Devices of Radio Over Fiber System based on Fiber Bragg Grating

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ABSTRACT

Nowadays, researches on microwave photonics become more and more important due to the needs for wideband and wireless multimedia. The typical utility system is the radio over/on fiber (ROF) system. In the past few years, fiber Bragg grating (FBG) has been widely used due to its unique characteristic of wavelength selectivity. Hence, a variety of ROF devices based on FBG have become one of the best programs. In this paper, two kinds of microwave photonic filter are studied, the frequency responses are simulated and the perfect results are gotten. Besides, a method is proposed to realize millimeter-wave sub-carrier generation at central station by using a double-uniform FBG filter scheme. The advantages are analyzed by designing a ROF downlink system, and the eye diagrams in different transmission distance are also analyzed.

Keywords: ROF;FBG; Microwave photonic filter(MPF); Microwave photonic generator(MPG)

1 INTRODUCTION

Wideband mobile communication which attracts a lot of interesting with the needs for multimedia communication has become more and more instance [1-2].Optical fiber becomes a focus because of its broad bandwidth, low loss, light weight, immunity to electromagnetic interference and so on. ROF technology modulates radio signals onto an optical carrier for transmission over low loss optical fiber, and microwave and millimeter-wave signal can be processed in the optical domain directly, so it is a cost effective way for the distribution of information and services that require large bandwidth and high data rates from a single central office to multiple base stations. ROF technology can also be used for range extension. The coverage area can be shifted to cover a larger area that could not have been previously possible in a wireless setup.

As a result, ROF system is believed as one of the best schemes for communication and has been a topic of interest for more and more researchers. As we all know, FBG has been the simple and practical implement due to its flexible wavelength selectivity and has been widely used in the laser, filter and sensor etc. Thus, forming the key implements in the microwave photonics employing FBG becomes one of the best shemes.

In this paper, two kinds of MPF are studied, the frequency responses are simulated and the perfect results are gotten. Besides, a method is proposed to realize millimeter-wave sub-carrier generation at central station by using a double-uniform FBG filter scheme. Two optical waves with a spectrum of a millimeter-wave sub-carrier distance heterodyne after detector at base station, then the wanted millimeter-wave signal can be gotten. The advantages of this millimeter-wave sub-carrier generator are analyzed by designing a ROF downlink system, and the eye diagrams after detection and interference demodulation in different transmission distance are also analyzed. Moreover, performance of this ROF downlink system could be improved by reducing the bandwidth of band-pass filter used in the millimeter-wave sub-carrier generator. The proposed scheme may be taken as one of the candidates for the next generation high-speed and large-capability ROF system. With the improvement of optical fiber technology and the development of specialty optical fiber, we believe that MPG in optical domain and the MPF are bound to practical in the near future.

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2 A TUNABLE MPF BASED ON TWO CASCADED MODULATORS AND CFBG

As one of the key technologies in microwave photonics, tunable MPF can process RF signal in the optical domain directly and flexibly [3-13]. It has been a subject of active research in ROF system in the past few years.

2.1 Structure of the tunable MPF based on two cascaded modulators and CFBG

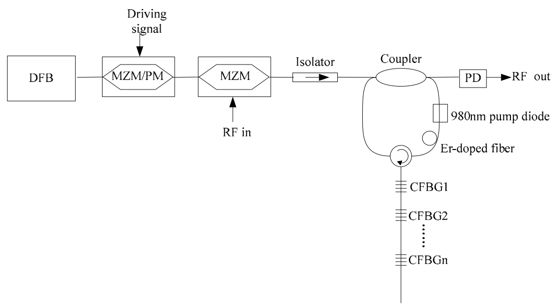

Fig.1 The structure of the tunable MPF

In view of the problems existing in the MPF such as complex structure, high cost, difficult to be adjusted, and so on, a tunable MPF with multiple carriers based on two cascaded modulators and chirp fiber Bragg grating (CFBG) is put forward and studied. The structure of the tunable MPF is shown in Fig.1.

