Novel tuneable filter based on MZ and an amplified ring resonator for OFDM networks

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Abstract: A novel reconfigurable fibre based tuneable filter is proposed. The module relies on a cascaded connection of Mach-Zehnders and an amplified fibre ring resonator. MHz range adjustable FHWM bandwidths and high crosstalk are achieved.

Introduction

Optical Frequency Division Multiplexed (OFDM) networks are very attractive because many users can easily access the enormous bandwidth of fibres. This technology is also expected to play an important role in multimedia access networks in terms of user multiplexing and service multiplexing [1]. Key components are tuneable filters, to extract pilot signal [1] and routers in a self-routing Frequency Division Multiple Access (FDMA) topology [2]. In those networks capacity increases with Free Spectral Range (FSR) if periodic filters are utilised. Some optical filters previously reported are cascaded Mach-Zehnder (MZ) demultiplexers [3], but they do not have narrow bandwidth, neither are easily reconfigurable. Amplified ring resonators (ARR) have narrow Full Width Half Maximum (FWHM), but FSR is limited by ring length.

In this paper a novel tuneable filter is presented. It has narrow FWHM and design flexibility of amplified ring resonators while FSR limitation is overcome by cascading MZ to its input and using aperiodic filters such as Bragg Gratings (BG). Basic architecture along with a practical design as a demultiplexer is reported. Channel allocation is aligned to normalised frequency grid proposes by ITU.

Principle and Design

Tuneable filter reported here comprises N cascaded Mach-Zehnder (MZ) interferometers and an amplified ring resonator (ARR). A diagram can be seen in Figure 1. MZ zeros are properly located to cancel some ARR poles in order to obtain a certain full device FSR, named FSR_T. Number of MZ, N, depends on FSR_T demand. FSR and physical lengths of different elements, see Fig.1 follow that:

$$FSR_T = 2^{N-1} \times FSR_N = 2^{N-2} \times FSR_{N-1} \ldots = FSR_1, \quad FSR_{ring} = FSR_N \qquad \text{So } \Delta L_2 = 2 \times \Delta L_1; \ \Delta L_N = 2^{N-1} \times \Delta L_1, \ L_{ring} = \Delta L_N \qquad (1)$$

Complexity increases for greater FSR_T, but ring resonator length limitation due to bend losses is overcome while preserving their advantages: narrow FWHM, reconfiguration, tuneable. MZ coupling coefficients Kij, where i denotes MZ number from 1 to N and j=1 or 2 to discriminate between two couplers in each MZ, are set to 0.5 to have zeros at desired wavelengths. Ring resonator gain, $G^* = G \cdot e^{-2\alpha Lr}$, coupler excess loss γ, and any power transfer function $F(\lambda)$ inside ring resonator, allow to reconfigurate filter behaviour. If we define: $H(\lambda) = (G^* \cdot (1-\gamma) \cdot F(\lambda))^{1/2}$, different application can be accomplished depending on $H(\lambda_0)$ values (where λ_0 is the channel wavelength):

-if $H(\lambda_0) > 1$ device behaves as a demultiplexer at output ports

-if $H(\lambda_0) < 1$ devices operates as a router $\qquad (2)$

Ring resonator coupling coefficient Kr, while operating in stable region, can be selected depending on desired FWHM. As indicated before, FSR limits number of channels in FDMA networks. MZ cascading allows increasing FSR but MZ number, N also increases. One method to solve this problem is including non-periodic bandpass filter as the one shown in Fig. 2, which consist on a 3dB coupler and two equals BG. This section can be inserted in ring resonator loop as reported in [4] for an integrated structure.
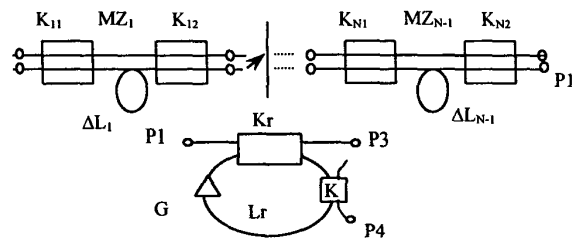
Figure 1: Filter schematic

Final novel non-periodic device concatenates tuneable filter of Fig.1 and bandpass filter. A specific case for N=2 is reported in Fig. 2.

Tuning process is done in two stages. Coarse tuning involves selection of transfer function maximum transmission power wavelength (MTPW) and it is reached by means of shifting BGs central wavelength [4]. Second step involves tuning ARR resonant frequency, which can be done with a piezoelectric device (PZT) [5].

