A novel optical labeling scheme using a FSK modulated DFB laser integrated with an EA modulator

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The feasibility of an optical FSK labeling scheme is demonstrated. An optical signal consisting of a 10Gb/s payload and a 312Mbps label was generated, and its performance was evaluated in an 88km transmission link.

1. Introduction

All optical label switching implements the packet routing and forwarding functions of multiprotocol label switching (MPLS) directly in the optical layer. This is a promising technology for next generation wavelength division multiplexing (WDM) networks. Several optical methods have been proposed and demonstrated as possible solutions [1], in which the label is attached by time multiplexing or subcarrier multiplexing with the data payload. The optical label can also be achieved by angle modulation that is orthogonal to the intensity-modulated payload [2]. In direct detection system, the label information can be modulated using either the differential-phase-shift-keying (DPSK) or frequency-shift-keying (FSK) format. The feasibility of the optical FSK label generator was experimentally validated [3]. However, this scheme imposes stringent requirements on the laser linewidth. The scheme of combined FSK/ASK modulation was demonstrated to be more applicable in practical networks [4].

In this paper, we report the construction of a novel optical FSK transmitter and investigation of the optical FSK labeled signal's performance. The generated signal consists of a 10Gb/s intensity modulated payload and a 312Mbps FSK format label, whose performance was evaluated in an 88km standard single-mode-fiber (SMF) transmission link.

2. Operation Principle of the Optical FSK Transmitter

The optical FSK transmitter plays an important role in optical labeling. The label information is impressed upon the frequency of the optical carrier through FSK modulation, while keeping its amplitude unaffected. Thus the optically labeled packet can be achieved when the payload information is modulated on the amplitude of the carrier.

An optical FSK signal can be generated simply by direct modulation of the electrical current of a DFB or DBR laser diode [5]. However, the drive current variation also results in a simultaneous intensity modulation of the emitted light. As for the optical labeling, such residual intensity modulation has a detrimental effect on the optical packet switching. The payload information is added. To overcome this problem, we propose a novel optical FSK label generation scheme based on a commercially available integrated DFB laser/semiconductor (EA) modulator, whose configuration is shown in Fig. 1.

![Fig. 1. Configuration of the optical FSK transmitter](image)

In such a configuration, the DFB laser is driven with a bias current far above the threshold and a relatively small modulation current is added. The intensity variation of the laser output is then compensated through the integrated EA modulator driven with the inverse data. In this way, only the frequency modulation is expected in the final output of this integrated device.

The measured optical characteristics of the DFB laser/EA modulator are shown in Fig. 2. The variation of injection current will change both output power and wavelength, as indicated in Fig. 2(a). In high bias current regime, a modulation current of nearly 30mA is needed to achieve a 20GHz (=0.125nm) frequency deviation, which is accompanied by a 3dB intensity variation. The integrated EA modulator shows a modulation efficiency of nearly 5dB/V, as shown in Fig. 2(b). Both the DFB laser and the EA modulator have 3dB modulation bandwidth of 2.5GHz. Fig. 3 shows the measured eye-diagrams and optical spectrum of the FSK modulated signal when the DFB laser was driven with a 90mA bias current and a 30mA modulation current. Without intensity compensation, nearly 3dB intensity fluctuation was observed, as shown in Fig. 3(a). Both the bias and modulation voltage of the EA modulator were optimized to compensate for the residual intensity modulation. The final output light had almost constant amplitude, as shown in Fig. 3(b). The perfect FSK signal with a peak-to-peak frequency deviation of 200kHz was finally generated, as indicated by the spectrum of Fig. 3(c).

![Fig. 2. (a) Characteristics of a DFB laser](image)

![Fig. 2. (b) Characteristics of an EA modulator](image)

![Fig. 3. (a) Direct output eye-diagram of the DFB Laser](image)

![Fig. 3. (b) Output eye-diagram after EA compensation](image)

![Fig. 3. (c) Output spectrum after EA compensation](image)

3. Performance of the Optical FSK Labeled Signal

To investigate the performance of the optical FSK labeling scheme, an 88km SMF transmission link was set up, as shown in Fig. 4. The optically labeled signal consisting of a 10Gb/s payload and a 312Mbps label was first generated, then transmitted over 88km SMF, and finally detected using direct detection receivers.