Firstly, the laser signal from DFB laser is launched into a Mach-Zehnder modulator(MZM) or a phase modulator(PM) with the electric driven, multiple light sources can be produced, and then the carrier into the second MZM with the RF signal driven. The final modulated signal transmits to the fiber loop with CFBG. The fiber loop contains certain length of erbium-doped fiber (EDF) to improve the quality factor.

The tunable MPF can decrease the cost of MPF which employing laser array by cutting down the number of the light source. And its tunablility can be achieved easily by changing the drive signal of the first modulator and the center wavelength of the CFBG.

2.2 Theoretical analysis

The laser signal of DFB we choose is 193.1THz, and the modulator’s bias voltage is zero. The modulating signal is sine wave at 32GHz or 64GHz respectively. After the first modulator, the results are shown in Fig.2. and Fig.3.

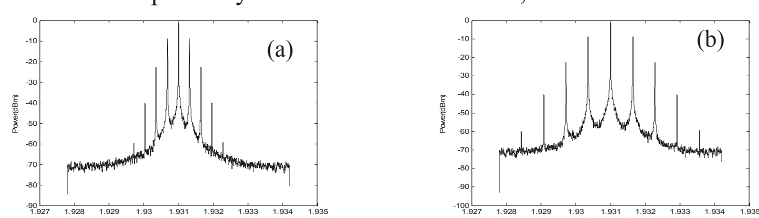

Fig.2 The modulated signal after modulating by a PM with different modulated signal (a) 32GHz (b) 64GHz

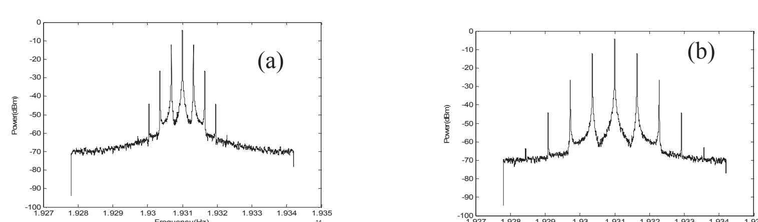

Fig.3 The modulated signal after modulating by a MZM with different modulated signal (a) 32GHz (b) 64GHz

From Fig.2 and Fig.3, we can see that some sideband are produced, and the modulated results are almost the same by using PM or MZM. As PM is insensitive to the fluctuation of the bias voltage of modulator, it is easier to get more stable results, so PM is always the better choice.

The multiple light sources after the first modulator like the laser array with a wavelength space w_S , where w_S is decided by the frequency of the modulating signal. By using CFBGs with different center wavelengths, different carriers can be chosen and the MPF with different performances can be gotten, as shown in Fig.4

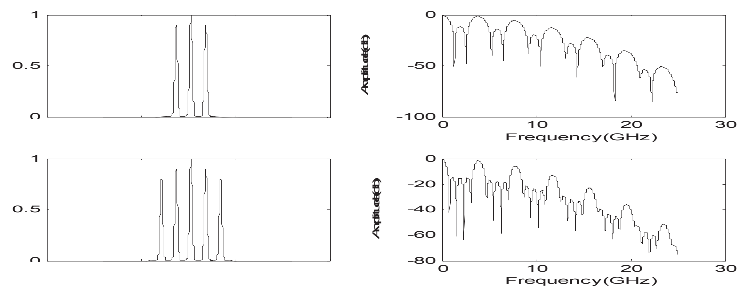

Fig.4 The performance of MPF with different number of carriers

From Fig.4, we can see that with the stable FSR, the more number of the carriers, the narrower of the 3dB bandwidth of the MPF, and the better of the MPF characteristics.

3 A FLAT MPF BASED ON MZM AND FBG

Recently there are many reports for MPF with various of methods based on FBG [6-13], but the flat response are not good enough which will prevent them from widely usage. So how to get the flat response of MPF is one of the key problems that need to be solved.

