Wavelength Converters in Optical Communication Systems

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***Abstract* - Wavelength conversion employing semiconductor optical amplifiers (SOAs) has become an important function in WDM networks. This paper gives introduction to different available wavelength conversion techniques and provides the comparative performances of the three most popular SOA wavelength conversion techniques: cross-gain modulation (XGM), cross-phase modulation (XPM) and four-wave mixing (FWM).The cross gain modulation scheme shows that there is degradation in extinction ratio for conversion to longer wavelengths. This can be overcome by using cross phase modulation in semiconductor optical amplifiers that are integrated into interferometric structures.**

***Keywords:* Wavelength converter, WDM, SOA,XGM,XPM,FWM, cross connect.**

1. INTRODUCTION

All Optical wavelength converters are expected to become key components in the future broadband networks. Their most important use will be for avoidance of wavelength blocking in optical cross connects in wavelength division multiplexed (WDM) networks[1],[2]. Thereby the converters increase the flexibility and the capacity of the network for a fixed set of wavelengths The potential of wavelength converters has already been demonstrated in a number of system experiments. Wavelength conversion is a very useful function in advanced optical systems. The requirements to the converters will be system dependent, the converters should have the following features:

- Bit-rate transparency (up to at least "10 Gb/s").
- No extinction ratio degradation.
- High signal-to-noise ratio at the output (to ensure cascadability).
- Moderate input power levels (~ "0 dBm").
- Large wavelength span for both input and output signals.
- Possibility for same input and output wavelengths (no conversion).
- Low chirp.
- Fast setup time of output wavelength.
- Insensitivity to input signal polarization.
- Simple implementation.

2. NEED OF WAVELENGTH CONVERTER

Since few years ago wavelength division multiplexing (WDM) has been an effective solution to increase traffic flow in optical communication networks. In spite of the theoretical huge bandwidth of an optical fiber [3], it is common to find that there are not enough different wavelengths to satisfy the requirements of the whole system. The same wavelength then could appear in the same path. To avoid this problem it is necessary to use wavelength conversion, which is a technique to convert one signal from an original wavelength λ_1 to a different objective wavelength λ_2. This process is performed using a device called wavelength converter (WC)[4].

Consider the portion of the network in Fig. 2(a). Two light paths have been established in the network: 1) between node 1 and node 2 on wavelength and 2) between node 2 and node 3 on wavelength . Now, suppose a light path between node 1 and node 3 must be set up. If there are only two wavelengths available in the network, establishing such a light path from node 1 to node 3 is now impossible even though there is a free wavelength on each of the links

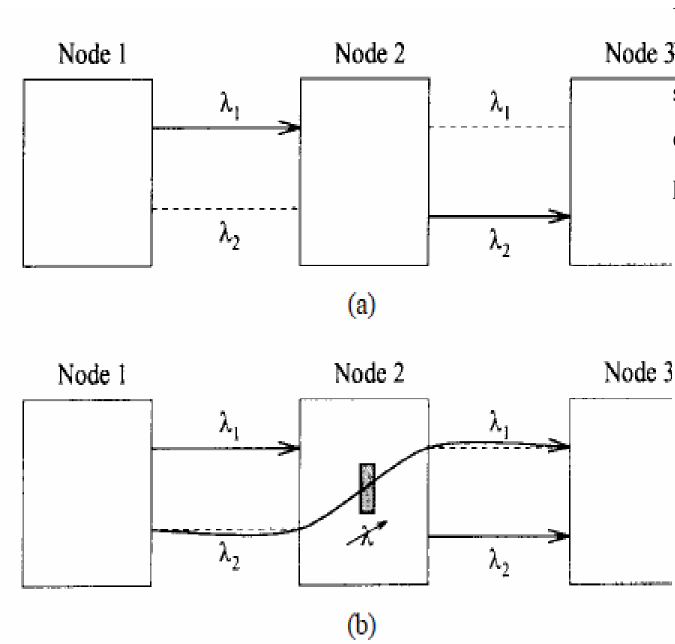


Fig. 2. Wavelength-continuity constraint in a wavelength-routed network: (a) without converter and (b) with converter.

along the path from node 1 to node 3. This is because the available wavelengths on the two links are different. Thus, a wavelength-continuous network may suffer from higher blocking as compared to a circuit-switched network. It is very easy to eliminate the wavelength-continuity constraint if we are able to convert the data arriving on one wavelength along a link into another wavelength at an intermediate node and forward it along the next link. Such a technique is feasible and is referred to as wavelength conversion.

3. WAVELENGTH CONVERTER TYPES

The converters are of four types: 1) Opto-electronic converters; 2) Laser converters; 3) Coherent converters 4) Converters based on optically controlled optical gates.

