Optics Communications 354 (2015) 140–147

Contents lists available at ScienceDirect

Optics Communications

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

Instantaneous microwave frequency measurement with improved resolution

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ARTICLE INFO

Article history:
Received 10 April 2015
Received in revised form
14 May 2015
Accepted 21 May 2015
Available online 28 May 2015

Keywords:
Microwave photonics
Instantaneous microwave measurement
Improved resolution

ABSTRACT

An approach of instantaneous microwave frequency measurement with improved resolution is proposed and analyzed. The primary component employed in the proposal is a polarization modulator (PolM) followed by a linear polarizer (LP) and a spool of dispersive fiber. To obtain a flexible amplitude comparison function (ACF), the polarization state between the PolM and the LP should be properly adjusted. It is found that the notch point of the ACF can be widely shifted by simply adjusting the bias voltage applied to the PolM, especially, a greater first-order derivative of the ACF ensures that the measurement resolution can be improved when compared with the work in the reference.

1. Introduction

In the field of electronic warfare (EW), instantaneous microwave frequency measurement (IFM) can be employed to identify the unknown radio frequency (RF) before its further processing, which has been considered as a topic of interest in the past few years. Compared to conventional electronic schemes, photonic IFM can afford considerable merits such as the high bandwidth, low loss, and immunity to electro-magnetic interference [1,2]. In general, a photonic IFM system can be implemented by using coherent optical RF channelizer [3,4], complementary optical filter [5–7], and fiber dispersion-induced power-fading functions [8–18]. For the approaches based on power-fading functions which were reported in [8–18], it is a promising solution to obtain large frequency measurement range and relative high resolution by monitoring the output powers with an optical microwave signal that experiences different power penalties imported. However, for most cases [8–12], the trade-off issue between the measurement range and resolution exists. In other words, to obtain a high resolution, we need to sacrifice the measurement range, which is not desirable in modern EW application. Fortunately, recent IFM technique with high resolution and tunable measurement range has been extensively studied to solve this problem. For instance, applying adjustable dispersion via tuning two optical wave-length with a large wavelength spacing [13] is an option. But the major limitation of this approach is that: the tuning range is restricted to few giga-Hertz due to the small dispersion change resulting from the wavelength tuning. Or it can be solved by employing a dual-output Mach–Zehnder modulator [14]. The measurement range can be extended by carefully tuning the laser's wavelength. Nevertheless, a huge wavelength tuning so as to reach a relatively higher dispersion variation is still required. Then a reconfigurable IFM system based on stimulated Brillouin scattering was reported in [15]. By varying the reference driving frequency, the measurement range as well as the resolution can be adjusted. Afterwards, the same group proposed a reconfigurable IFM system based on a dual-parallel Mach Zehnder modulator (DP-MZM) and a Mach–Zehnder modulator in [16]. It is further demonstrated that the measurement range can be tuned not merely by adjusting laser wavelength as previous wavelength tuning methods, but also by adjusting the DC bias voltage. But the above two approaches [15,16] all use one or two MZMs and relatively complex structure, which may result in high cost and complex parameter manipulation. Later in 2013, a flexible IFM system based on a polarization modulator (PolM) is proposed [17]. By simply adjusting a polarization controller, both of the range and the resolution can be finely tuned though large wavelength spacing is still indispensable in this scheme. Then in [18], we have proposed an improved IFM prototype using only one laser source but no optical filter so that the setup has been simplified. The range and resolution are tunable if the polarization angle is carefully adjusted. However, the approach in [18] still suffers from the trade-off problem at a relative large measurement range.