3.1 Structure of the flat MPF based on MZM and FBG

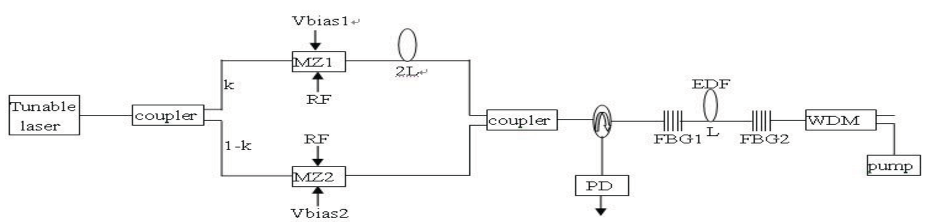

Fig.5 The structure of the flat MPF

Different bias voltage can make different phase for a MZM [14-15]. And a pair of FBG with EDF can make a lot of taps [10]. Based on these, a flat MPF with multiple taps by using the MZM, FBG and EDF is put forward, and the structure is shown in Fig.5.

This flat MPF includes two important parts which work as two filters, the first part includes a pair of couplers, with two MZM in the connecting arms separately, different bias voltage for the two modulators modulating RF signal are used to get π phase difference due to the MZM particular characteristic and the negative coefficient can be gotten[5]. A $2L$ length difference between two arms is used, and the same FSR to the second filter can be gotten, which will make sure that the period is not changed by superposing the response of the two filters. In this situation, wave crest of one filter is corresponding to the trough of the other filter to get the flat effect by superposing. The second part comprises EDF within a pair of FBGs[10]. FBG1 has a reflectivity of R_1 and FBG2 has a 100% reflectivity. Part of the light is reflected off FBG1, and part is transmitted passing through the EDF amplifier before fully reflected off FBG2. Upon reflection from FBG2, the signal follows a return path through the EDF and encounters FBG1 again. FBG1couples part of the signal to the output forming the taps of the impulse response, while returning some of the signal to be re-amplified and to repeat the process. Hence the signal is reflected successively from the gratings by passing it back and forth between the gratings and the EDF.

The response of MPF can be changed by the coupler's factor, reflectivity of the FBG or the gain of the EDF. And the FSR of the MPF can be changed by the length of the EDF.

3.2 Theoretical analysis [6] [14-15]

By studying the transfer function signal flow chart of the filters, the transfer function is gotten, as follows,

$$H = H_1(w) \times H_2(w) = [k-(1-k)e^{jwT}] \cdot [\frac{R_1 z - 2R_1 R_2 g + R_2 g}{z - R_1 R_2 g}] \quad (1)$$

Where, k is the factor of the coupler, g is the gain of the EDF and R_1 is the reflectivity of the FBG1. R_2 is the reflectivity of the FBG2 and the parameter is 1. The different response of MPF can be gotten by changing any value, and the results are shown in Fig.6.

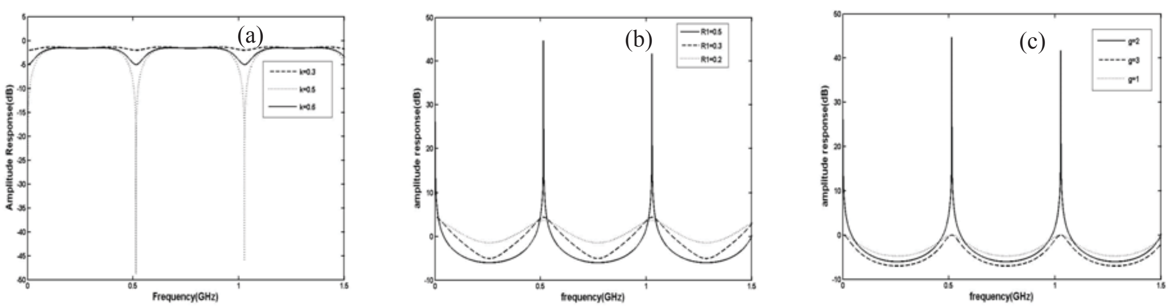

Fig.6 The influence of different values on the response of MPF(a)The influence of the coupler's factor to the amplitude of the first filter;(b) The influence of the reflectivity of FBG1 to the amplitude of the second filter when $g = 2$; (c)The influence of the gain of the EDF to the amplitude of the second filter when $R_1 = 0.5$

From Fig.6(a), we can see that the biggest depth of pass band can be gotten when k is 0.5, it is because the two arms have different power due to the different coupler factor, and the different phases make the power change after interference and superposition.

