LCOS-based Gridless Wavelength Blocker Array for Broadband Signals at 100Gbps and Beyond

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Abstract: We demonstrate a gridless wavelength blocker array for advanced broadband signals, which is characterized by ultra-wide passband and sub-GHz frequency control. The 0.5dB-passband and frequency setting resolution for 50-GHz systems are 40 GHz and 0.2 GHz, respectively.

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1. Introduction

To meet ever-increasing demand for network capacity, both the spectral efficiency and symbol rate carried by a single channel have been increasing dramatically. As a promising candidate, high-order quadrature amplitude modulation (QAM) format with multiplexing schemes such as time division multiplexing (TDM) and orthogonal frequency division multiplexing (OFDM) has been widely researched and the symbol rate reaches up to 400 Gbps per channel [1]. In general, such high speed broadband signals become more sensitive for bandwidth narrowing caused by cumulative filtering in concatenated reconfigurable optical add/drop multiplexer (ROADM) nodes [2]. On the other hand, flexible bandwidth networks have also been proposed as a spectrally efficient networking technology, which effectively supports dynamically varying traffic demands. The flexible bandwidth networks allow us to deal with the mix of various traffics with arbitrarily variable symbol rates and modulation formats, which are not only 10 Gbps legacy channels but also core traffic channels over 100 Gbps. In such networks, bandwidth and frequency variable gridless ROADM components play an important role. In this paper, we demonstrate a liquid crystal on silicon (LCOS) based gridless wavelength blocker (WB) array for flexible bandwidth networks handling advanced broadband signals, which is characterized by ultra-wide clear passband and sub-GHz fine tuning of center frequency. To our knowledge, this is the first demonstration of gridless ROADM filters with super-Gaussian transfer function of order n=6.

2. Design of filter shape

Figure 1 shows the idealized filter shapes defined as a super-Gaussian transfer function for a 50-GHz ROADM filter. The filter transfer function is expressed by

$$ IL[dB] = 10 \cdot \log\left[\exp\left(-\ln(2) \cdot (2 \cdot \Delta \nu / BW)^{2n}\right)\right] $$

where $IL$, $\Delta \nu$ and $BW$ is the relative insertion loss in decibels, frequency detuning from the channel center frequency and 3dB-passband width, respectively. $n$ is the Super-Gaussian order parameter and higher $n$ means an excellent filter shapes with steeper falling edge and wider flat passband section.

![Fig. 1. Super-Gaussian transfer function of order n=1, 2, 4 and 6 for 50-GHz WDM systems. 3dB-passband widths are set to 50GHz.](image1)

![Fig. 2. Schematic diagram of gridless wavelength blocker array.](image2)
The passband shape with \( n=4 \) is typical for current wavelength selective switches (WSS) using free-space optics. As a means to evaluate the expected passband tolerance in the field, we need to consider the passband narrowing due to passing thorough multiple ROADM nodes. According to references [2-3], ROADM filters with a super-Gaussian order \( n=6 \) become target criteria for broadband signal transmission over 100 Gbps under concatenating of multiple ROADM nodes. Figure 2 shows the optical geometry for LCOS-based gridless wavelength blocker array [4]. The spectrometer block, consisting of transform lens and dispersive element, disperses the wavelength division multiplexing (WDM) channels spatially and project onto channel-by-channel different LCOS pixels. We adopt a 4-f imaging system consisting of a pair of condenser and transform lens, which disperses wavelength in X-axis and split different ports along Y-axis enabling array function. Here, we also define the figure of merit \( \xi \) in order to give the design guideline of ROADM filter shapes [5]. The dimensionless factor \( \xi \) is defined by

\[
\xi = \left( \frac{\nu_{ch} \cdot dx/d\nu \cdot 2 \cdot a_0 \cdot M}{\omega_0} \right)
\]

