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Investigation of the influence of key parameters on system performance in all-optical label switching based on FSK/ASK orthogonal modulation format*

Wei Lai(魏 莱), Xin Xiang-Jun(忻向军)†, Ma Jian-Xin(马建新),
Zhang Qi(张 琦), Wang Kui-Ru(王葵如),
Yu Chong-Xiu(余重秀), and Liu Bo(刘 博)

School of Electronic Engineering, Beijing University of Posts and Telecommunications, Beijing 100876, *China*
Key Laboratory of Optical Communication and Lightwave Technologies
(Beijing University of Posts and Telecommunications), Ministry of Education, Beijing 100876, *China*

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The transmission characteristics of the optical label switching system based on the FSK/ASK orthogonal modulation format is investigated. The factors that affect the transmission performance, such as the FSK tone space, dispersion compensation and coupler split ratio, are studied by numerical simulation. The proposed scheme is also experimentally demonstrated with a transmission of 155 Mbit/s FSK label combined with 10 Gbit/s ASK payload.

Keywords: optical label switching, frequency shifted keying, amplitude shifted keying, dispersion compensation

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1. Introduction

Optical label switching (OLS) has attracted considerable attention in the optical communication research area in recent years due to its large switching capacity which matches the dense wavelength division multiplexing (DWDM) transmission technology. In an OLS network, the packet is labelled in the optical domain. Its routing and forwarding are carried out directly in the optical domain according to the label with easily processed low bit rate in the electronic domain.[1−13] A few optical label switching techniques have been reported, such as the bit serial label, the optical subcarrier multiplexed label,[1−5] etc. The bit serial label technology mutiplexes a fixed bit rate label in front of the IP packet. For optical subcarrier multiplexed label technology, the label is firstly modulated onto an RF sub-carrier, then multiplexed with the packet. Recently, another OLS technology, the combined orthogonal modulation format[4−11] was proposed, and is considered as suitable technology to implement an all-optical label switching network. In this scheme, the label information and payload information are encoded on the optical carrier by an orthogonal modulation format such as frequency shift keying (FSK)/amplitude shift modulation (ASK), or differential phase shifted keying (DPSK)/ASK, where the label information is encoded on the optical carrier through FSK or DPSK modulation. Due to the orthogonality of the modulation format, it is simple to separate the label at the forwarding node and perform the label reading/replacing process.

In this paper, system performance in all-optical label switching based on the FSK/ASK orthogonal modulation format is studied, where 10 Gbit/s ASK payload combined with a 155 Mbit/s FSK label is considered. The influence of key factors, such as FSK tone space, dispersion compensation ratio, coupling coefficient and laser nominal centre wavelength, on the received data are investigated by numerical simulation. Finally, a transmission experiment with a com-

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†Corresponding author. E-mail: xjxin@bupt.edu.cn, xinxiangjun@gmail.com

bined orthogonal format of 155 Mb/s label bit rate and 10 Gb/s payload bit rate is performed.

2. Scheme of the FSK/ASK orthogonal modulation optical label switching transmission network

The scenario of an FSK/ASK orthogonal modulation optical label switching transmission network is illustrated in Fig.1. It is composed of ingress (egress) edge routers and core routers.[1−5] IP packets from the access network are managed in the ingress edge routers. An optical label written in FSK format is assigned to the IP packet, which contains the routing information. At the core router, the optical label can be extracted by optical FSK demodulation. Based on the detected label, the core router performs the routing and forwarding operation of the IP packet. The packet is always kept in the optical domain unless it leaves the egress router and is delivered to the access or metro network.