From Fig.6(b) and Fig.6(c), we can see that when $R_1 = 0.5$, the second filter has the biggest depth when $g = 2$, if the gain is bigger or smaller, the depth is very small. This is because that the FBG2 has a reflectivity of 100% to make sure getting more and more taps, so the gain of the EDF should make the power at the FBG1's output which is through back and forth between the gratings and the EDF is equal to the power of the FBG1's first output.

Hence we can control the shape of the second filter through changing the gain of EDF and the reflectivity of FBG1, while control the shape of the first filter by modulating the value of the coupler factor. The better results are gotten which show the flat band pass or flat band stop microwave photonic filter response, as shown in Fig.7.

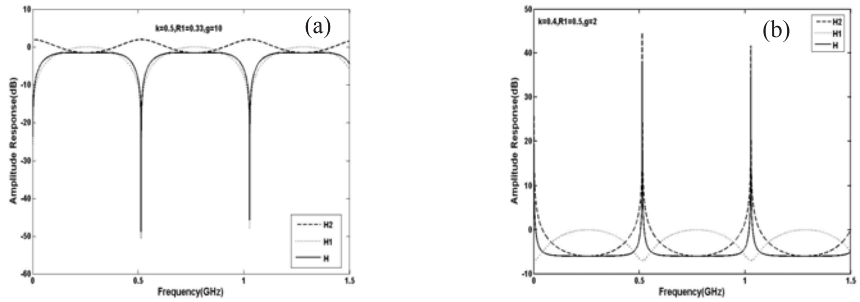

Fig.7 The response of flat MPF (a) Flat band top (b) Flat band stop

Fig.7(a) is the response of a flat top MPF, where the optimized parameters are $g = 10$, $R_1 = 0.33$ and $k = 0.5$, Fig.7(b) is the response of a flat stop MPF, where the optimized parameters are $g = 2, R_1 = 0.5, k = 0.4$. From the results we can see that the flat response is decided by the wave crest and the trough of the two filters. Hence a flat response can be realized if the wave crest is just matched with the trough.

4 MPG BASED ON FBG

ROF system needs a stable source as the local oscillation, so the study of microwave generator with stable performance becomes one of the key issues. In order to solve the exist problems of electrical microwave generator, microwave generator based on optical implements comes into being.

4.1 The structure of the MPG based on FBG

In the document [16], it put forward a method of producing millimeter signal by FBG. But it can not decrease the phase noise in total. In view of the problem, we put forward an improved frame ,as shown in Fig. 8.

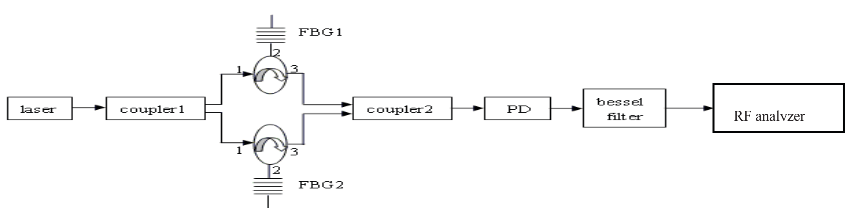

Fig.8. The structure of the MPG based on FBG

Light from the laser is divided into two even waves by coupler1 and go into two circulators with two FBGs connected in port 2 respectively. The center frequency difference of the two FBGs is the frequency of the microwave signal we need. Two lights reflected by two FBGs transmit into photo-detector(PD) through port 3 of two circulators. Finally, the heterodyne light enters the RF analyzer and gets the RF signal.

4.2. Analyzing and discussion

By analyzing, the expression of the output current of PD is gotten, as follows:

$$I = \alpha E_1 \cdot E_2 \cdot \cos(\omega_c t + (\Phi_1 - \Phi_2)) \tag{2}$$

Where, the dark current of the PD is 10nA, the responsibility is 1A/W. ω_c is the difference of two reflective lights from two FBG. Φ_1, Φ_2 are the phase respectively. E_1, E_2 are the electric field intensity.