In this work, we report an IFM system with improved resolution. The proposal utilizes two-wavelength laser source. Unlike the approaches in [13,14,17], there is no requirement of a large wavelength spacing, which leads to less parameter manipulation

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http://dx.doi.org/10.1016/j.optcom.2015.05.050
0030-4018/

during dispersive element processing. The key component is a PolM to which the DC voltage is applied. The principle leys as follow, firstly the lightwaves from two laser sources are aligned with orthogonal polarization via a polarization beaming splitter (PBS) and the wavelength spacing can be small in this approach. Then the lightwaves are coupled to the PolM with $\pm 45°$ relative to one principal axis of the PolM. After modulation, the lightwave is sent into a linear polarizer (LP) followed by a spool of dispersive fiber. The polarization angle of the LP is introduced so that the amplitude comparison function (ACF) can be constructed properly. Finally, by simply tuning the bias voltage, the notch point of the ACF can be widely shifted and the ACF has a larger slope over the same measurement range when compared with the approach in Ref. [18], which represents an improved resolution. Besides, the trade-off problem can be relieved.

2. Theory and discussion

2.1. Operation principle

The schematic setup of the proposed IFM system is shown in Fig. 1. Two continuous-wave (CW1 and CW2) lasers serve as the optical source. The lightwaves from the two lasers should be firstly aligned with orthogonal polarization via the two polarization controllers (PC1 and PC2) followed by a polarization beaming splitter (PBS), which are employed to adjust the polarization state of two-path lightwaves. Then the lightwaves are coupled to the polarization modulator (PolM) with $\pm 45°$ relative to one principal axis of the PolM, which can be controlled by the third PC (PC3). The PolM is driven by the unknown microwave signal to modulate the lightwaves and it is connected with a linear polarizer (LP) via PC4 with a polarization angle of 10°. Then the output signal is launched into a 2 km single mode fiber (D=17 ps/km nm) and the dispersion is introduced. After the fiber transmission (neglecting the attenuation, constant phase and high order terms of dispersion), a wavelength division multiplexer (WDM) is used to separate the two lightwaves. Finally, the microwave powers are detected via photodiodes (PD1 and PD2) and the AC terms of the photocurrent can be simply obtained as [18]:

$$i_{PD1}(t) \propto |E_1|^2 J_0 J_1 \sqrt{1-(0.34\ \cos\ \varphi_0)^2}\,(0.94\ \sin \Phi_1 - 0.34\ \cos \Phi_1 \sin\ \varphi_0)\sin \Omega t \tag{1}$$

$$i_{PD2}(t) \propto |E_2|^2 J_0 J_1 \sqrt{1-(0.34\ \cos\ \varphi_0)^2}\,(0.94 \sin \Phi_2 + 0.34 \cos \Phi_2 \sin \varphi_0)\sin \Omega t \tag{2}$$

where E_1- and E_2-magnitude of optical carriers, J_n-the Bessel function of the first kind of order n, $\Phi_1=-\lambda_1^2 DL\Omega^2/4\pi c$ and $\Phi_2=-\lambda_2^2 DL\Omega^2/4\pi c$ represent the dispersion-induced phase shift, Ω-the angular frequency of the unknown microwave signal, λ_1 – and λ_2 – the optical wavelength, c – the speed of light in vacuum, L – fiber length and D – chromatic dispersion parameter. $\varphi_0=\pi V_0/V_\pi$ is the bias voltage-induced phase shift, V_0 – the bias voltage and V_π – the half-wave voltage of PolM.

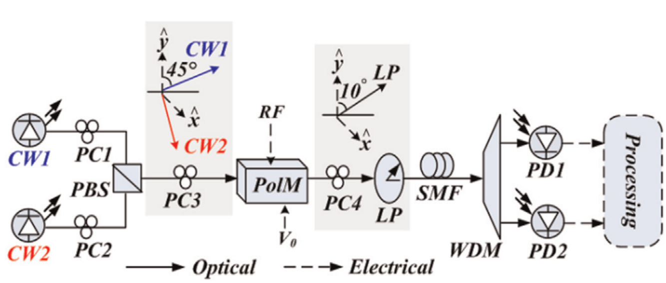

Fig. 1. Schematic setup of the proposed IFM system (CW, continuous wave; PC, polarization controller; PBS, polarization beam splitter; RF, radio frequency; PolM, polarization modulator; LP, linear polarizer; SMF, single mode fiber; WDM, wavelength division multiplexer; PD, photodiode).