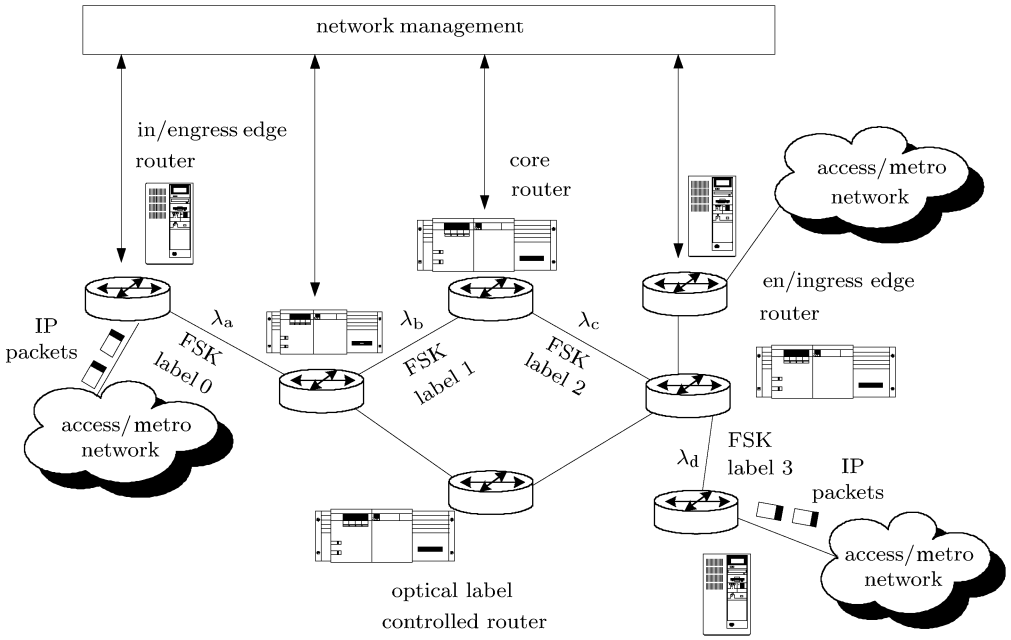


Fig.1. Scenario of an all-optical label switching transmission network based on FSK/ASK orthogonal modulation. FSK: frequency shift keying, ASK: amplitude shift keying.

Figure 2 depicts the schematic diagram of the ingress edge router. It firstly performs buffering, aggregation, forwarding equivalent class (FEC) functions, etc., for the IP packet. Then an available wavelength λ_a for the tunable laser is assigned according to the network state, and directly modulates the current of the laser to achieve optical FSK modulation.[4] The FSK signal is used as an optical carrier for the high speed payload information, which is executed by amplitude modulation of the FSK optical carrier. Finally, the combined FSK/ASK format is generated. According to the label information, the core router carries out forwarding until the payload reaching the appropriate egress router.

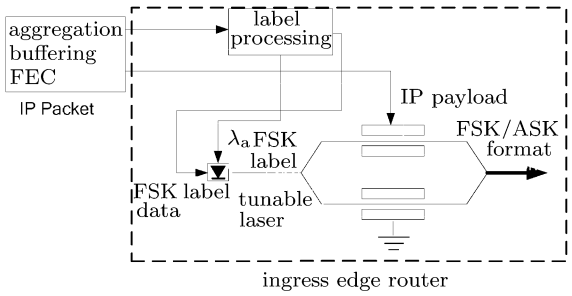


Fig.2. Schematic diagram of the ingress edge router.

The core router performs routing and forwarding operations based on the optical FSK label. Figure 3 presents its schematic diagram. To read the label information, a fraction of the incoming signal is tapped and detected through opto-electronic conversion processing. A new FSK label with new nominal optical wavelength is then assigned by the core router according to the network resource and combined with the delayed IP payload again, which can be realized by all-optical wavelength conversion (AOWC) with the function of erasing the old label simultaneously. The AOWC in Fig.3 can be realized through cross phase modulation in SOA set in one arm of a Mach–Zehnder (M–Z) interferometer.

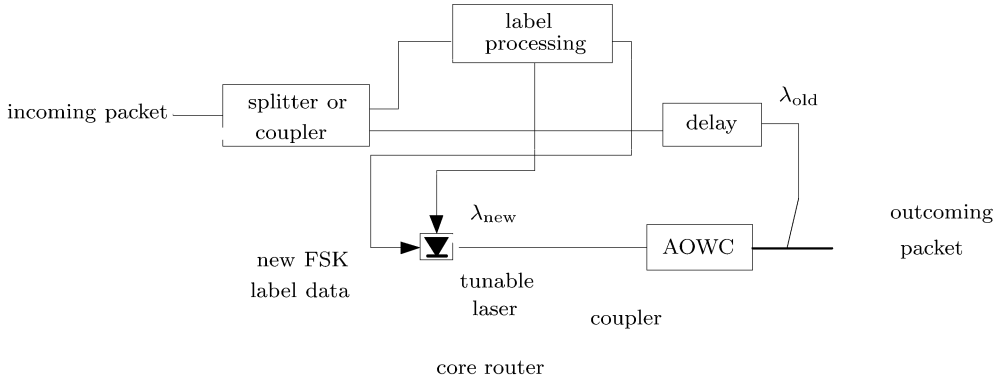


Fig.3. Schematic diagram of the core router for FSK/ASK orthogonal modulation. AOWC: all optical wave converter.

