Amplified spontaneous emission rejection with multi-functional MEMS tunable filter


A multi-functional microelectromechanical system (MEMS) tunable optical filter as an amplified spontaneous emission (ASE) rejection filter in an optical communication system is presented. The MEMS tunable filter can tune both the centre wavelength and the passband independently and continuously in C-band. This filter was applied to a 10 Gbit/s system and system-performance improvement by adjusting the amount of ASE noise rejection was observed.

Introduction: In wavelength division multiplexing systems, effective wavelength selection and ASE rejection are very important for overall system performance. A key component enabling dynamic wavelength provisioning and optimum signal-to-noise ratio (SNR) in the optical domain is the tunable optical filter. Among several technologies implementing tunable optical filters, optical MEMS technology has shown particular promise by enabling independent and precise tuning of both the centre wavelength and the passband [1–5]. However, optical MEMS filters based on micromirror arrays only provide discrete tuning of the centre wavelength and the passband [2, 3], and earlier reported filters with continuous tuning [1] put limits on aperture size that result in clipping losses. To overcome these problems, we have demonstrated a multi-functional MEMS tunable optical filter that provides precise, continuous and independent control of both the centre wavelength and the passband [5]. In this Letter we investigate the performance of this MEMS tunable filter as an ASE rejection filter in optical communication.

Filter design: The MEMS spatial light modulator (SLM) (Fig. 1a), at the core of our tunable optical filter, is based on MEMS platform technology. Gold-coated mirrors are micro-assembled on movable MEMS platforms to create the SLM. The SLM tunes the optical bandwidth and the centre wavelength by actuating bidirectional lateral combdrive actuators. The actuators have a maximum displacement range of 44 μm in both directions, thus achieving the total displacement of 88 μm. The mirrors of the SLM extend out of plane, so the light path is never interrupted by underlying actuators, resulting in improvement of insertion loss.

Fig. 1 Microscope image of MEMS SLM and schematic diagram of MEMS tunable optical filter

The schematic diagram of the multi-functional tunable optical filter is shown in Fig. 1b. It consists of a MEMS SLM, a circulator, an f = 20 mm Fourier lens, a ruled grating with 900 gro/μm, and a fibre beam collimator with ~1.76 mm beam diameter. The light from the input/output fibre is collimated and dispersed by a diffraction grating. The angularly dispersed light is then focused on the MEMS SLM through a Fourier lens. A set of spatially distributed wavelengths reflected from the fixed-back mirror traces back through the optical system and couples into the input/output fibre. All other wavelengths are incident on the blocking mirrors and are deflected out of the system. Therefore, the centre wavelength and the passband can be precisely adjusted by actuating the blocking mirrors. The SLM can tune the 3 dB bandwidth from 0.3 to 1.5 nm while changing the centre wavelength within the entire C-band [5].

Fig. 2 Tunability of MEMS filter with precise channel control

ASE rejection: The performance of the optical communication system is studied by measuring the bit error rate (BER) while varying the filter passband, which controls the amount of rejected ASE noise. The bit error is caused by electrical and optical noise sources. The electrical noise includes shot noise and thermal noise of the preamplifiers in the receiver, while the optical noise includes laser relative intensity noise (RIN) and ASE noise of the optical amplifiers. The total noise in the optical receiver can be expressed as follows:

\[ N_{\text{total}} = N_{\text{shot}} + N_{\text{thermal}} + N_{\text{RIN}} + N_{\text{ASE}} \]  

Among these noise components, the ASE noise can be controlled using the optical filter. Assuming that the signal line-width is much narrower than the bandwidth of the optical filter and that the ASE noise spectrum is flat over the spectral range of interest, the optical signal-to-noise ratio (OSNR) can be approximated as:

\[ \frac{P_s}{P_{\text{ASE}}} \approx \frac{1}{B_s} \frac{P_s'}{P_{\text{ASE}}'} \]

where \( B_s, P_s, P_s', P_{\text{ASE}} \) and \( P_{\text{ASE}}' \) are the bandwidth of the optical filter, the filtered signal power, the input signal power, the filtered ASE power, and the input ASE power in units of power per unit-wavelength, respectively. Equations (1) and (2) illustrate that a narrower filter bandwidth results in improved system performance, as is well known.

Fig. 3 shows the experimental setup to investigate the bandwidth-dependent system performance using the MEMS tunable filter. The bit rate and the pattern are a 10 Gbit/s (non-return-to-zero) and pseudorandom bit sequence of length \( 2^{23} - 1 \), respectively. To adjust the OSNR, an ASE source (i.e. an erbium-doped fibre amplifier) and a variable optical attenuator are added as shown. A short length of optical fibre is used in order to investigate only the bandwidth-dependent system performance.

Fig. 3 Experimental setup to investigate bandwidth-dependent system performance

To observe the performance improvement gained by using the MEMS filter, we measured the BER values with and without the filter after setting the bandwidth to 0.5 nm (Fig. 4). For the signal with 25 dB OSNR, the power penalty for no filtering is 1.5 dB at the BER of 10⁻¹². The 25 dB OSNR is for the signal before filtering, and it is measured by an optical spectrum analyser (OSA) with 0.1 nm resolution. Because the OSA resolution is narrower than the filter bandwidth, OSNR is almost the same after filtering. For the signal with 20 dB
OSNR, only the filtered signal can be detected, while the information in the unfiltered signal is lost owing to low SNR in the receiver.

Using the tunable optical filter, we also investigated system performance against filter bandwidths. Fig. 5 shows the relationship between the BER and the 3 dB bandwidth. At a centre wavelength of 1549.99 nm, the filter bandwidth is swept from 0.5 to 1.5 nm, resulting in BER increases from $1.7 \times 10^{-7}$ to $2.1 \times 10^{-6}$. This result indicates that the bandwidth of the ASE rejection filter is one of the most important factors in the determination of system performance, as predicted by (2).

Conclusion: We have demonstrated a multi-functional MEMS tunable optical filter as an ASE rejection filter in a 10 Gbit/s optical communication system. The centre wavelength and the passband of this MEMS optical filter can be precisely and continuously controlled to support the channel spacing for dense WDM in C-band. With the optical filter, ASE noise is effectively rejected, resulting in improvement of the BER.

References