

Evaluation of the performance of SCM-based access networks using the spectrally-sliced ASE from a semiconductor optical amplifier

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Abstract: We report on the distribution of SCM signals using the spectrally-sliced Amplified Spontaneous Emission (ASE) from a SOA. Also, we have developed a model for the ASE, and have obtained good agreement with the measurements.

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1. Introduction

The appearance of new services such as video-on-demand, high-speed internet access, and tele-monitoring [1] has required the development of the optical access network. One of the schemes that have been proposed to broadcast the data is to use the spectral slicing of a broadband source. We propose to modulate the ASE from the SOA. The modulated signal can then, through the technique of spectral slicing, be sent to various destinations. The technique of spectral slicing of broadband sources has been proposed several times already; e.g. using Light Emitting Diodes (LEDs)[2],[3] or Erbium Doped Fibre Amplifiers (EDFAs)[4],[5]. Compared to EDFAs, SOAs are compact and integrable, they have a low power consumption and their injection current can be modulated up to the bandwidth of the signals transmitted through an access network. Compared to LEDs, SOAs (or Superluminescent LEDs) have a higher modulation bandwidth and output power. In this paper, we specifically analyse the suitability of the technique for the distribution of SCM signals.

We have modulated the ASE spectrum of the SOA with the output of a Multitone Signal Generator, so as to obtain a broadband optical source modulated by CATV video signals. This method enables us to use Arrayed Waveguide Gratings (AWGs) as signal distribution element and to share the signal with a great number of subscribers. Furthermore, our scheme could be used not only to distribute the signals but also to remodulate the optical signals received by the users and to transmit them back to the central unit, following schemes such as the one proposed by Takesue et al [6].

In section II, we present the model for the ASE of the SOA. We have checked the validity of the model with the measurements we have made. The model helps us to understand the behaviour of the SOA when it is modulated with several Radio-Frequency (RF) tones and to see how the SOA can be optimised for the specific application. We have calculated the Composite Second Order (CSO) and Composite Triple Beat (CTB) for different types of SOAs and under different conditions. Section III deals with the measurements that have been done to check the validity of our model. We have implemented the distribution network of Figure 1 and we have measured the receiver RF-power of the tones and the CSO and CTB parameters. Finally, Section IV gives the conclusions.

To the best of our knowledge, this is the first investigation of the simultaneous use of the SOAs as broadband source and as a modulator for the transmission of SCM signals (such as CATV signals).

2. Model to calculate the behaviour of the ASE spectrum of the SOA

The ASE spectrum of the SOA consists of contributions at different wavelengths, λ , (or optical frequencies, ν) at every z-position. The total optical power of the ASE at each point of the SOA, $P(z)$, can be expressed as:

$$P(z) = \sum_{\nu} P_{\nu}(z) \delta\nu \quad (1)$$

where $\delta\nu$ is the chosen slice of the ASE spectrum. Due to the amplification inside the SOA, the optical power of the forward and backward propagating waves will vary exponentially with z and there will be a strong z -dependence of the total power. Due to carrier depletion by stimulated emission, there will thus also be a strong z -dependence of the

carrier density. One can in principle take into account the z-dependence of the optical powers $P_v(z)$ and of the carrier density $N(z)$ by expanding $P_v(z)$ and $N(z)$.

However, we have chosen for a simpler model in which the non-uniformity of the carrier density is not included, and which also was in good agreement with measurements. The total power at frequency ν is given by the sum of forward and backward propagating power. From this last equation, one can derive the average for each frequency ν :

$$P_\nu = \frac{2\Gamma g_\nu(N_0)n_{sp}h\nu}{\Gamma g_\nu(N_0) - \alpha} \left\{ 2 \frac{\exp\left[\frac{(\Gamma g_\nu(N_0) - \alpha)L}{2}\right]}{(\Gamma g_\nu(N_0) - \alpha)L} \sinh\left[\frac{(\Gamma g_\nu(N_0) - \alpha)L}{2}\right] - 1 \right\} \quad (2)$$

One finds for the output power (i.e. forward propagating power at $z=L$)

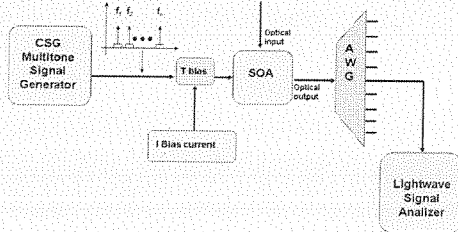
$$P_f(L) = \sum_\nu \delta\nu \frac{h\nu n_{sp} \Gamma g_\nu(N_0)}{\Gamma g_\nu(N_0) - \alpha} \left\{ \exp\left[\frac{(\Gamma g_\nu(N_0) - \alpha)L}{2}\right] - 1 \right\} \quad (3)$$

While the carrier density N_0 is determined by the equation:

$$\frac{dN_0}{dt} = \frac{I}{qV} - \frac{N_0}{\tau(N_0)} - \sum_\nu \frac{\Gamma g_\nu(N_0)}{V} \delta\nu \frac{2\Gamma g_\nu(N_0)n_{sp}}{\Gamma g_\nu(N_0) - \alpha} \left\{ \frac{\exp\left[\frac{(\Gamma g_\nu(N_0) - \alpha)L}{2}\right] - 1}{\Gamma g_\nu(N_0) - \alpha} - L \right\} \quad (4)$$

3. Measurements of the distribution network implementation

In this section, we report on the validity of the previous model. Figure 1 depicts the distribution network we have implemented to check the model. We have utilized a Kamelian SOA (OPA-20-N-C-FA), an Aeroflex CSG Multitone Signal Generator that generates 159 independent channels/tones from 44 to 998 MHz, an AWG and a HP Lightwave Signal Analyzer (Agilent mod. 71400 C) to measure the received signal.



