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2014

Feng, Z., Fu, S., Tang, M., Lin, R., Wang, R., Shum, P., & Liu, D. (2014). Photonic generation of microwave signal with capability of arbitrary phase shifting using XPM in HNLF. Asia Communications and Photonics Conference 2014, ATh3A.84-.
doi:10.1364/ACPC.2014.ATh3A.84

<https://hdl.handle.net/10356/87837>

<https://doi.org/10.1364/ACPC.2014.ATh3A.84>

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Photonic generation of microwave signal with capability of arbitrary phase shifting using XPM in HNLF

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Abstract: Photonic generation of microwave signal with capability of full range phase tuning is proposed using XPM in the HNLF. Continuous phase shift with range of 360° is achieved together with compatible WDM operation.

OCIS codes: (350.4010) Microwaves; (060.5625) Radio frequency photonics; (050.5080) Phase shift.

1. Introduction

Microwave signals with arbitrarily tunable phases are critically important for many microwave applications, such as microwave phase shifter (MPS), phase-array antennas and microwave filters [1]. Until now, several photonic approaches have been demonstrated to realize MPS [2-6]. However, it suffers from a narrow range of MPS tuning, severe power fluctuation, and fixed frequency of tunable MPS operation, which limits its practical applications. Moreover, the operation of tunable MPS based on conventional techniques cannot be simply applied to wavelength division multiplexing (WDM) signals.

In this paper, we report a photonic approach to generate microwave signals with continuously tunable phase shifts based on cross phase modulation (XPM) effect arising in highly nonlinear fiber (HNLF). The frequency of generated microwave signal can be widely tunable, while the phase shift can be controlled dynamically thanks to the ultra-fast response of Kerr effect in the HNLF. Moreover MPS of multi-wavelength channel can be achieved due to the intrinsic WDM compatible property of photonic approach. The proposed method is theoretically analyzed and verified by simulation. The generated microwave signals with phase tuning range from 0-360° at the frequency of 25 GHz is obtained. And simultaneous two-wavelength channels phase shifting is also evaluated. Excellent agreement between the simulated results and theoretical derivation is achieved.

2. Operation Principle

Fig.1. Scheme of photonic generation of microwave signal with tunable phase shift based on XPM in HNLF.

The proposed system is schematically shown in Fig. 1. The probe light consists of two wavelengths aligned with two orthogonal states of polarization (SOP), namely x and y, respectively. The pump signal polarized at y direction co-propagates with the probe light through the HNLF where XPM effect occurs. Subsequently a polarizer is used to complete polarization-to-intensity conversion after the pump is de-multiplexed, so that two probe signals can be detected coherently by the photodiode (PD). Light travelling in different SOP will experience a different refractive index changes induced by Kerr effect due to different nonlinear coefficients with respect to the SOP. Thus two-wavelength probe with orthogonal SOP will bear different phases and microwave signal with phase shifts can be achieved after polarization rotation and heterodyne beating at the PD. In addition, the phase shift is dependent on the optical pump power so phase shift can be arbitrarily controlled by continuously tuning the pump power. Theoretically, the refractive indexes in x and y-axis of the HNLF is determined by the pump power if the self-phase modulation (SPM) of pump is neglected [5].

$$n_x = n_{x0} + 2n_2 |E_{Pump}|^2; n_y = n_{y0} + 2n_2 b |E_{Pump}|^2 \quad (1)$$

where n_x and n_y are refractive indexes in x and y-axis of the HNLF, n_{x0} and n_{y0} are linear part of the refractive indexes, n_2 is nonlinear index coefficient, E_{Pump} is the amplitude of the pump optical signal. If the origin of the third order susceptibility χ^3 is purely electronic, $b=1/3$ [5]. Therefore, the corresponding phase shifts of the probe light in two polarizations induced by the pump signal has the following expression,

$$\varphi_x = \frac{2\pi}{\lambda_1} n_x L_{eff}; \varphi_y = \frac{2\pi}{\lambda_2} n_y L_{eff} \quad (2)$$

where L_{eff} is the effective length of HNLF and λ_1, λ_2 are the wavelengths of x and y direction components of the probe light. The output probe light of the HNLF and the optical signal after polarizer can be expressed as

$$E_x = A_x \cos(\omega_1 t + \varphi_x); E_y = A_y \cos(\omega_2 t + \varphi_y) \quad (3)$$

$$E_{out} = E_x \cos \theta + E_y \sin \theta \quad (4)$$

where A_x and A_y are the optical signal amplitude of probe light in x, y directions; ω_1 and ω_2 are their angular frequencies, θ is the angle between the polarization orientation of the polarizer and x-axis direction. After beating at a PD with limited response bandwidth, we can get the microwave signal:

