High bit-rate combined FSK/IM modulated optical signal generation by using GCSR tunable laser sources

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Abstract: We report on the generation of combined FSK/IM modulation format by using GCSR tunable laser sources. FSK modulation, up to 100 Mbit/s, has been achieved by modulating the phase section of a GCSR laser source. We experimentally demonstrate generation of combined FSK/IM modulation at 100Mbit/s and 10 Gbit/s, respectively. We also report on successful FSK label insertion using a SOA-MZI wavelength converter.

OCIS codes: (060.4250) Networks; (060.0060) Fiber optics and optical communications; (060.2330) Fiber optics communications

References and links

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1. Introduction

Optical label swapping (OLS) is a promising technique for implementing IP packet routing and forwarding functions over Wavelength Division Multiplexing (WDM) optical networks [1]. OLS reconciles the gap between the high data rate of data transmission over WDM links and the speed and complexity required to handle IP traffic at the core nodes of the network. A promising technique to label IP bursts (packets) is combined frequency-shift keying/intensity modulation (FSK/IM) for the label/data modulation, respectively, due to its compact spectrum, simple label swapping and scalability to high bit-rates. This technique is being studied in the STOLAS project [2]. FSK/IM generation has been reported earlier in [3] using a DFB laser with an integrated electro-absorption modulator (EAM). Due to their agile wavelength tuneability single grating assisted coupler sampled reflector (GCSR) laser sources represent a key component for next generation optical networks and form a building block for dynamic optical crossconnect nodes. Device fabrication, tuning mechanisms, and performance of these lasers have been described elsewhere [4]. In this letter we report on the FSK generation by modulating the current of the phase section of the GCSR laser. The GCSR laser can be tuned to the desired wavelength channel according to a table of current settings for its reflector, gain, phase and coupler section while careful small modulation of the phase current generates the FSK signal for labelling purposes. The FSK bit-rate achieved with the current device is 100 Mbit/s and the IM bit-rate used was 10 Gbit/s. This combined FSK/IM generation method is compact, simple, and advantageous for designing core nodes supporting optical label switching.

2. Architecture of an all-optical packet switched network based on a combined FSK/IM labelling

The network is composed of an edge and a core transport layer. As is shown in Fig. 1, at the ingress edge routers the incoming IP packets are assigned two-level optical labels, i.e. the wavelength of the signal carrier λ and the FSK label, orthogonally modulated to the IM payload [2]. The core nodes perform routing and forwarding operations based on the information retrieved from the FSK optical label. They also perform label swapping with wavelength conversion to assure that packets reach their destination. In this way a proper label switched path is established across the network.

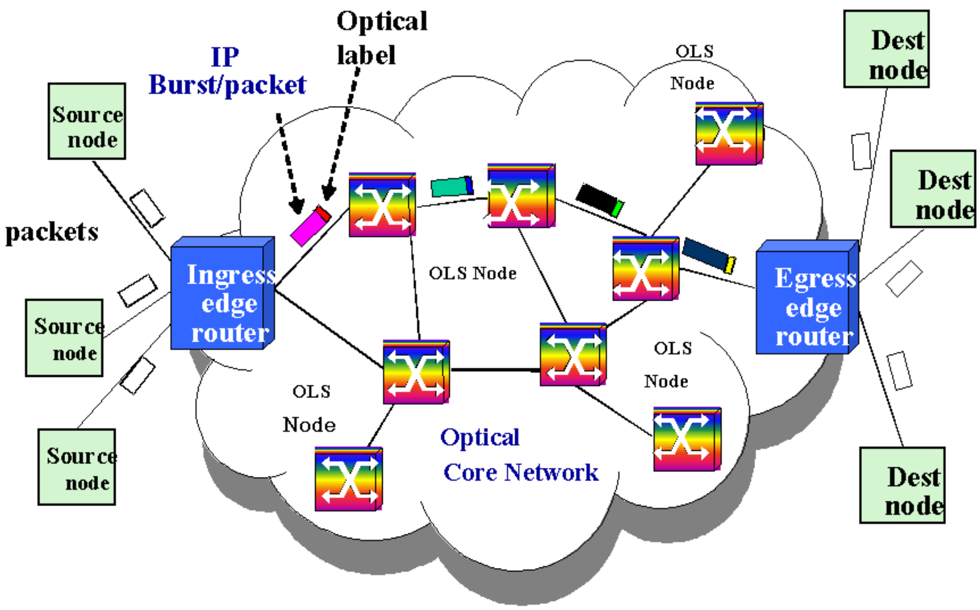

Fig. 1. General overview of the Optical Label Switching (OLS) network architecture.