Channel location, λ_p can be selected at desired wavelength, properly selecting ring resonator length as an integer multiple M of λ_p:

$M \cdot \lambda_p = n_{eff} L_{ring}$, n_{eff} is ARR effective refractive index $\quad (3)$

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Specific demultiplexer design

Compact fibre based tuneable filter can be obtained if erbium doped fibre is used to implement the ARR. Minimum ring resonator fibre length depends on critical radius to avoid bend losses and minimum required gain. Fibre Gratings Bandwidth, FGB are typically at best at 0.1nm range so this value is selected. For obtaining adequate cross talk (CT) defined here as the relation between ximum secondary channel to gain at MTPW channel (we choose the worst case of gain at secondary channel as 1, as can be appreciate in the inset of fig. 4.b):

$$FGB \leq 3 \times FSR_{ring} \qquad (4)$$

So ARR must be designed with $FSR_{ring} \geq 0.033$ nm, L_{ring} is selected taking into account previous constraints and considering channel location at a wavelength compatible with normalised frequency grid proposes by ITU. Depending on application a certain CT would be required along with a specific FWHM. To help process design, curves of CT and FWHM versus design parameters K, G* are reported in Figure 3.a and Fig.3.b respectively at port P3. We want to design a demultiplexer so equation (2) imposes a restriction on possible G* parameter. On the other hand, our goals are to have a CT around 20dB and FWHM of 50 MHz. We have a commitment between FWHM and CT, as can be seen in Figs.3. But a low gain, G=3.18, is chosen. So K= 0.65, value far away from inestable operation. Those parameters imply a demultiplexer with 20 dB CT, 50 MHz FWHM, and a net gain on selected channel of 20 dB, at port 3. Fabrication tolerances can be corrected by tailoring G through pump power levels and if necessary variable coupling coefficient couplers can be used. Full FSR_{ring} can be tuned via PZT actuation. FGB is modified by thermal or piezoelectric effects [6]. At this last case total continuos tuning range of 1.3 nm were previously obtained. Frequency shift of around 1GHz/K at 1.55 μm window will affect frequency channel demultiplexer location so thermal stabilisation should be provided.
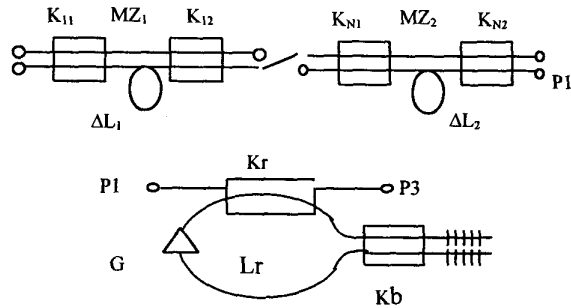
Figure 2: Non-periodic filter diagram.

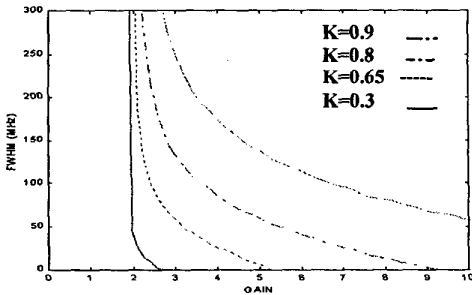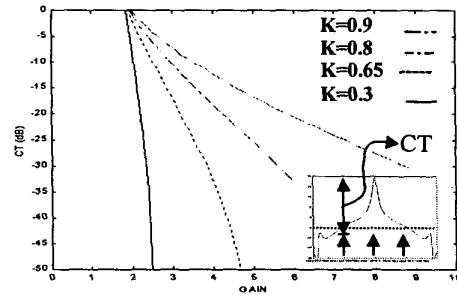**Figure 3.a. FWHM versus G* and K at Port P3.**

Figure 3.b. CT versus G* and K at Port P3.

Conclusions

A novel tuneable filter has been presented. A practical design as a demultiplexer to operate in FDMA networks with channel locations compatible with ITU standards is reported. It has a FWHM of 50 MHz, a 1.3 nm tuneable range and net gain of 20 dB on selected channel. The present device has the potential of being integrated as a building block in large, multifunctional chips using semiconductor optical amplifiers, implementation can also be realize in fiber technology.

Acknowledgements

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