3. System performance analysis

The transmission performance of the combined FSK/ASK with orthogonal modulation format is analysed through simulation based on the scheme shown in Fig.4.

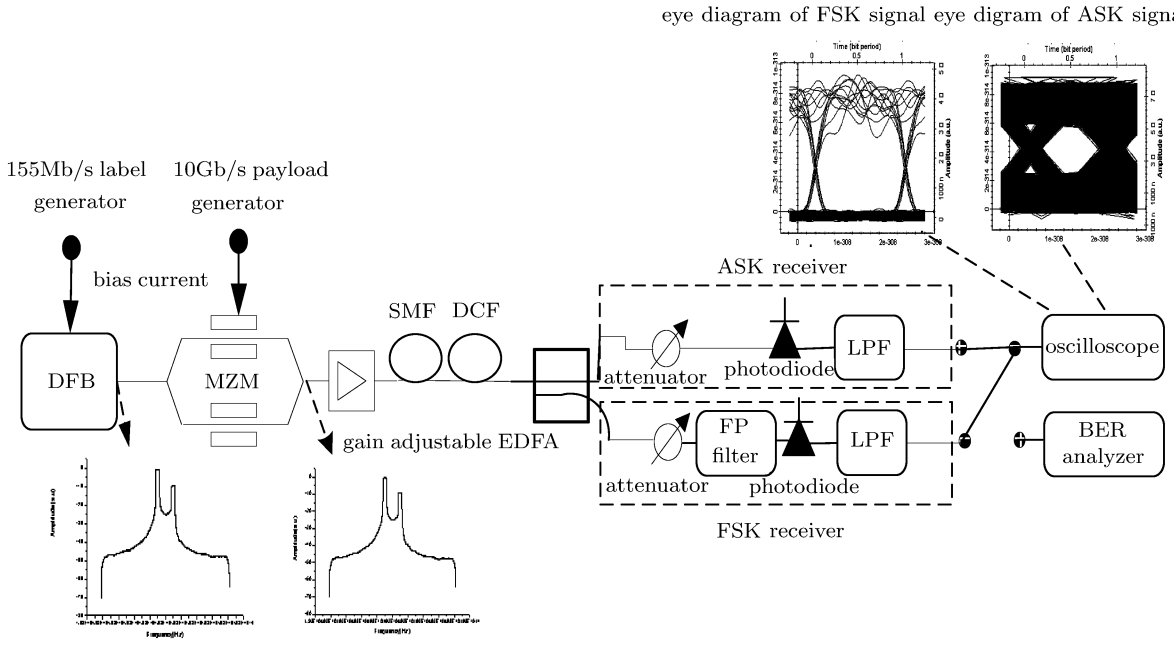


Fig.4. Transmission performance analysis scheme of the combined FSK/ASK with orthogonal modulation format. DFB: distributed feed back laser, MZM: M–Z modulator, PRBS: Pseudo-random binary sequences, EDFA: erbium doped fibre amplifier, FP Filter: Fabary–Perot filter.

