate for reconfiguration of a network. This technology has been recognized as essential for the proper functioning of telecom systems at bit rates of 40 Gbit/s and above [2]. At these high bit rates, the sensitivity to dispersion is at the level of 10s to a few 100 ps/nm. As this paper will

show, such dispersion can be designed into a discrete device with a practical signal bandwidth. At lower bit rates, 10 Gbit/s and below, tunable dispersion is required only for static trimming of the system to compensate dispersion slope mismatch, or system reconfiguration. However, because of the higher dispersion tolerances, the useful tuning range is several 100s to 1000s of ps/nm, and this dispersion is more difficult to achieve in a single discrete device. Moreover, as electronic equalizers improve in speed and performance, the need for tunable optical dispersion compensation at 10 Gbit/s also diminishes. Therefore, tunable dispersion compensation is primarily geared toward 40 Gbit/s, where cost per bandwidth is more favorable, dispersion range is more easily realized, and electronic equalizers are less practical. Our primary focus will therefore be on the TDC technologies that have been most extensively developed and tested to meet 40 Gbit/s TDC requirements.

Tunable dispersion has been implemented in various technology platforms, including fiber gratings, planar waveguides, thin film etalons, and bulk optic technologies. This paper will focus on fiber grating based tunable dispersion compensation, because fiber gratings are at present one of the best developed TDC technologies available. The paper is divided into three parts. In the first part we describe grating based TDC technologies and discuss their advantages and disadvantages. We focus on thermally tuned linearly chirped fiber gratings, as these have to date been the most successful grating technology for 40 Gbit/s. We also compare grating TDCs to two other prominent tunable dispersion technologies: thin film etalons and planar waveguide ring resonators. In the second section we describe the techniques used to fabricate high performance dispersion compensation gratings as well as the theory of the primary defect of fiber grating dispersion compensation: group delay ripple (GDR). In the third section we describe the telecom system related issues for tunable gratings, including characterization of grating performance, tunability requirements and results from actual system trials using tunable FBGs.

1. Fiber Grating TDC Technology Overview

In section 1 we review fiber grating TDC technology. We first discuss the basic concept behind fiber grating dispersion compensators and give simple design rules. We then describe different methods of making fiber gratings tunable and discuss different fiber grating TDC designs. Finally we compare fiber gratings to other well developed TDC technologies.

1.1. Fiber Gratings as Dispersion Compensators

The basic principle behind almost all fiber grating dispersion compensators is Bragg reflection in a fiber grating. It has been known since 1978 that periodic modulations of the refractive index may be inscribed into the Ge-doped core of the standard single mode step index fibers used in optical telecommunications [3]. These Fiber Bragg Gratings (FBGs) reflect light over a narrow range of wavelengths determined by the period of the grating. Such reflectors have been used as laser mirrors and narrowband WDM filters for adding and dropping channels as well as optical taps and broadband filters [4,5]. A significant aspect of the fiber grating technology is that the grating