3.1 Opto-Electronic Converters

Several techniques have been proposed to achieve wavelength conversion. The straight forward solution is an electro-optic converter consisting of a detector followed by a laser that retransmits the incoming signal on the new wavelength. Disadvantages of the electro-optic converter such as complexity and large power consumption [4].

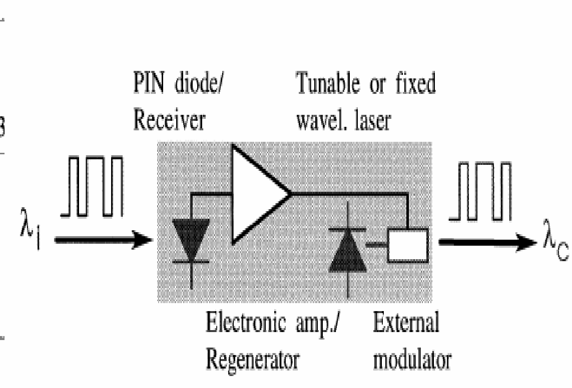


Fig. 3.1:- Schematic of opto-electronic converter.

3.2 Laser Converters

All-optical wavelength conversion can be performed in a very simple way by optical control of single frequency lasers as shown in Fig.3.2. The input signal (λ_i) to be converted is launched into the laser where it causes gain saturation that controls the oscillation of the laser. The result can be either IM or CPFSK output formats depending on the operation of the laser . The lasing wavelength (λ_c) is either fixed or electronically tunable depending on the system requirements.

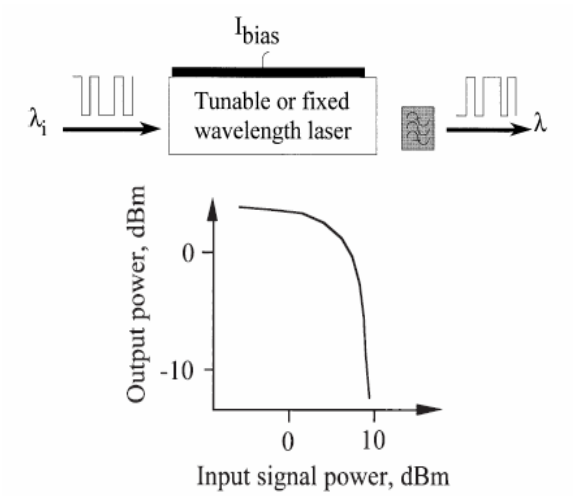


Fig.3.2:-Principle of wavelength converters based on semiconductor lasers together with schematic of output versus input power characteristic for laser converter.

Note, that the laser converter basically consists of a single component, so it is conceptually simple. Its optical input power requirements are “0-10 dBm”, but unless a special waveguide design is implemented for the gain section of the laser, it is polarization dependent .Moreover, the maximum bit rate, determined by the laser's resonance frequency, is limited to around “10 Gbit/s” [5]. Because of the speed limitation, laser converters are less interesting.

3.3 Coherent Converters

Under these types of Converters four wave mixing (FWM) using semiconductor optical amplifiers (SOAs) converters falls. The scheme is inherently fast for both fiber and semiconductor nonlinear elements. The converters can handle all signal modulation formats in contrast to other types of converters that are more suited for IM input signals[7].The conversion efficiency is normally low (typically around “-20 Db”), so optical power levels of ~10dBm have to be used for the pump of SOA converters while “10-20dBm” is needed for fiber based converters. Because of the low conversion efficiencies the signal-to noise ratio for the converted signals needs attention, especially if converters have to be cascaded. Experiments using SOA converters with very long cavities have, however, resulted in conversion efficiencies approaching 0 dB [8], thereby making FWM more attractive.

A serious drawback for the FWM converter is the dependency of the output wavelength on both the pump (λ_p) and the input signal (λ_i) wavelengths, so the pump must be tunable even for converters with fixed output wavelength. Moreover, two pumps will be needed to ensure polarization insensitive operation [8].

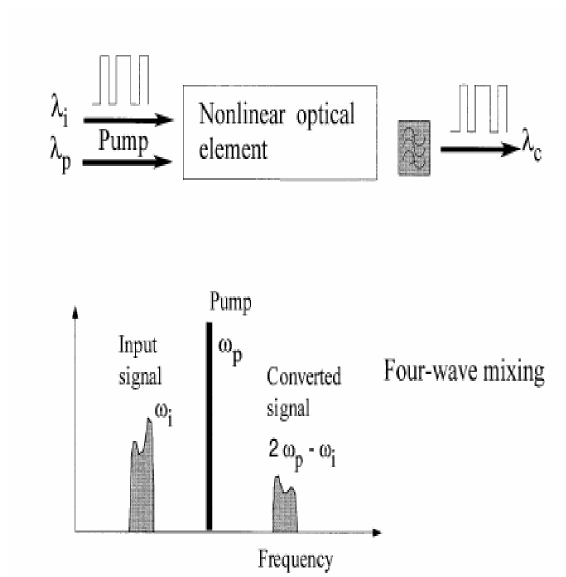


Fig. 3.3:- Schematic of conversion in nonlinear element using four-wave mixing.