To perform label swapping, a fraction of the incoming signal is tapped for opto-electronic label processing. The remaining part of the signal is input to a SOA-MZI for wavelength conversion by intensity-driven cross-phase modulation, label removal and new label insertion. Replacing the label is easy because the FSK label information is lost during the wavelength conversion in the SOA-MZI. Therefore only the payload information will be copied onto the output wavelength of the SOA-MZI, which is FSK modulated with the new label information. Modulating the phase section of a GCSR tunable source enables FSK generation, as we report below, and this signal is used as the new output wavelength for the SOA-MZI converter. In this way, both the λ label and the FSK label are swapped and the packet is ready for the next hop transmission, when followed by a passive wavelength router (e.g., an arrayed waveguide router), the new wavelength will determine the switching inside the node.

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3. Experiments and results

Generation of the FSK modulation format is obtained by modulating the current applied to the phase section of the GCSR source. The current applied to other sections of the GCSR (coupler, reflector and gain) will be used for tuning to a desired wavelength among 41 channels, supported by the current device, in the range of 1529.55 to 1561.42 nm with a channel spacing of 100 GHz. The magnitude of the frequency deviation of the generated FSK signal is dependent on the current applied to the phase section. Frequency deviation values up to 40 GHz were measured by applying a current not exceeding the maximum tolerable value of 10 mA. For the experiments reported here, a frequency deviation of 20 GHz was selected. The achievable FSK bit-rate with the current device was measured to be in the order of 100 Mbit/s. In Fig. 2 is shown the optical signal spectrum for different FSK modulation bit-rates. As we can see in Fig. 1, for modulation bit-rates above 100 Mbit/s the present device started to introduce secondary modes and distortions in the signal spectrum. The same behaviour was observed for the other channels.

The experimental setup for FSK/IM generation and label insertion is shown in Fig. 3. We choose to operate at the 1558.98 nm wavelength with a frequency deviation of 20 GHz. The current of the gain section was adjusted to 110mA and the output power of the GCSR was measured to be 2 dBm. The two tones of the FSK signal exhibited the same power level and were symmetric around the nominal wavelength (inset a in Fig. 3), therefore external compensation was not required as in the case of FSK generation by using a DFB laser [3]. Moreover, no residual intensity modulation due to FSK modulation was observed. In conclusion, generation of FSK signals with a GCSR does not require IM compensation with an EAM as e.g. needed in [3]. The generated FSK signal is introduced into an amplitude modulator where intensity modulation is imposed at a bit-rate of 10 Gbit/s. The modulator amplitude and bias controller were adjusted to yield an output signal with a measured extinction ratio of 6dB, which provides the point optimum for label and payload receiver sensitivity. A fiber Bragg grating (FBG) was used as an optical frequency discriminator to achieve frequency-to-intensity conversion, i.e., FSK demodulation (see Fig. 3). The FSK receiver sensitivity was measured to be –29dBm while for the IM receiver it was -30dBm, for a bit-error rate (BER) $<10^{-10}$; see Fig. 3.

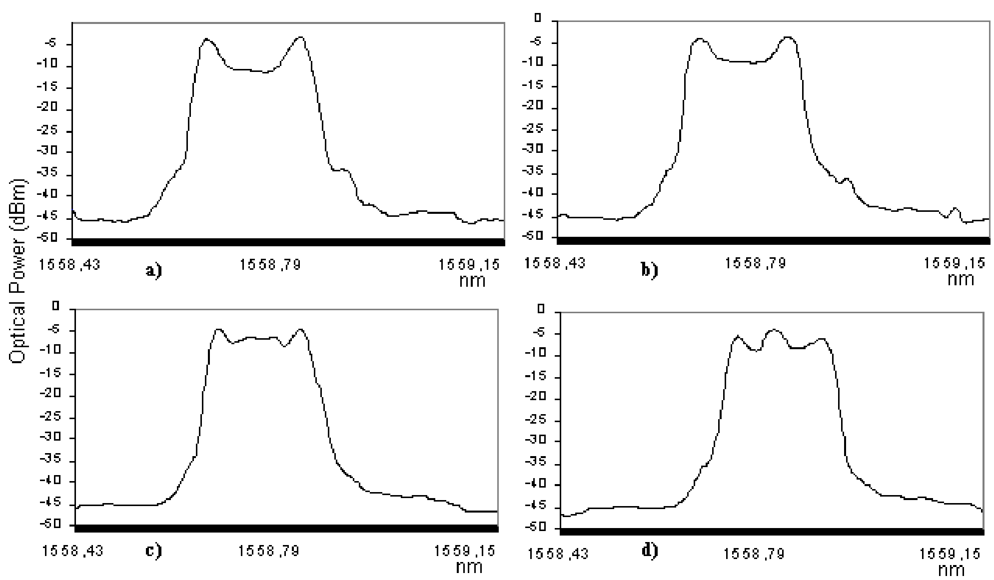

Fig. 2. FSK optical signal with a modulation rate of 50 Mbit/s (a), 78 Mbit/s (b), 120 Mbit/s (c) and 155 Mbit/s (d).