where \( \nu_{ch} \), \( dx/d\nu \), \( a_0 \) and \( M \) is the WDM channel frequency spacing, the spectral frequency dispersion on LCOS plane, the Gaussian mode field radius of the beam from single mode fiber and the magnification factor of the imaging system, respectively. The factor \( \xi \) expresses how well the Gaussian mode is confined within the channel selector and reflects the passband performance. Thus, the passband performance can be controlled by varying the ratio of the channel selector width to the magnified Gaussian mode size on image plane. We adjust the GRISM geometry and magnification of anamorphic prism as \( \xi \) becomes 6.7 for 50-GHz WDM systems, which corresponds to the filter shape of Super-Gaussian order \( n=6 \). The designed \( dx/d\nu \) and \( M \) was 1.8 \( \mu \)m/GHz and 1.27, respectively. In addition, especially when liquid crystal (LC) switching elements are used for ROADM filters, we have to consider the distortion of filter edge due to a fringing-field effect. As a rule of thumb, the width of fringing-field effect is proportional to the LC layer thickness and thus thinner LC layer is helpful for high order filter shape [6]. We minimized the LC layer thickness with high birefringence LC.

3. Filter performance of WB array

Figure 3 shows filter transmission profiles of 12 input/output ports WB array and typical WSS using free-space optics for 50-GHz WDM systems. The WB’s filter shape corresponds to super-Gaussain transfer function of order \( n=6.0 \) and shows steeper falling edge and wider passband compared to conventional WSS’s. The 0.5dB- and 3dB-passband was 41 GHz and 49 GHz, respectively. The total insertion loss is less than 6 dB across the entire C-band and extinction ratio of better than 40 dB was obtained. Figure 4 shows the insertion loss and polarization dependent loss (PDL) profiles at attenuation (ATT) settings of 0, 6, 10 and 15 dB. Measured PDL within the standard clear passband of +/-12.5 GHz for 50-GHz systems was less than 0.15 dB. In addition, the PDL within +/-20GHz was less than 0.2 dB, which is evident that the proposed WB has wider tolerance for advanced broadband signals such as 100 Gbps formats and beyond. Figure 5 shows bandwidth variable operation from 10 GHz to 120 GHz by 10 GHz increment thorough firmware control. The bandwidth can be tuned without significant filter shape distortion or degradation of insertion loss and low PDL performance is maintained over any bandwidth setting. A center frequency detuning as well as a passband narrowing is also critical factor restricting broadband signal transmission under concatenating of multiple ROADM nodes. The center frequency variation may arise from component imperfection, misalignments under manufacturing process, or external stress. Conventional ROADM components

![Fig. 3. Filter passband profiles of santec WB and typical WSS for 50-GHz systems. Inset shows entire profiles including blocking band.](image)

![Fig. 4. Insertion loss and PDL at ATT settings of 0, 6, 10, and 15dB.](image)
can not correct these errors if the variations arise after installing to the network systems. However, gridless function enabling precise frequency control supports an error-correcting of the variations in real-time. Figure 6 shows the bandwidth variable operations with minimum setting resolution of 0.2 GHz. In general, the minimum setting resolution is limited by the product \( (d \cdot d\nu/dx) \) between a LCOS pixel pitch \( d \) and reciprocal linear dispersion \( d\nu/dx \) on LCOS plane, which is 4.7 GHz for the proposed WB. For higher setting resolution, we adopt an original LCOS driving method that applies adequate multilevel voltages not only to the designed pixels but also to its adjacent appropriate pixels at the same time.

**4. Conclusions**

We demonstrated LCOS-based gridless WB array for advanced broadband signal transmissions, which is characterized by ultra-wide passband width and sub-GHz fine tuning of center frequency. The 0.5dB-passband width was over 40 GHz and the filter shape corresponds to transfer function with super-Gaussian order of \( n=6 \). And the precise frequency control of 0.2 GHz resolution was also demonstrated with original LCOS driving method. The performance of WBs is much tolerable for filter bandwidth narrowing in multi-ROADM networks and allows us to expand the amplifier span and applicable number of ROADM nodes. Proposed concept will contribute to the realization of intelligent next generation ROADMs with colorless, directionless, and wavelength contentionless capabilities.

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**5. References**