Comparing the microwave power from PD1 and PD2 at the post-processing stage, we can obtain the amplitude comparison function (ACF) as:

$$ACF = \frac{P_{PD1}}{P_{PD2}} = \eta \frac{(\sin\ \Phi_1 - 0.36\ \cos\ \Phi_1\ \sin\ \varphi_0)^2}{(\sin\ \Phi_2 + 0.36\ \cos\ \Phi_2\ \sin\ \varphi_0)^2} \tag{3}$$

where $\eta=(E_1/E_2)^4$ represents the power ratio between two lasers. By adjusting the output power of CW1 and CW2, we can obtain η=1. As can be seen in Eq. (3), ACF is dependent on several variable factors including the wavelengths of two lasers (λ_1 and λ_2), the dispersion DL and the bias voltage-induced phase shift φ_0. Taking λ_1=1550.12 nm, λ_2=1550.92 nm (the wavelength spacing is as small as 0.8 nm), DL=34 ps/nm and $V_0=0.5V_\pi$ for example, Fig. 2(a) and (b) illustrate the spectrum property of the power fading and the ACF. As shown in the Fig. 2(b), the notch point of ACF is around 20.2 GHz so the ACF decrease monotonically from 0 GHz to around 20.2 GHz, which can be used to measure the frequency.

2.2. The maximum measurement range and its manipulation

For practice applications, tuning the measurement range is quite necessary. The upper measurement range of the proposed IFM system is limited to the position of the first notch of the ACF so as to avoid frequency ambiguities. Note that the notch point of an ACF curve can be shifted to a high frequency band and the maximum measurement frequency f_{MAX} is dependent on λ_2, DL and φ_0. It can be given by:

$$f_{MAX} = \sqrt{c\frac{\arctan(0.36 \sin \varphi_0)}{\lambda_2^2 DL\pi}} \tag{4}$$

By solving Eq.(4), we can see that the measurement range can be extended by decreasing the wavelength λ_2 and dispersion DL or by increasing bias voltage V_0. In Ref. [13,14,17], the impact of wavelength on measurement range has been discussed. So here we only focus on the other two variable factors. Firstly we set $V_0=0.5V_\pi$ and the f_{MAX} versus dispersion DL is analyzed and plotted in Fig.3. Apparently, when the dispersion DL is smaller, the measurement range becomes larger. However, the dispersion cannot be tuned continuously, thus the simpler manipulation of bias voltage V_0 might be a proper solution.

2.3. Tuning the measurement range using active bias voltage control

In order to explore the relationship between the measurement range and bias voltage, we fix the dispersion DL=34 ps/nm and adjust the bias voltage V_0 from 0 to V_π. The f_{MAX} versus bias voltage V_0 is shown as in Fig. 4(a). We can see the axisymmetric curve firstly ascends and then descends so that the maximum value is obtained in its symmetric axis, therefore, the maximum measurement range can be achieved as 20.2 GHz when $V_0=0.5V_\pi$. Moreover, four cases are marked with symbols of a ($V_0=0.07V_\pi$), b ($V_0=0.14V_\pi$), c ($V_0=0.23V_\pi$), and d ($V_0=0.36V_\pi$) and the correspondent ACFs are plotted in Fig.4(b). As can be seen the measurement range can be extended by increasing bias voltage V_0. Fig. 4(b) presents that the notch point is shifted roughly from 9.3 GHz to 19.3 GHz when V_0 is adjusted from $0.07V_\pi$ to $0.36V_\pi$, i.e. the measurement ranges are 0–9.3 GHz, 0–13.5 GHz, 0–16.6 GHz