![Fig. 4. Experimental Setup](image)

Two pseudo-random pattern generators were used to generate the payload and label information. The label information was impressed upon the optical carrier (1555.0 nm) through FSK modulation, while the payload information was added by using a 10Gb/s Mach-Zehnder intensity modulator (MZM). The power of the labeled signal was amplified to 10dBm and input into the fiber. The transmission span consisted of 88km SMF and a matching length of dispersion compensating fiber (DCF). The DCF was inserted into the link based on a hybrid dispersion compensation map (i.e. split before and after the transmission fiber) to give optimized transmission performance. At the receiver node, the labeled signal was split using a 3dB optical coupler. One arm was directly detected by a photodiode and thus the payload was converted into the electrical domain. In the other arm, a fiber-Bragg-grating (FBG) was used to filter only a single lobe of the FSK labeled signal.
signal, thus achieving the FSK demodulation. The demodulated label was received by an electrical receiver with 1.8 GHz bandwidth. Fig. 5 shows the eye-diagrams of the payload and label.

Fig. 5 (a) Eye-diagram of optically labeled signal

Fig. 5 (b) Eye-diagram of received payload (electrical)

Fig. 5 (c) Eye-diagram of received label (electrical)

In the labeling scheme used, interference is introduced between the payload and label through the intermodulation distortion, as indicated in Fig. 5(c). The intensity modulation depth of the payload and label and the extinction ratio of payload in the back-to-back case. A good trade-off between the payload and label performance can be achieved with nearly 6dB extinction ratio. Fig. 6(b) shows the transmission performance of the signal with 6dB extinction ratio. The transmission penalties for label and payload are 2.0dB and 1.0dB respectively.

Fig. 6 (a) Payload and label receiver sensitivity versus extinction ratio of the payload

Fig. 6 (b) BER performance of the optically labeled signal

4. Conclusions

We have proposed a novel optical FSK label generation scheme based on commercially available integrated DFB laser/EA modulator. An optically labeled signal consisting of a 10Gb/s payload and a 1320Gb/s label was generated. Both payload and label data could be recovered error free after transmission over 88km SMF, validating the feasibility of the optical FSK labeling scheme.

References

5. R. S. Vodhanel et al., "Performance of directly modulated DFB lasers in 10Gb/s ASK/FSK/DMF/DMF: the services would need more bandwidth than the copper plant allowed, and would need a new architecture, but revenues from new services such as Video on Demand (VOD) were expected to support a fiber build-out.

Development in the 1960s, 1970s, and 1980s prepared the ground for today's digital revolution. The availability of low-cost high-performance computers, the rise of the microelectronics industry, and the development of the Internet have created new opportunities for communication and information technology.

Prospects for the Future

Overriding all of the plans, of course, is the need for the network to make money for its owner; early advocates estimated that the customer's willingness to pay for phone, video, and miscellaneous services would support a cost of $1500 per subscriber for infrastructure, which is still a reasonable guess today. Much activity in 4G and standards groups such as the Full Service Access Network (FSAN) in the First Mile (FMM) activities supports the vision, and vendors are within striking range of these costs. Furthermore, there are several major trials run by ILECs (dating back to the 1980's), and some MSO trials have recently begun, but the players are developing technological experiments for more massive FTTH rollouts. We believe that a major deployment is unlikely for the foreseeable future for several reasons.

First, the cost calculations require essentially monopoly conditions. The major cost of the FTTH network is the installation of ubiquitous distribution fiber that permits a drop to any potential customer. This fixed cost of passing every customer must be borne by this fraction of customers who actually subscribe. In a competitive market is 25%, for example, then the effective cost per customer is nearly 4 times the