3.4 CONVERETERS BASED ON OPTICALLY CONTROLLED GATES

These types of wavelength converters are: Semiconductor optical amplifiers (SOA's) used in the cross gain modulation (XGM) mode or the cross phase modulation (XPM) mode .

The conversion speed is determined by the carrier dynamics that are governed by the relative slow interband carrier recombination's [10]. Simple guidelines for achieving high bit rate conversion is to operate the SOAs with:

1) Large current injection
2) High optical power levels

Moreover, the SOA waveguides should have following characteristics:

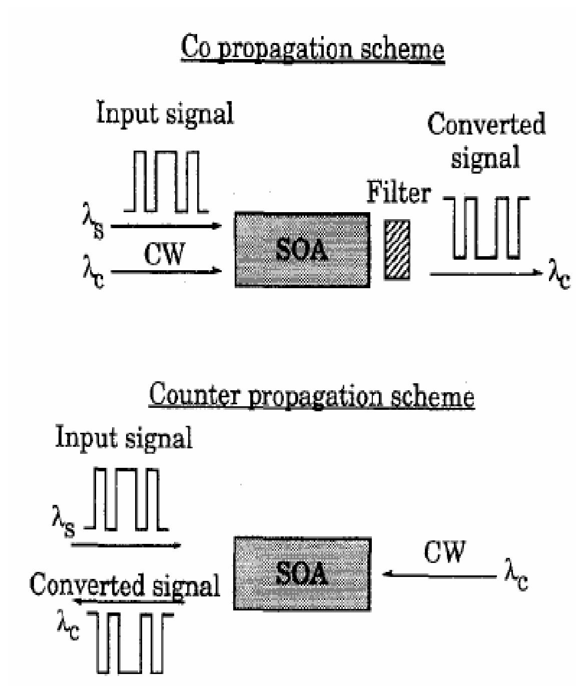
3) Large optical confinement factors
4) Large differential gain

Since the allowed injection current is limited the conversion speed can also be increased using longer cavity lengths.

3.4.1 XGM SOA CONVERTERS

(a). Basic Characteristics

An all optical wavelength converter is a device that transfers information from one wavelength to another without entering the electrical domain. A simple technique for the realization of this function **is** the use of cross gain modulation (XGM) in semiconductor optical amplifiers (SOA's). The principle is depicted in Fig. 3.4.1(a)[9] [11] showing an intensity modulated input signal that modulates the gain in the SOA due to gain saturation. A CW signal at the desired output wavelength is modulated by the gain variation, so after the SOA it carries the same information as the intensity modulated input signal. As shown the input signal and the CW signal can be launched either CO- or counter directional into the SOA. In the latter case the output filter, that is needed for the co-propagation scheme, can be avoided and it is possible to convert to the same wavelength. The XGM SOA converter is polarization independent .Such amplifiers with high fiber-to-fiber gain are now fabricated in many laboratories. Fig. 3.4.1(b) gives an example of measured waveforms for input- and converted-signals at 10 Gb/s. As noted the XGM scheme gives a wavelength converted signal that is inverted compared to the input signal.



(a)

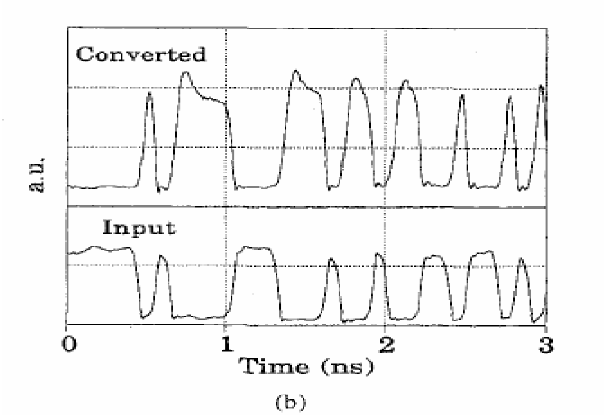


Fig. 3.4.1. Schematic of the CO- and counter-propagation XGM wavelength conversion principle (a) and measured waveforms for the converted signal (co-propagation) and the input signal at 10 Gb/s (b). The measurements are performed with a 1200 pm long SOA.