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To assess the feasibility of FSK label insertion we introduce a wavelength converter based on a Mach-Zehnder interferometer with semiconductor optical amplifier (SOA). The input signal at 1559.98 nm is IM modulated at 10Gbit/s. The output signal from the GCSR laser with the FSK modulation at 100 Mbit/s is used as the probe signal for the SOA-MZI. This configuration allowed us to insert the FSK label onto the incoming IM signal. The input power level at the wavelength converter is adjusted using an EDFA up to –2 dBm for the IM signal in order to operate in the non-inverting part of the conversion curve of the SOA-MZI. The power level of the FSK signal is set to 0 dBm.

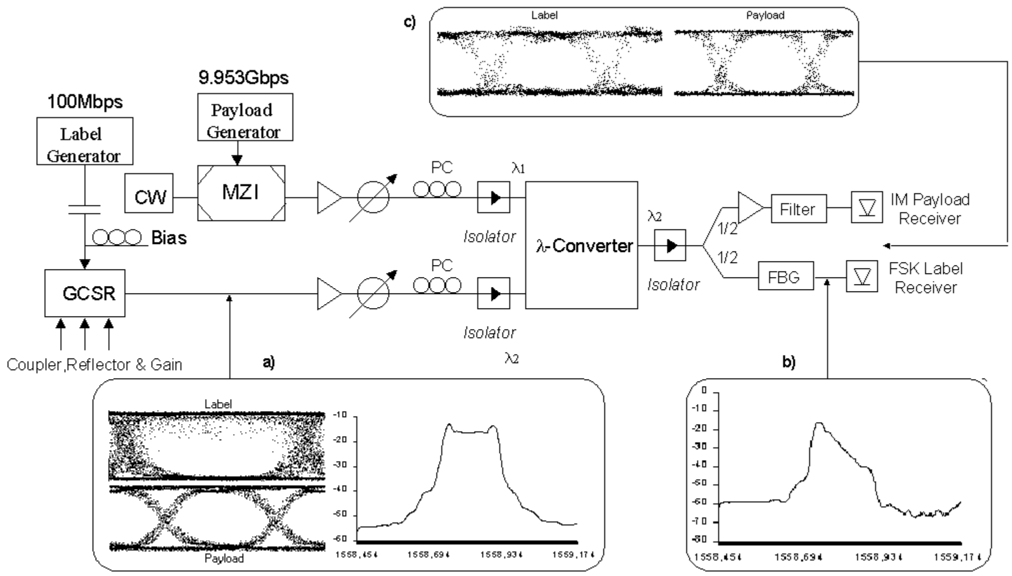

Fig. 3. The experimental setup for FSK/IM generation and label insertion (a), where we can observe the recovered FSK signal (b) and the recovered eye patterns (c).

The signal output power level was 1.5dBm and the extinction ratio was measured to be 7dB. The improvement in the output extinction ratio is due the operating point of the wavelength converter that was adjusted to maintain the same extinction ratio value ratio for the IM signal. This is a requirement for proper detection of the FSK signal.

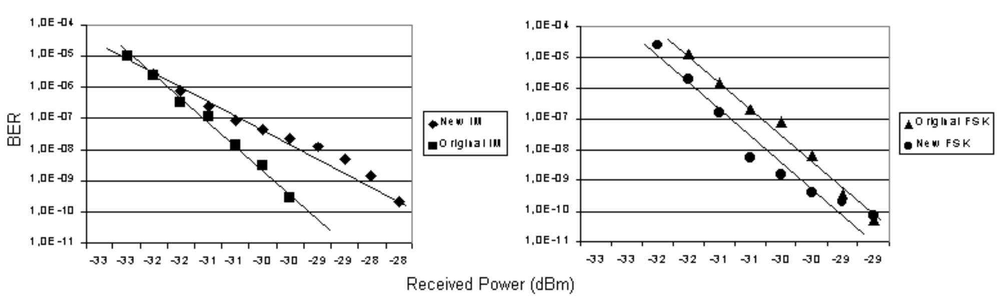

Fig. 4. Comparison of the BER versus the receiver sensibility for the FSK and the IM signal after and before the wavelength converter.

In Fig. 4 is presented the bit-error rate (BER) as function of the input power. As it can be observed in this figure, the inserted FSK signal suffers only from 0.5dB power penalty on the receiver sensitivity, and less than 1.5 dB power penalty on the receiver in the case of the IM signal.

4. Conclusions

We presented a novel application for agile GCSR laser sources, namely the generation of combined FSK/IM modulation for labeling signals for optical labeled switched networks. The generated FSK signal exhibits a symmetric spectrum and no residual intensity modulation, and therefore external compensation is not required. Modulation rate up to 100 Mbit/s were experimentally shown, however, GCSR devices could be designed to support higher modulation rates. Insertion of FSK signals generated by using GCSR laser was demonstrated in a SOA-MZI wavelength converter with a receiver sensitivity penalty below 1dB, validating the feasibility of this FSK/IM generation method for application in optical label switched networks.

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