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Microwave 180-degree Hybrid Formed on $LiNbO_3$ Substrate for Frequency Chirp Modulation by Electro-optic Modulator

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Abstract A microwave rat-race (RR) circuit, which operates as the 180-degree hybrid, was designed with 2:1 power split ratio and fabricated on *z*-cut $LiNbO_3$ (LN) substrate. The property was confirmed by the experiment. An electro-optic modulator integrated with the RR circuit for frequency chirp modulation was designed on a single LN substrate.

Keywords Frequency chirp, Electro-optic modulator, Rat-race, 180-degree hybrid

1. Introduction

The frequency chirp in optical intensity modulation is caused by the parasitic phase shift induced with the intensity variation.[1] Electro-optic (EO) modulators can operate at microwave or millimeter-wave frequencies and are mainly applied to optical fiber communications. Moreover, EO modulators can induce intensity modulated light signals of well-controlled frequency chirping. Flat optical comb signals are created by such modulated light signals.[2] Optical comb signals can be used in applications such as optical frequency reference for accurate optical frequency measurement. Chirping light signals are also applicable to the pre-chirp modulation scheme for compensating the effect of optical fiber dispersion.

2. Frequency chirping of EO modulator

The EO intensity modulation is performed by interfering between two phase-modulated light waves as shown in Fig.1. The frequency chirp is caused by imbalance of the phase modulation in two arms. The chirp parameter in the small signal operation is approximately presented as $\alpha=(A_1+A_2)/(A_1-A_2)$, where A_1 and A_2 are amplitude of the phase modulation in two arms. The frequency chirp can be purposely induced if the driving signals of different power are applied to those phase modulation sections. The chirp

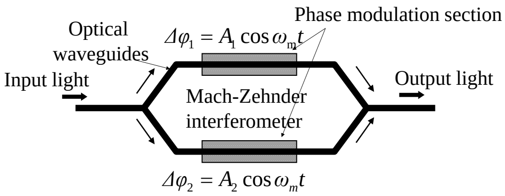


Fig.1 Electro-optic intensity modulator.

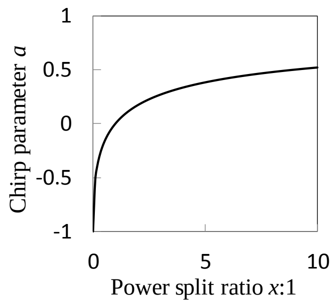


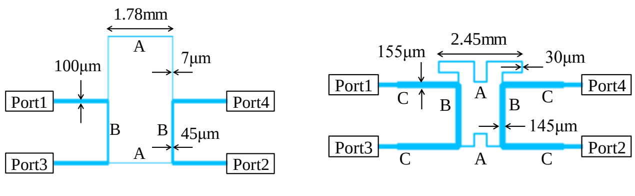
Fig.2 Chirp parameter as function of power ratio of driving signals between the two phase modulation sections

parameter of the modulated light is shown in Fig.2, where the power ratio of driving signals between the two phase modulation sections is represented by *x*:1.

We consider using a rat-race (RR) circuit, which operates as the 180-degree hybrid, of controlled power split ratio. Moreover, the RR circuit is integrated with modulation electrodes on a single modulator substrate for small-sizing and one-tip configuration.

3. Microwave rat-race circuit on $LiNbO_3$ substrate

Fig.3(a) shows a conventional RR circuit of 2:1 power split ratio on a *z*-cut $LiNbO_3$ (LN) substrate with the microstrip-line structure, where the ratio is adjusted by difference in characteristic impedance



(a) (b)

Fig.3 RR circuits designed on a LN substrate.

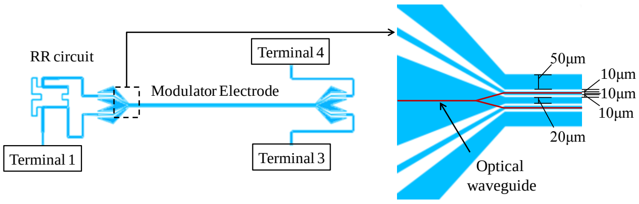


Fig.4 Electrode pattern of the modulator.

between line A and B. However, because of high characteristic-impedance of line A and high dielectric-constant of the LN substrate, the minimum line width, 7µm, is too narrow to fabricate. Fig.3(b) shows the proposed circuit pattern. The impedances of the lines are lowered to extend the line width. The quarter wavelength lines, C, are added for impedance matching with 50Ω ports. Moreover, the circuit is miniaturized by bending the lines A.

Fig. 4 shows the electrode pattern of the proposed modulator. The modulation electrodes are individually placed on two optical waveguides of the MZ interferometer. The output ports of the RR circuit are connected to the modulation electrodes through two lines of the same electrical length to keep the 180-degree phase difference. When the RR circuit of 2:1 power split ratio is used in the electrode pattern, modulated light signals of α of 0.17 will be expected as seen from Fig.2.

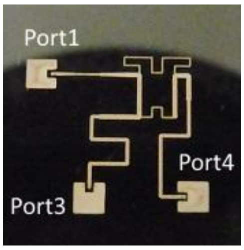


Fig.5 RR circuit part formed on a LN substrate.

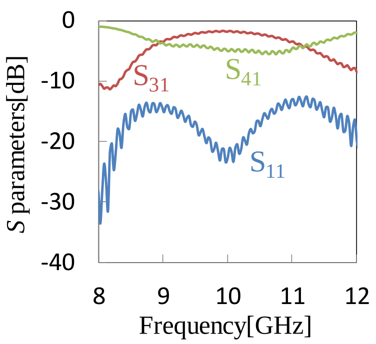


Fig.6 Measured frequency response of the RR circuit.

4. Experiment

Fig.5 shows the RR circuit part formed on a LN substrate. Fig.6 shows its frequency responses of *S* parameters measured by a prober system. $|S_{41}/S_{31}|$ =3.2dB at around 10GHz, which corresponds to the power split ratio of about 2.1:1. Optical modulation with chirp parameter α of around 0.18 is expected from the measured split ratio.

5. Conclusion

The RR circuit of asymmetric power split ratio was designed on a $LiNO_3$ substrate at 10 GHz for chirp modulation by EO modulator. The RR circuit was fabricated and the properties as the 180-degree hybrid with power split ration of 2.1:1 were confirmed by the experiment. By using this RR circuit for EO modulator, light modulation with chirp parameter of about 0.18 is expected.

Acknowledgments

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