The DFB Laser, with a bias current above the threshold and having a nominal centre wavelength of 1552.56 nm, is driven by 155 Mb/s pseudo-random bit sequence (PRBS) non return zero (NRZ) with a sequence length of $2^7 - 1$ to generate the FSK modulation format due to the laser's chirp. Two distinct frequency 'tones' , as shown in the inset in Fig.4, represent "1" and "0" data bits of the optical label, respectively. 10 Gb/s PRBS with a sequence length of $2^{23}-1$ is intensity-modulated on the carrier by an M–Z modulator to realize the FSK/ASK combined orthogonal modulation format. The EDFA is used to compensate for the signal fading due to the attenuation introduced by the single model fibre (SMF) utilized, which is assumed to have a dispersion coefficient of 16 ps/nm/km, dispersion slope of 0.08 ps/nm^2/km, and optical attenuation of 0.2 dB/km at the wavelength used. Due to the spectrum expansion of the FSK modulation, the payload transmission is severely limited by the fibre dispersion. To reduce the dispersion limitation, dispersion compensation fibre (DCF) is used. At the receiver end, the labelled payload is split by an optical coupler. The payload in one output of the coupler is directly detected by a photodiode. The FP filter whose 3 dB passing bandwidth is set as 12 GHz for 10 GHz FSK tone space and 22 GHz for 20 GHz FSK tone space, respectively, is used to filter out one tone of the FSK label. The attenuator used in the receiver is to adjust the received optical power. The eye diagram and bit error rate of the demodulated FSK label and ASK payload are monitored by the oscilloscope and BER analyser, respectively. Some of the aforementioned factors affecting system performance are discussed.

3.1. Extinction ratio of M–Z modulator, laser linewidth and FSK tone space

In order to exhaustively analyse the influence of the laser linewidth and FSK tone space, a 50-km SMF with the parameters mentioned in the last section, and a 10-km dispersion compensation fibre (DCF) with dispersion coefficient of –80 ps/nm/km, dispersion slope of –0.28 ps/nm^2/km, and optical attenuation of 0.23 dB/km at the wavelength mentioned above, are used to remove the influence of the fibre dispersion. Figure 5(a) shows the Q factor as a function of extinction ratio (ER) with 20 GHz FSK tone space for several values of the laser linewidth, and (b) shows this with a laser linewidth of 100 MHz for several values of the FSK tone space, respectively. It can be seen that the laser linewidth within a reasonable range has little influence on the Q factor. A weak influence from the tone space is observed, but can be almost neglected when compared with the ER that affects the Q factor severely. The requirement for ER is the opposite for FSK label detection and ASK payload. A higher ER is preferable for ASK payload. A compromised ER should be between 5 and 7 dB so that both formats can achieve acceptable results.

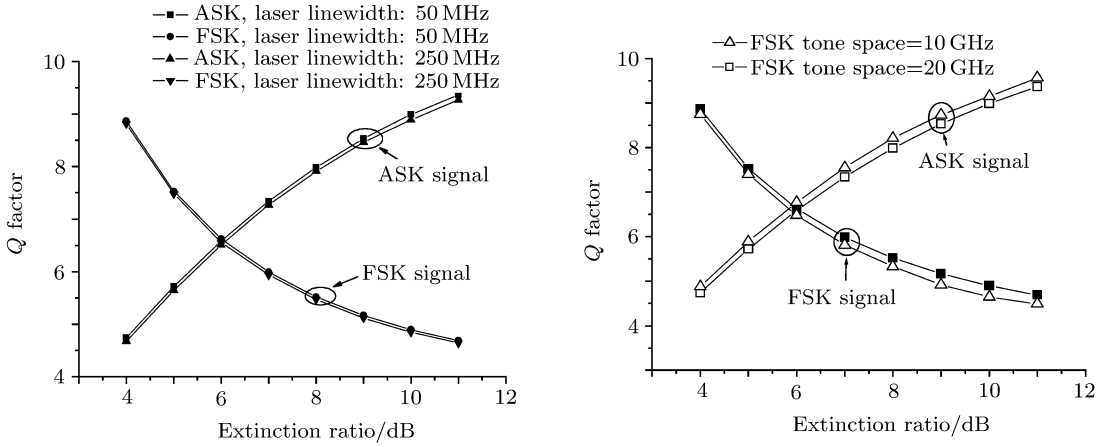


Fig.5. (a) Q factor as a function of extinction ratio with FSK tone space of 20 GHz for several values of the laser linewidth. (b) Q factor as a function of the extinction ratio with a laser linewidth of 100 MHz for several values of FSK tone space.

