Add/Drop in Subcarrier Multiplexed Optical Networks

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ABSTRACT

The realisation of the add/drop functions in the subbcarrier multiplexed (SCM) optical networks is a relevant problem. Namely branching one channel (a microwave subcarrier with information) is difficult without attenuating the other channels. The application of Semiconductor Optical Amplifiers (SOAs) means a smart answer for this question. An experimental and theoretical study will be presented for the transmission and noise characteristics and application possibilities of SOAs.

Keywords: Semiconductor Optical Amplifier, Subcarrier Multiplexed Optical System, Add/Drop function, Theoretical and experimental analysis, Noise and optical gain properties

1. INTRODUCTION

The optical loss is high in case of very long optical link or usage of several optical dividers in the relatively short optical way. For example in a mobile communication system [1] and in broadband fibre-radio networks [2] the optical link can be used for distributing the radio-frequency signals to different base stations. The distribution network contains optical power splitters, which introduce considerable losses into the system. Hence, some optical amplifiers may be needed to compensate these optical losses. In practice three traditional applications of optical amplifier are used. In first method, SOAs operate as a post-amplifier to optical transmitter. In a non-regenerative repeater the incoming optical signals are directly amplified and so this process compensates the fiber loss. Finally, the SOA can be used as a pre-amplifier to the receiver, it can amplify the incoming weak signal, thereby improving the sensitivity of receiver. On the other hand the SOAs means very good accomplishment in the branching functions as you can see in the following. The studies of noise and gain properties of the devices are important for these applications.

2. NOISE PROPERTIES OF SOAS

The spontaneous emission is the main source of noise in semiconductor optical amplifier and it is a random process, which is statistically stationary and will cause fluctuations in both amplitude and phase of optical signal. In addition, the spontaneous emission photons can interact directly the signal. It means that the optical output from optical amplifier is composed of an amplified optical signal and an amplified spontaneous emission (ASE) of a broad spectral width. Moreover interference is created between ASE components and light signal [3]. So several types of noises (the shot noise of the signal and spontaneous emissions, beat noise between signal and spontaneous emissions, beat noise between spontaneous emissions components and excess noise due to incoherence of the input signal) can be observed, when the output photons are detected by a photodetector. [4]

Some types of semiconductor optical amplifiers were measured in the experiments. The typical graphs will be showed in presentation.

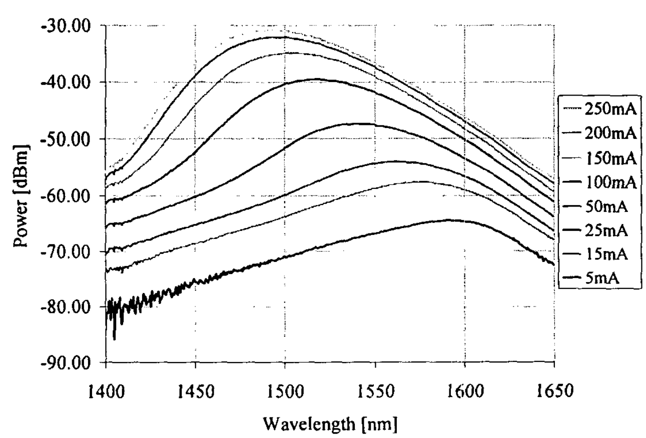


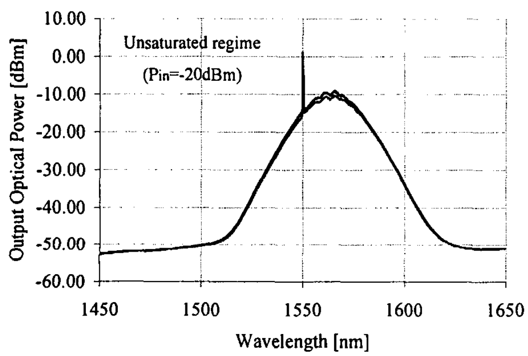
Figure 1. ASE spectrum versus bias current.

The main noise source is the amplified spontaneous emission. The ASE spectrum has a finite bandwidth and changes as a function of the electrical bias current (Fig. 1). The ASE increases when the bias current increases, since the population inversion, which causes the spontaneous emission becomes higher. And we can observe at same time, that the maximum of the ASE spectrum is shifted to the lower wavelength and the bandwidth changes when the bias current increases.