Taking the microwave frequency is 60GHz as an example, the center wavelength of the laser is 1551.52nm, and the power is 10dBm. The center frequency of FBG1 is 193.14 THz and the center frequency of FBG2 is 193.2 THz. We get the frequency spectrum before heterodyning in the PD, as shown in figure 9(a). From it we can see that the heterodyne light entering the PD comprises two frequencies and the difference is 60GHz. In addition, the powers at the two frequencies are different due to the different reflectivity of two FBGs. After detecting, the spectrum at the output of PD is shown in Fig. 9(b). The RF signal after detecting includes two parts that are 0-15GHz and 46GHz-74GHz. So it is necessary to use a filter to get the needed millimeter signal. The final spectrum is shown in Fig. 9(c).

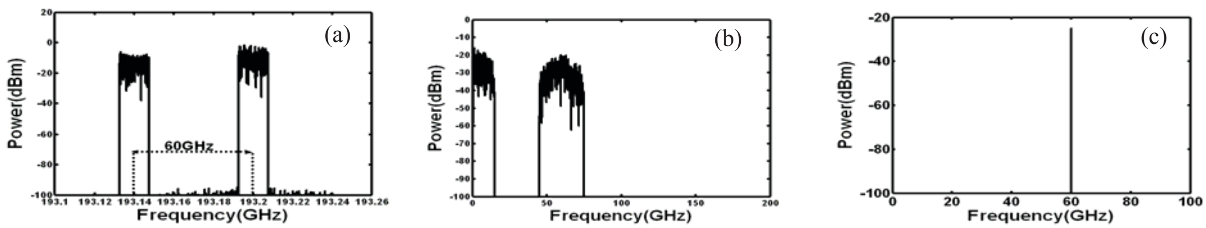

Fig.9 The spectrum of MPG (a) Heterodyne light before PD (b) Output of PD (c) 60GHz millimeter wave after filtering

Based on our MPG, we build the ROF downlink system. The eye diagrams are got at the base station receiver after PD and coherent demodulator with different transmission distance. Fig.10 gives the eye diagram after demodulation at base station when the transmission distance are 30km and 40km, and the results show that the program can maintain a fairly good performance after 30km transmission.

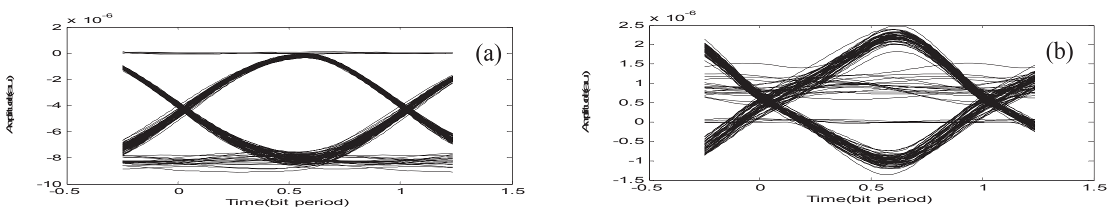

Fig.10 Eye diagram after demodulation in different transmission distance at base station(a)30km (b)40km

In short, the program provides a large transmission bandwidth and it could realize broadband communications. Moreover, the base station does not require high RF local oscillation source to converse the frequency, so it greatly simplifies the base station settings. It not only relaxes the bandwidth requirements for the FBG as a filter, but also avoids introducing of additional phase noise caused by the receiving end of restoring base-band signal, hence it greatly extends the transmission distance.

5 CONCLUSIONS

FBG has the unique characteristic of wavelength selectivity. Varies of fiber implements based on FBG has gone to practical gradually with its facture becomes more and more consummate especially in filter and laser domain. In addition, MPG and MPF have been one of the key issues due to the development of the ROF system and the increasing needs for wideband communication. In view of the situation, we study deeply in the microwave photonic filter and the millimeter wave producer. The simulation matches well with the theoretical analysis and the advantages of the FBG are incarnated perfect in the microwave photonics. With the improvement of optical fiber technology and the development of specialty optical fiber, we believe that MPG in optical domain and the MPF is bound to practical in the near future.

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