3.2. Dispersion compensation

Figure 6 shows the Q factor of the ASK payload and FSK label as a function of the dispersion compensation ratio for a 7 dB modulator ER, where two FSK tone spaces, namely 10 GHz and 20 GHz, and 100 MHz laser linewidth are considered. The dispersion compensation ratio is changed by adjust-

ing the DCF compensation length. Different dispersion compensation schemes (pre-compensation, post-compensation and hybrid-compensation) are also considered. The highest Q factor is obtained by the pre-compensation scheme. It can be seen that the best performance is reasonably achieved when the compensation ratio is 100%. Both higher and lower dispersion compensation ratios will result in the deterioration of the ASK signal. Meanwhile, due to the broadness of the spectrum, the ASK signal is affected more seriously than the FSK signal. For the FSK signal, only one of its narrow peak spectra is detected, and that is almost immune to the dispersion. Therefore, the FSK signal keeps a constant performance for all dispersion compensation ratios, with a Q factor of 7.86±0.05 for 20 GHz of FSK tone space and 7.94±0.05 for 10 GHz of FSK tone space.

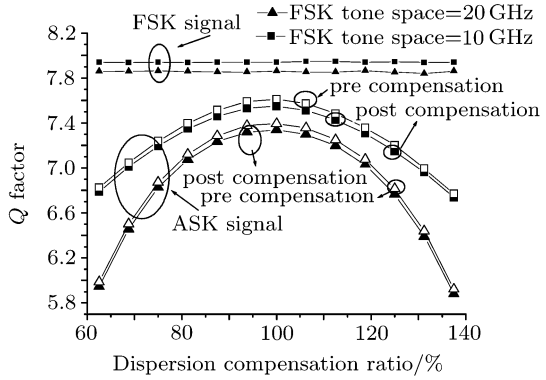


Fig.6. Q factor for the ASK signal and FSK signal as a function of the dispersion compensation ratio.

3.3. Coupling coefficient

The Q factor for the FSK label and ASK payload can be optimized by adjusting the coupling coefficient of the coupler at the receiver end, as shown in Fig.4. The ASK receiver will get more power when the coupling coefficient decreases. Figure 7 shows the Q factor as a function of coupling coefficient for several values of total input optical power at the receiver end, where 20 GHz FSK tone space and 100 MHz laser linewidth are assumed. It can be seen the Q factor of the ASK signal increases as the coupling coefficient decreases. A higher total input optical power at the receiver end is preferable for achieving a better performance for the ASK payload. However, the FSK label keeps almost constant for different values of coupling coefficient and total input power. Such results are reasonable because ASK is sensitive to optical power, and FSK mainly depends on FSK tone.

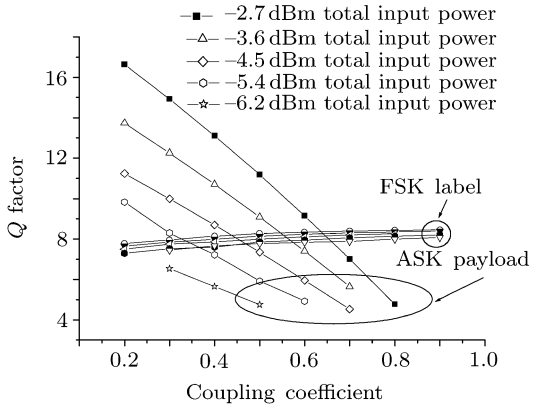


Fig.7. Q factor as a function of coupling coefficient with 20 GHz FSK tone space, 100MHz laser linewidth.

4. Transmission experiment of combined FSK/ASK with orthogonal modulation format

The transmission performance of the combined FSK/ASK with orthogonal modulation format is evaluated experimentally. The experimental setup used is shown in Fig.8. 155.52 Mb/s nonreturn to zero (NRZ)