3. GAIN PROPERTIES OF SOAS

The optical gain depends on the bias current, a minimum injection current is necessary for providing population inversion for suitable optical amplification. Naturally, the optical gain is not the same for all frequencies of the input signal, the typical optical gain spectrum has a finite bandwidth, because of the waveguiding action of SOAs and the finite bandwidth of the material gain.

Naturally, a finite range of input and hence output power also limits the signal gain of an optical amplifier. If the input power to the SOA is increased, once the gain starts to drop. This is the gain saturation effect, which can be observed in the amplified spontaneous emission spectrum, too. In the case of small signal amplification, that is the input optical power is low, the ASE spectrum is not affected by input signal. Important difference between the ASE spectrum with and without small input signal is not observed (Fig. 2.a,). On the other hand the input signal has essential influence on the ASE spectrum in the saturated regime. The ASE spectrum decreases when the input optical signal increases as you can see in the Fig. 2.b. The reason is not to complicate since as we increase the input power, a point arrives where a rate of draining due to amplification is greater then the rate of pumping, such the population inversion level starts to fall. However, the spontaneous emission is proportional with the level of population inversion, hence the ASE decreases. The noise is less, but the optical amplification is also smaller and the nonlinearity of the operation is higher than in the unsaturated region.



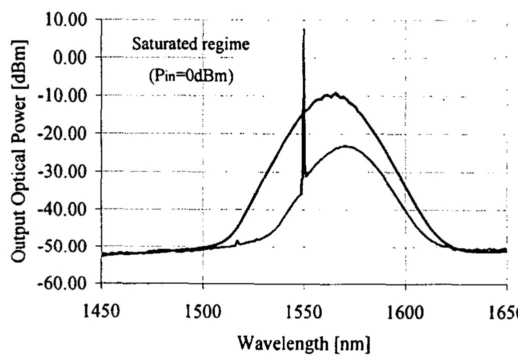


Figure 2. Optical spectrum in unsaturated and saturated regime

4. APPLICATIONS OF SOAS IN SCM OPTICAL SYSTEMS

There are several interesting applications of SOAs in subcarrier multiplexed (SCM) optical networks. For instance the SOA can be used as a gating optical switch, there are two operational mode ("on" when pumping is on and "off" when pumping is off). Similarly the amplifier can be used as an external optical modulator. In this case the electrical bias current is modulated, so the material gain and the gain of the amplifier consequently the intensity of the output power will be modulated. In this way a modulator is developed, which can be integrated easily with the laser source (because of the same material and technology). Fig. 3. demonstrates the modulation working mode of a SOA. Namely, the diagram presents the detected electrical power in case of intensity modulated light by SOA versus at a given working state and input optical power with different modulation power.

The nonlinearity of the device in this operation mode is an interesting parameter. There are several phenomena which cause distortion in intensity modulated optical systems. As the number of carrier increases the linearity become more and more serious because many third order mixing products appear in the used band. The nonlinearity depends on many things: bias current, temperature, structure of SOA, input optical power and last but not least the optical reflection which is very important. There are several possibilities to test the non-linearity of two port circuits. For characterizing the level of third order nonlinearity in a given application the third order intercept, IP_3 is used. The figure of merit when the nonlinearity is investigated together with noise is the spurious free dynamic range, SFDR. In the experiments the semiconductor optical amplifier was biased and modulated by the two microwave signal. The output signal levels were measured for both the fundamental (P_1) and the third harmonic mixing products (P_3). In addition, the non-linearity can be tested utilising the spectrum measurement method. It applies two input signals, one of them is much smaller than the other one.

The high power large signal is used to drive the circuit into the non-linear regime and the small signal is used to get information about the non-linearity. The small signal can be considered as a sideband of the large signal. Based on this approach the AM Compression and AM-PM conversion can be computed.

