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Design of 10-to-40 GHz and higher pulse-rate multiplication by means of coupled Fabry–Perot resonators

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Abstract

Limitations of a general autoregressive multistage-coupled filter for repetition rate multiplication are addressed. With only two or three stages, the useable filter passband is broadened by more than two orders of magnitude compared to single-stage (e.g. Fabry–Perot) filters thereby improving the robustness of the device to frequency detuning. Multi-stage filters also show improved performance in the pulse-to-pulse power uniformity.

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1. Introduction

The increasing demand for optical communication bandwidth has motivated extensive research of novel techniques for generating optical pulse sequences at repetition rate of 40 GHz or higher. One attractive method is to multiply the repetition rate of a lower rate pulsed source by time interleaving [1] or by spectral filtering with a periodic amplitude or phase filter [2]. Time interleaving may be implemented with unbalanced Mach–Zehnder or Michelson interferometers or with arrayed-waveguide gratings (AWG) [1]. Periodic spectral filtering can be performed with a variety of filters including interferometers [1,3] and fiber Bragg gratings (FBGs) [2,4]. In this case, repetition rate multiplication is achieved by selecting a subset of the pulsed-source mode spectrum. To obtain a high-quality pulse train, the amplitude and phase distortions of the optical filter response must be

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minimized. Furthermore, the periodic filter should have a sufficient number of periods to cover the whole source spectrum and thus optimize the pulse duty-cycle of the high-repetition rate output [4].

Among the spectral filtering techniques, amplitude filtering implementation is usually preferred in order to minimize in-band phase distortion and peak-to-peak phase variations. Also, operation in transmission, rather than in reflection, avoids the use of a circulator thereby reducing complexity, cost and loss. Such transmissive filters, with separate input and output ports, include a special category of interferometers known as purely autoregressive (AR) filters [5], represented by Fabry–Perot (FP) etalons in transmission [3] or thin films coupled-cavity filters (CCF) in transmission. Compared to finite impulse response filters like Mach–Zehnder interferometers, they are strictly minimum phase and therefore their amplitude and phase cannot be designed independently [5]. Nonetheless, coupled-cavities FP filters are simple devices that can be implemented with well-known technologies like thin film mirrors [6], or by technologies compatible with optical fibers, like superimposed chirped FBGs [7] or superstructured FBGs, with advantages inherent to all-fiber solutions including low loss, compactness, and robustness and with additional benefit from working in transmission, unlike most FBG devices. The impact of the design constraint resulting from the interdependence of the amplitude and phase response of AR filters can be understood by considering a FP etalon, which is an example of a single-stage AR CCF. FP etalons used in transmission are characterized by an impulse response having an instantaneous rise time and a slow exponential decay. This time response results in high peak power variations in the generated pulse train. This power variation can be reduced by increasing the FP finesse which results in a longer cavity decay time. However, higher finesse makes the system very sensitive to frequency or free spectral range (FSR) mismatch between the FP filter and the pulsed source spectrum. It was also proposed to improve the impulse response by double passing through FP using orthogonal polarizations [8]. This approach, however, requires an additional polarization beam splitter and a Faraday mirror.

In this paper, we propose to improve the performance of FP etalons by introducing coupled cavities. The aim of this paper is thus to investigate performance limitations of a general AR multi-stage CCF for repetition rate multiplication. We demonstrate that CCF designs provide a larger useable bandwidth thereby increasing the robustness of these filters, compared to a single-stage AR filter, in terms of wavelength detuning and FSR mismatch.

2. Design and results

This work presents a detailed analysis of pulse-rate multiplication of 10-to-40 GHz, but multiplications of 10-to-80 and 10-to-160 GHz are also addressed. We compare the performance of AR CCF to the response of a classical single-cavity FP etalon considering an incident pulse width of 5 ps. First, we demonstrate AR CCF potential by comparing filters having the same finesse of 15, which for the simplest coupled cavity (two CCF) design ensures power variations less than 1 dB (sufficient for some applications) in the generated 40 GHz repetition rate signal. A detailed comparison of the filters is then performed on designs leading to power variations of less than 0.5 dB, which is supposed to be sufficient in most applications.

The impulse response of a single cavity FP etalon with a 40 GHz FSR, which corresponds to cavity length of 3.75 mm (in air at the wavelength of 1550 nm), and a finesse of 15 is shown by the solid line in Fig. 1. It is clearly seen that the generated pulse train shows strong peak power variations due to the in-band variations of the group delay (GD) (Fig. 2). When a pulse train is incident on the FP device, the impulse response of the individual pulses overlap. The temporal response of the single-cavity FP filter to a 10 GHz pulse train is shown by the solid line in Fig. 3 where more than 5.5 dB power variations is observed. The power uniformity of the output pulse train can be improved by increasing the FP finesse, which results in a longer cavity decay time. Fig. 4 shows that a finesse of 140 is required to achieve peak-to-peak pulse power variations (p-pPPV) smaller that 0.5 dB. However, this increased finesse also indicates that the transmission peak bandwidth is se-