$$i = \frac{1}{2} R A_x A_y \sin(2\theta) \cos((\omega_1 - \omega_2)t + (\varphi_x - \varphi_y)) \quad (5)$$

$$\Delta\phi = \varphi_x - \varphi_y = L_{eff} \frac{2\pi}{\lambda_0} (\Delta n_L + \Delta n_{NL}) \quad (6)$$

where R is the responsivity of PD, $\Delta n_L = n_{x0} - n_{y0}$, $\Delta n_{NL} = 2n_2(1-b)P_{Pump}/A_{eff}$ are the linear and nonlinear differential refractive index between x and y direction; A_{eff} is effective area of HNLF; λ_0 is the average wavelength of λ_1 and λ_2 , and can be used to replace λ_1 and λ_2 when the wavelength spacing is small. Let $\theta = 45^\circ$, maximum output current can be obtained. As can be seen from Eq. (1)-(6), photonic microwave signal generation with tunable phase shift can be realized by tuning the pump power, and the system can be regarded as a optically controlled microwave phase modulator whose half-wave optical pump power, with the same definition of half-wave voltage for traditional phase modulator, is determined by the nonlinear coefficient γ :

$$P_{pump}^\pi = \frac{3\pi}{4L_{eff} * \gamma} \quad (7)$$

3. Simulation Results

To verify the principle the proposed microwave phase shifting, Optisystem 7.0 and matlab are used as our simulation platform. In our simulation, the dual wavelength spaced at 0.2 nm with orthogonal polarization probe light is generated by two independent laser sources, but in practice we can use carrier suppressed modulation scheme to obtain two phase-correlated carriers [6]. The length, attenuation parameter and the nonlinear coefficient γ of HNLF are 2 km, 0.2 dB/km and $10.02 \text{ (W.Km)}^{-1}$, respectively. Firstly, we investigate the relationship of the phase shift variation with the optical pump power. The optical pump power can be continuously tuned from 0 to 246 mW and the phase shift of the generated 25 GHz microwave signal is summarized in fig.2. We can see that the phase shift linearly changes with the pump power and when the pump power is 123 mW, the microwave signal reverses corresponding to an accurate π phase shift, which matches well with theoretical prediction in Eq.(7). Moreover the range of phase shifting can be continuously controlled from 0 to 360° and the power variation is small enough during phase tuning operation.

Fig.2 microwave signals with different phase shifts controlled by different pump power and power variation with phase tuning

Subsequently, two pairs of wavelengths with orthogonal polarization are used as probe light to demonstrate the WDM compatible operation of our proposed system. As can be seen from Fig.3, not only phase shift operation simultaneously in two channels but also different frequencies of microwave signals with phase shift can be realized simultaneously using only one pump optical signal. Therefore, the capability of WDM operation is verified.

Fig.3. phase shift of two microwave signals without and with half-wave pump power at different frequencies: left at 25 GHz, right at 50 GHz

4. Conclusion

We have proposed a photonic approach to achieve microwave signals with a full 360° tunable phase shifting range. Phase shifted microwave signals at different operation frequencies are shown by simulation results. Continuously tunable microwave phase shift with small power variation can be obtained. Furthermore, simultaneous phase shift operation for multi-channel microwave signals is also demonstrated.

This work was supported by the 863 High Technology Plan (2012AA011301) and National Natural Science Foundation of China (61275069, 61331010).

5. References

- [1] Zhenhua Feng et al, "Multichannel continuously tunable microwave phase shifter with capability of frequency doubling," IEEE Photonics Journal, **6**, 1-8 (2014)
- [2] Zhenhua Feng et al, "Continuously Tunable Microwave Phase Shifter with Capability of Frequency Doubling Based On Spectral Shaping Technique," in ACPC 2013 paper: ATh3F.3
- [3] Huizi Li et al, "Photonic Generation of Frequency-Quadrupled Microwave Signal With Tunable Phase Shift," IEEE Photon. Technol. Lett. **26**, 220-223 (2014).
- [4] Shilong Pan et al, "Tunable and wideband microwave photonic phase shifter based on a single-sideband polarization modulator and a polarizer," Opt. Lett. **37**, 4483-4485 (2012)
- [5] Jianyu Zheng et al, "Photonic-assisted microwave frequency multiplier based on nonlinear polarization rotation," Opt. Lett. **39**, 1366-1369 (2014).
- [6] Han Chen et al, "Microwave photonic phase shifter based on birefringence effects in a semiconductor optical amplifier," Opt. Lett. **38**, 3272-3274 (2013).