Optik - International Journal for Light and Electron Optics 169 (2018) 208–213

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.com/locate/ijleo

Original research article

Cross-correlation technology for decreasing the noise figure of microwave photonic link

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ARTICLE INFO

Keywords:
Cross-correlation technology
Noise figure
Microwave photonic link

ABSTRACT

The cross-correlation technology is applied to decrease the noise figure of microwave photonic link(MPL) for the first time in this paper. Firstly, both effects of the intensity of the laser and the bias voltage of the EOM on the noise figure of MPL are analyzed and optimized. Then, a cascaded low-noise amplifier is added in front of MPL for lower noise figure. Finally, the double laser - double detector structure based on cross-correlation technology is used to offset different kinds of uncorrelated noise in the link and experiments show that the noise figure is further reduced by 3 dB.

1. Introduction

Traditional microwave link is an important part of many commercial and military communication systems, which can be widely used in the fields of aerospace, radar, electronic warfare, high frequency communications, remote sensing, precise measurement and so on [1–6]. However, with the increase of transmission distance, the insertion loss of the traditional transmission media such as cable and waveguide increases rapidly, especially in the microwave and millimeter wave band. The bottleneck of the large insertion loss is more and more obvious to the microwave link. The loss of typical coaxial cable in X band is higher than 1.8 dB/m(1.8×10^3 dB/km), while the loss of commercial SMF-28 communication optics fiber at 1550 nm wavelength is only close to 0.2 dB/km.

Microwave photonic link (MPL) is one of the most effective ways for solving the bottleneck of traditional microwave link, especially suitable for long distance transmission. MPL based on Intensity Modulation - Direct Demodulation(IM-DD) has been widely used in the fields of radar, electronic warfare, accurate measurement and so on [6–10]. The optical signal is used as carrier to transmit microwave signal as for MPL, and the disadvantage of traditional microwave link could be overcome due to the low loss characteristics of optics fiber. In addition, MPL owns the advantages of light weight and anti-electromagnetic interference compared with electric cable, owning a bright application prospects.

MPL belongs to a typical active module and owns kinds of inner noises, so the optimization of noise figure(*NF*) for MPL is an important prerequisite for its application [11]. In following sections, both system parameters of the intensity of the laser and the bias voltage of electro-optic modulator(EOM) are optimized to reduce the NF firstly, and then a cascaded low-noise amplifier is added in front of MPL for lower NF. In order to reduce system noise in essence, we propose a new structure of “double laser - double detector” of MPL and apply the cross-correlation technology to offset different kinds of uncorrelated noises.

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https://doi.org/10.1016/j.ijleo.2018.05.054
Received 30 March 2018; Received in revised form 8 May 2018; Accepted 15 May 2018

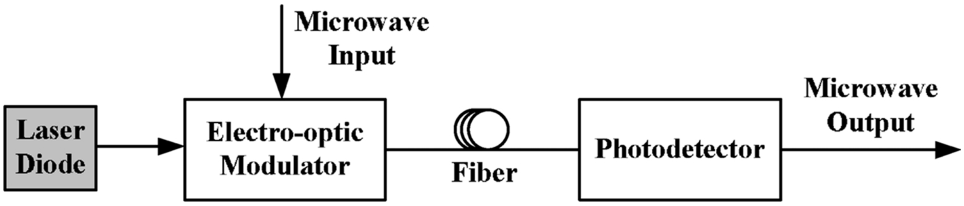

Fig. 1. Typical structure of IM-DD MPL.

2. Optimization for lower NF

2.1. Basic structure of MPL

Typical structure of IM-DD MPL is shown in Fig. 1. The link includes a laser diode which provides a CW light source, and an EOM which realizes the microwave-optical conversion, and a photodetector which accomplishes the optical-microwave conversion. The microwave signal is modulated to the amplitude of the optical carrier by the EOM and recovered at the end of the photodetector after the transmission of the optical fiber.

As for typical IM-DD MPL shown in Fig. 1, the noise factor(F) can be expressed by[12–14]

$$F = 1 + \frac{k_B T + 2qI_{dc}Z_L + RINI_{dc}^2 Z_L}{(I_{dc}\sin(\varphi_b)\frac{\pi}{2V_\pi})^2 Z_L Z_{in} k_B T}, \tag{1}$$

Where k_B is the Boltzmann Constant and $k_B = 1.38 \times 10^{-23}$ J/K, T is Ambient temperature for the experiment, q is a unit of electronic charge, RIN is the relative intensity noise of the laser (LD), both Z_L and Z_{in} are the matched impedances of output load and EOM, φ_b is the DC bias angle of the EOM and determined by $\varphi_b = \frac{V_b}{V_\pi}\pi$ (V_b is the bias voltage of EOM), and I_{dc} is the average photocurrent of the detector and expressed by

$$I_{dc} = \frac{1}{2}\rho\alpha P_o(1 + \cos\varphi_b). \tag{2}$$

In Eq. (2), ρandαare the detector's responsivity and the loss coefficient of EOM respectively, and P_o is the input optical power. Combining Eqs. (1) and (2), we can get

$$F = 1 + \frac{k_B T + q\rho\alpha P_o(1 + \cos\frac{V_b}{V_\pi}\pi)Z_L + \frac{1}{2}RIN\,[\rho\alpha P_o(1 + \cos\frac{V_b}{V_\pi}\pi)]^2 Z_L}{[I_{dc}\sin(\frac{V_b}{V_\pi}\pi)\frac{\pi}{2V_\pi}]^2 Z_L Z_{in} k_B T}. \tag{3}$$

Both F and NF are used to measure the noise performance of electronic systems and their relationship can be expressed by

$$NF = 10 \times \log_{10}F. \tag{4}$$

The value of NF was measured by the Noise Figure Analyzer (Agilent N8975 A) in following experiments.

2.2. Noise figure optimization

Optimization of the bias voltage of modulator and the output power of the laser is an effective way to reduce the NF of MPL. Parameters in Table 1 were used for numerical analysis and experimental validation in following section. The LD used in experiments is a distributed feedback semiconductor laser (EM4) with the full rated power of 100 mW (In experiments, a variable optical attenuator could be placed between LD and EOM in Fig. 1 and employed to adjust the input optical power of the EOM). The EOM (Optilab) in our experiments is a Mach-Zender Modulator(MZM). Since high output of the LD make its relative intensity noise (RIN)

Table 1
Value of parameter for simulation.

Parameter	Value
Input optical power P_o	1–100 mw
Half-wave voltage V_π	3.2 V@10 GHz
Relative intensity noise RIN	−160 dB/Hz
Electron charge q	1.6×10^{-19}C
Loss coefficient of EOM α	0.25
Detector's responsivity ρ	0.8 W/A
Boltzmann constant k_B	1.38×10^{-23} J/K
Experimental temperature T	300 k
Matched impedances of EOM Z_{in}	50Ω
Matched impedances of output load Z_L	50Ω