3.4.2 XPM SOA CONVERTERS

To overcome the problems with extinction ratio degradation for the XGM scheme, the SOA converter can be used in a cross phase modulation (XPM) mode [13]. The XPM scheme based on the dependency of the refractive index on the carrier density in the active region of the SOA. An incoming signal that depletes the carrier density will modulate the refractive index and thereby result in phase modulation of a CW signal(wavelength λ_c) coupled into the converter. The phase modulated CW signal can be demultiplexed after the converter or even better the SOA can be integrated into an interferometer so that an intensity modulated signal format results at the output of the converter[14.]

The XPM scheme has the distinct feature that the converted signal can be either inverted or noninverted compared to the input signal depending on the slope of the demultiplexer (e.g., the interferometer slope used in the Mach-Zehnder configuration). Normally, it is advantageous for the converted signal to be noninverted (same polarity).

From Fig.3.4.2(b). The XPM conversion scheme has the advantage of being very power efficient compared to the XGM scheme. Because of the small gain modulation the XPM scheme offers converted signals with a narrow spectrum compared to the XGM scheme. A narrow spectrum for the converted signal is attractive because it allows transmission over long distances. Moreover, the spectral crosstalk is reduced in, e.g., WDM demultiplexers.

As an example, structures for Mach-Zehnder interferometric converters are shown in Fig. 3.4.2. The SOA's are placed in asymmetric configurations so that the phase change in the two amplifiers is different.

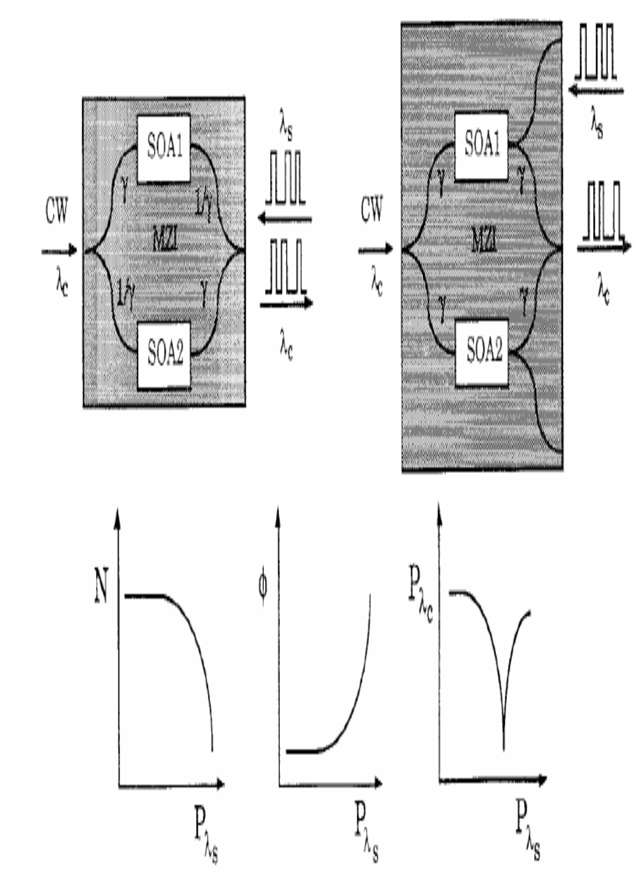


Fig. 3.4.2. Schematic and principle of operation for interferometric wavelength converters based on XPM in SOA's. (a) Asymmetric

MZI wavelength converter. b) Symmetric MZ1 converter with additional coupler for the input signal.

As a consequence, the CW light is modulated according to the phase difference. In the first configuration in Fig. 3.4.2(a), asymmetric splitters ensure that an intensity dependent phase difference is achieved between the interferometer arms due to the different saturation of SOAl and SOA2. In the second configuration in Fig. 3.4.2(b), the MZI is formed by symmetric splitters and the input signal is fed to only one of the SOA's through an additional coupler. The saturation is asymmetric since the other SOA is not affected by the input signal power. The converter could also be constructed with only one amplifier in one of the interferometer arms , but this scheme gives less output power and will be sensitive to changes in the polarization of the CW signal. Besides wavelength conversion the interferometric SOA configurations are also very well suited for all optical demultiplexing. Moreover, it should be noted that the converters also feature polarization conversion since an arbitrarily polarized input signal is converted to the polarization state of the CW-light source.

CONCLUSION

Wavelength converters offer numerous advantages which will benefit engineers in many future all-optical applications. In this paper, SOA wavelength converters employing XGM, XPM and FWM techniques have been extensively analyzed. It is shown that FWM has the lowest conversion efficiency as compared to XGM and XPM[14].

In terms of extinction ratio, we found that it remains practically constant as function of the bit rate. However, in contrast to Quality factor, there is an increase in the average input power of the injected signals that reduces the extinction ratio. This means that a trade-off between Q and extinction ratio.

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