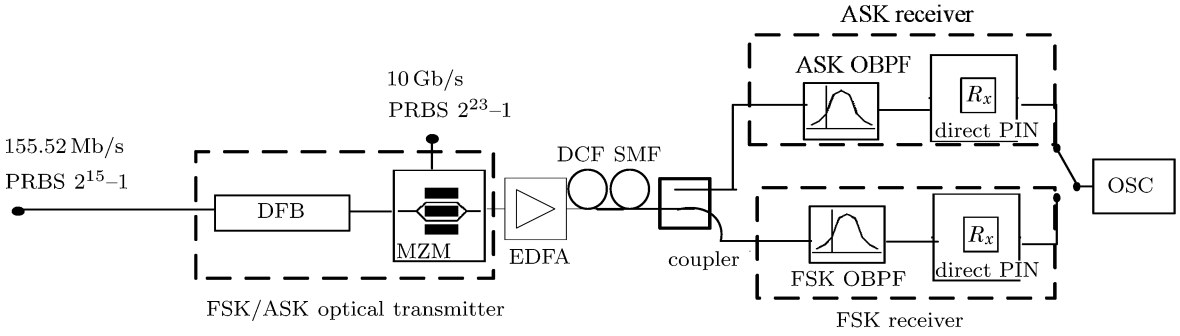


Fig.8. Experimental setup for the FSK/ASK combined modulation format scheme. MZM: M–Z modulator, PRBS: pseudo-random binary sequences, EDFA: erbium doped fibre amplifier, OBPF: optical bandpass filter, OSC: Agilent Infiniium DCA 86100A wide-bandwidth oscilloscope.

code of the synchronous-transport-module-1 in SDH with $2^{15}-1$ PRBS acting as label directly drives the DFB laser that is biased above the threshold. This procedure results in frequency modulation of the output light due to the laser's frequency chirp, and two tones (peaks) are generated. We add a 10 Gb/s NRZ code with $2^{23}-1$ PRBS acting as payload by an M–Z modulator (MZM). Thus, an ASK signal labelled by an FSK signal is generated. The combined FSK/ASK optical signal is amplified by an erbium doped fibre amplifier (EDFA) with adjustable gain and about 6 dB noise figure. Through 50 km SMF transmission with matched DCF, the combined modulation signal is split by a 50:50 coupler followed by an optical bandpass filter (OBPF) and detected by the FSK and ASK receivers, respectively. A wide-bandwidth oscilloscope is used to monitor the signal's quality. Figure 9(a) and 9(b) display eye diagrams with enough opening degree for the FSK label and ASK payload, respectively.

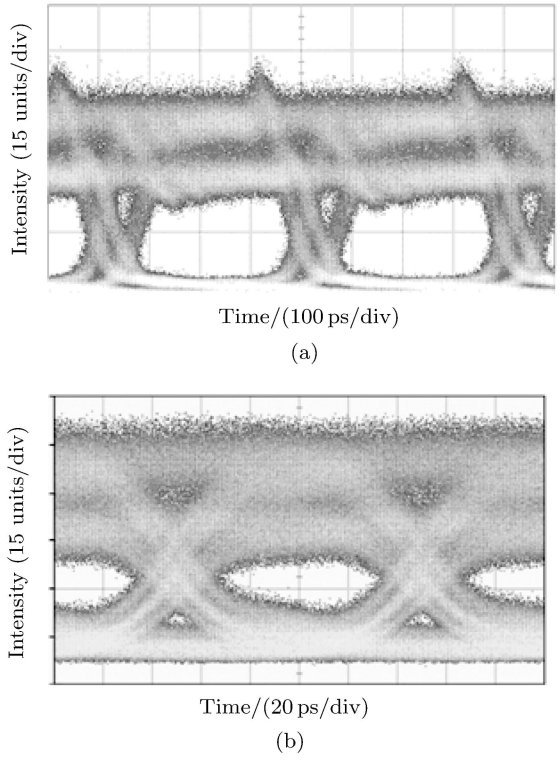


Fig.9. Eye diagram of FSK label and ASK payload.

5. Conclusions

Optical label switching based on the FSK/ASK orthogonal modulation format is a feasible scheme for all optical networks, which will play a key role in next-generation networks. The transmission characteristics of the proposed scheme are investigated and analysed. The factors that affect the transmission performance, such as laser linewidth and FSK tone space, dispersion compensation degree and coupler split ratio are studied by numerical simulation. The results show that the performance of the label/payload signals is not severely influenced by the laser linewidth for fully dispersion-compensated links. A weak influence from the tone space is observed, but can be almost neglected compared with the extinction ratio that changes the Q factor severely. ER should be between 5 and 7 dB for the detection of both ASK and FSK signals. The highest Q factor is obtained by the pre-dispersion compensation scheme. The transmission performance can be optimized by adjusting the coupling coefficient of the coupler that assigns the optical power at the receiver end. The performance of the proposed scheme is evaluated experimentally with a 155 Mibt/s FSK label combined with a 10 Gbit/s ASK payload.

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