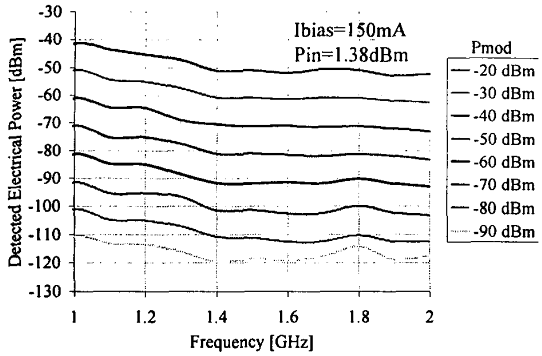


Figure 3. Modulation with SOA

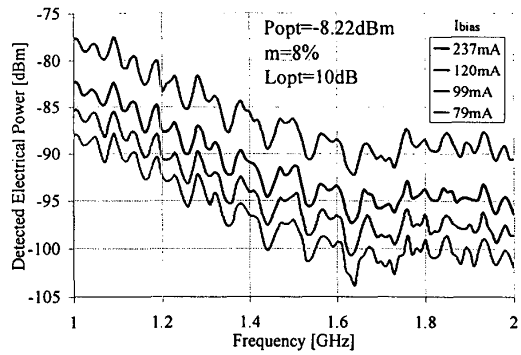


Figure 4. Detection with SOA

On the other hand the SOA can detect the intensity of the light (the electrical current is proportional to the optical intensity). If the input signal is intensity modulated, the fluctuation in the optical intensity due to modulation will induce fluctuation in the injection current. So this current fluctuation can be detected and the SOA becomes an in-line detector/monitor. Naturally the sensitivity of SOA as a detector is smaller than the sensitivity of a traditional optical detector (for example a pin photodiode), but this device can detect and gain the incoming weak intensity modulated optical signal at same time. Fig. 4. shows the detected electrical power by SOA versus modulation frequency in case of different bias current. When the bias current increases, i.e. the population inversion and the gain are higher the detected power increases. So the conversion efficiency can be controlled by the bias current and the optical gain increases at same time.

5. ADD/DROP by SOAs

The branching function follows from the above applications in the subcarrier multiplexed optical networks. The Fig. 5. shows the simplified block diagram and same time the experimental setup of this application. In this case the SOA works as a multifunctional device. It means that the SOA operates as a modulator to add a new channel and a detector to drop the needed channel. The separation of add and drop channels can be achieved with an electrical circulator or an electrical branching filter. Naturally there are several channels in the system. In the first case an electrical filter is needed also for separation of the branched subcarriers, and the second case the realization of a reconfigurable add/drop multiplexer is difficult. The experimental results of this operation mode can be observed in the Fig. 6. It means detection of one channel (drop function) and modulation of another channel (add function). So you can see the detected electrical power of the drop and add channel as a function of the modulation frequency (the difference between the two measured channel was 0.5 GHz, the other parameters can be read from the diagram).

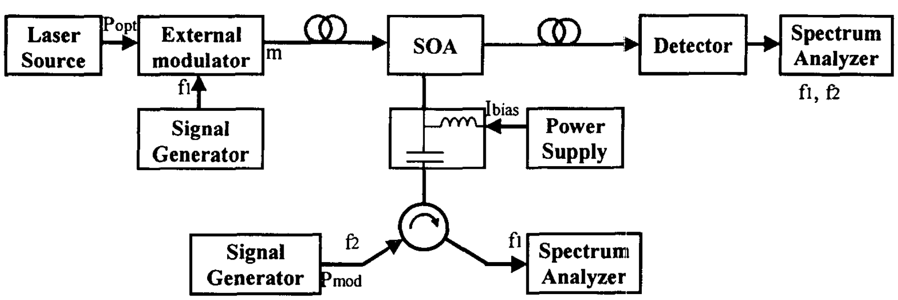


Figure 5. Experimental setup for Add/Drop function

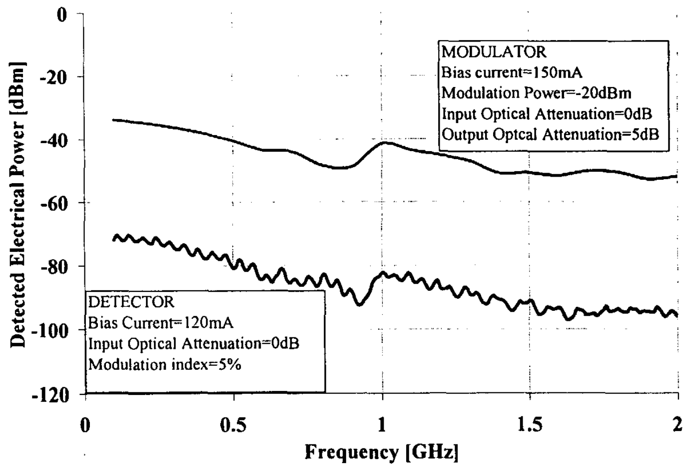


Figure 6. Modulation and detection with SOA

6. CONCLUSION

The SOA is the most promising device of the future optical networks. An experimental and theoretical study has been presented for the transmission and noise characteristics of semiconductor optical amplifiers (SOAs). On the other hand the application possibilities have been studied concentrating on the branching function in subcarrier multiplexed optical networks. In the presentation these application methods will be demonstrated by theoretical (modeling) and experimental approaches.

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