Influence of external electrooptical modulator biasing on gain and nonlinear distortions in analog fiber-optic links

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Abstract. The dependences of gain and nonlinear distortions in analogue fiber-optic links on bias of an external electrooptical modulator were investigated. The increase in the gain by up to 5 dB as compared with the conventional quadrature point operation was demonstrated by shift the bias voltage applied to the external electrooptical modulator to a low transmission. Dependences of nonlinear distortions on the bias voltage of an electrooptical modulator were investigated. A minor increase in nonlinear distortions (less than 0.5 \%) was observed at the conditions of a maximum gain. Proposed theoretical model is in a good agreement with the experimental data.

1. Introduction
Microwave fiber-optic links offer many advantages over coaxial cables and other metal guides. These are very low transmission losses (~ 1 dB/km), large bandwidths, small weight, and a high degree of immunity to radiation and electromagnetic interference [1]. The main drawbacks of these links are a limited dynamic range performance because of a low gain and nonlinear distortions.

It has been shown that maximal transmission coefficient (gain) and minimal nonlinear distortions in microwave fiber-optic links correspond to the quadrature bias point of the external electrooptical modulator [2]. A fairly low gain (\(\sim 20\) dB) in this case is mainly caused by the photodetector saturation due to a high power in the unmodulated carrier which does not convey meaningful information.

In this report we analyze the influence of bias voltage applied to the external electrooptical modulator on the main transmission characteristics of analog fiber-optic links. The gain optimization of the fiber-optic link with an external electrooptical modulator and an erbium doped fiber amplifier is performed.

2. Experimental setup and samples
In figure 1 the scheme of investigated radio-frequency (RF) fiber-optical transmission line is presented.
Junction laser (1) with laser central wavelength 1551 nm and controlled output to 20 mW was used as optical carrier source. The Mach-Zehnder modulator with half-wave voltage 6 V and modulation band width to 55 GHz and optical losses 5 dB was used as external electrooptical modulator (2). The bias voltage in range ±20 V (which fixes a work point) and sine wave signal generator at radiofrequency 100 MHz were applied to the input of the modulator. After modulator the optical signal was applied to input of erbium doped optical fiber power amplifier with pump wavelength 980 nm (3). Enhanced signal was transformed to digital signal by wide-band photoreceiver (5) and registered by oscilloscope (6). Optical attenuator (4) with propagation factor ~ 10 dB was used for increasing of transmission ratio.

In the experiments we measured the relative amplitude of fundamental harmonic (for transmission ratio evaluation) and the relative amplitudes of the second and the third harmonics (for evaluation of non-linear distortion influence).

3. Results and discussion

We investigated the optimization of RF fiber-optic link by bias voltage applied to the external electrooptical modulator to the transmission minimum. We used method based on the increasing of the optical signal modulation contrast and optical carrier suppression.

The transmission rate dependence of Mach-Zehnder electrooptical modulator is detailed described in [3]:

Figure 1. Experimental setup for investigation of radio-frequency fiber-optic link: 1 – laser; 2 – electrooptical modulator; 3 – erbium doped fiber amplifier; 4 – optical attenuator; 5 – wide-band photoreceiver; 6 – oscilloscope; 7 – optical power meter; 8 – laser pump diode; 9 – DC adjustable power supply; 10 – high-frequency generator.
where $I_0, I_1, I_2, I_3$ are the amplitudes of the zero, the first, the second and the third harmonics, $J_0, J_1, J_2, J_3$ are the zero, the first, the second and the third order Bessel functions of the first kind, $V_x$ is the half-wave modulator voltage, $V_{bias}$ is the modulator bias voltage, $V_{rf}$ is RF modulating signal voltage, $\omega$ is the frequency of RF signal.

In case of the modulator bias voltage shift to a low transmission of the amplitude-modulated optical signal, the constant component decreases faster than the first harmonics, which leads to increase in the optical signal modulation depth.

The dependence of the gain coefficient of optical erbium doped fiber amplifier on input optical power is [4]:

\[ G_{edfa} = \frac{G_0}{1 + (G_0/P_mz/P_{max})^\alpha}, \]

where $G_0$ is the amplification ratio of small signal, $P_{mz}$ is the modulator output optical power, $P_{max}$ is the maximal output power of amplifier in saturation regime, $\alpha$ is the empirical coefficient (which is close to 1).

At low modulation amplitude approximation the output modulator power may be evaluated as power of zero harmonic:

\[ \langle P_{mz} \rangle = \frac{P_{laser}}{2} [1 - J_0(\pi V_{rf}/V_x) \cos(\pi V_{bias}/V_x)], \]

where $P_{laser}$ is the output laser power, $J_0$ is the zero-order Bessel functions of the first kind.

Equation (2) describes the amplifier saturation due to increasing of the input optical power. In case of shift to a minimum transmission ratio of modulator the coefficient became equal to the amplification ratio of small signal, which increases with saturation power.

So, the transmission ratio of RF signal has the quadratic dependence on optical power and gain of optical amplifier:

\[ G_{rf} \propto [G_{edfa} \cos(\pi V_{bias}/V_x + \pi V_{rf}/V_x \sin(\omega t))]^2 \]

In figure 2 the theoretical curves of transmission ratio and non-linear distortions of RF optical-fiber link, which were calculated using equations (4) and (1) taking into account the experimentally evaluated parameters of the amplifier ($G_0 = 200$, $P_{mz} = 0.2$ mW, $P_{max} = 5$ mW, $V_x = 6.5$ V, $V_{rf} = 1$ V, $\alpha = 1$).

The increase in the link gain of up to 5 dB as compared with the conventional quadrature point operation was experimentally demonstrated. A minor increase in the nonlinear distortions (0.5 %) was observed for the relative bias voltage shift (0.5V) corresponding to the maximum gain.

As one can see from the presented data, the proposed theoretical model is in a good agreement with the experimental data.
Figure 2. Nonlinear distortions ($K_{nl}$, squares) and gain ($G_{rf}$, triangles) of a radio-frequency fiber-optic link as functions of relative shift of bias voltage ($V = (V_0 - V_{\text{min}})/V_r$) of external electrooptical modulator. Solid lines are calculated theoretical dependences and dotted lines are corresponded to experimental data.

4. Conclusion

The theoretical model describing the increase of transmission coefficient was developed. In accordance with it a shift of the modulator bias voltage to a low transmission and amplification of the amplitude-modulated optical signal by an optical amplifier operating near its saturation provide an optical carrier suppression, an increase in the optical signal modulation depth and, as a consequence, an increase in the maximum link gain limited by the photodetector saturation current. Theoretical dependences of gain and nonlinear distortion coefficient on the bias voltage of the external electrooptical modulator were calculated. They were found to be in a good agreement with the experimental data.

The results can be useful for the emerging technology of radiophotonics taking advantages of optical methods for generation, transmission, transformation, and processing of analog radiofrequency signals.

References

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