First, we have checked the model under static conditions. We have calculated the total ASE power emitted from the SOA and then we have checked with experimental data. Fig. 2 shows the total power of the ASE of the SOA, calculated from the model and measured. Figure 3 shows that our model also reproduces the spectral dependences. The peak of the ASE spectrum shifts and also the broadening of spectrum and the gain saturation effects are well defined in the model. From the static curve we can infer that the SOA will be more linear as the dc current increases.

Fig1. - Implemented Distribution Network

Therefore, if we use the SOA to transmit several RF signals we should bias it with a high continuous injection current. We have made also dynamic measurements to check the model and the previous assumptions. We have taken into account the dynamic effects as a consequence of the carrier lifetime of the SOA [7]. We have injected a RF-tone at 155 MHz and we have measured the receiver power at the same frequency, f_1 , and at the double frequency, $2f_1$, to measure the harmonic distortion. A good agreement is obtained between the experimental data and the data calculated from the model. We have varied the electrical power of the RF-tone and the agreement between the model and measurements is maintained, too.

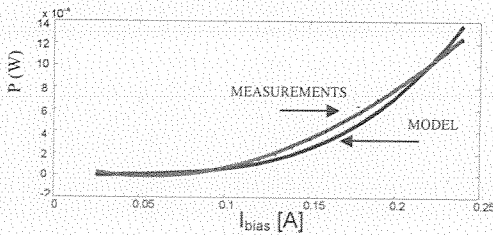


Fig. 2. - Total Power of ASE, Model and Measurements

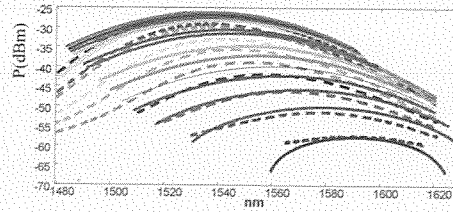


Fig. 3. - Spectrum ASE for I_{bias} =25, 45, 65, 85, 105, 125, 135, 155, 175, 195, 210, 220, 230 and 240 mA. Dashed line (Measured), Solid line (Simulated).

Finally, Figure 4 shows the measured and calculated CSO. Again, the experimental data fit with the data calculated from the model. The CSO falls when we increase the injection current as we predicted before. The decrease of the CSO is about 8 dB both in simulation and measurement. As minimum value we have obtained 26dB. Although it is a low value, it is near the limit for digital video transmissions. SOAs with higher current injection may accomplish with the requirements.

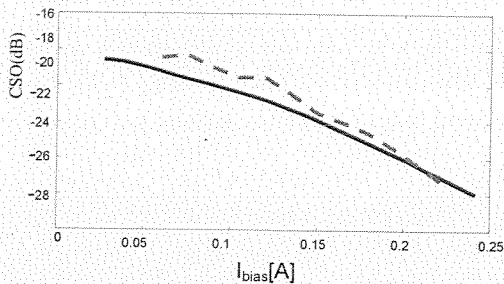


Fig. 4. - Simulated and measured CSO versus I_{bias} . Model (solid line), Measurements (dashed line).

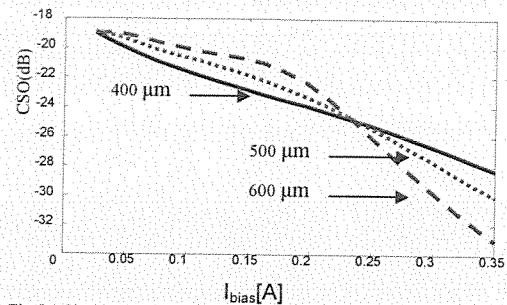


Fig.5. - Simulated CSO for SOAs of 400, 500 and 600 μm length

We have used the model to simulate the CTB behaviour. We have seen that the level of CTB is lower than the CSO, which is in agreement with our measurements. The CTB also decreases with increasing injection current, in agreement with the predictions from the measurements of Figure 2. After having demonstrated that the model is in agreement with the measurements, the next step is to study how lower levels of CSO and CTB can be achieved. In Figure 5 one can observe the influence of the device length and see that the CSO decreases with device length at higher currents. Also we have seen that the CSO decreases when the differential gain is increased, because the SOA gain saturates for a lower injection current and the SOA becomes more linear.

4. Conclusions

We have investigated a novel technique for the distribution of SCM signals in access networks using a low-cost scheme. The study of the linearity of the modulation process has shown that the signal quality is really near that required for digital video transmission. Furthermore, our scheme could be used not only to distribute the signals but also to remodulate the optical signals received by the users, following schemes earlier proposed.

We have made numerical simulations based on a simple model and have obtained a very good agreement of the simulation results with measurement results. Using this model, we have also investigated the influence of device parameters such as length, differential gain and gain curvature.

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