Optical Mixing of Antenna Signals in WDM Systems

B. Cabon Member, IEEE, V. Girod, G. Maury

LEMO-ENSERG, 23 rue des Martyrs - BP 257 - 38016 GRENOBLE Cedex – France
Ph : (33) 4 76 85 60 27 ; Fax : (33) 4 76 85 60 80 ; E-mail: cabon@enserg.fr

Abstract — We present here an original method for optical generation of microwave mixing on different multiplexed optical carriers : usually, mixing is achieved with active devices, here it is achieved with a passive optical device. Mixing on several multiplexed optical channels is obtained with the same device, a unique interferometer, working on any wavelength range, and is neither limited in the number of optical carriers nor in the number of RF ports. Thus, the presented technique can be advantageously applied to radar signal processing in optical systems because this type of multiplexing cannot be obtained in the pure electrical domain.

I. INTRODUCTION

The growing demand on opto-microwave processing in optical systems induced a few years ago the emergence of intense research in the domain of opto-microwave interactions [1]. Photonic techniques are developed for processing high bandwidth microwave signals and can be advantageously applied to the future antenna systems.

In this paper, we focus on optical generation of microwave mixing. Parallel microwave mixing is obtained using WDM. We use directly modulated Laser Diodes (LD) and a passive interferometer integrated on glass substrate for production of mixing. This is a low cost solution that can be implemented on industrial antenna systems, that provides mixing conversion gain and parallelism in processing channels.

Mixing can be applied first to up-conversion : using this method, converted signals which frequency is well beyond the usual modulation bandwidth of a directly modulated LD can thus be obtained. For example, RF signals at 5 GHz (the oscillation frequency of the laser diode being 6,5 GHz), can be up-converted to 11 GHz by a local oscillator at 6 GHz. This can be applied to fibre-radio systems. Mixing on the optical link can also be applied to down-conversion : down-converted microwave subcarriers transmitted over fibers can then be processed more easily. This case finds applications in antenna systems.

Many solutions for microwave mixing using optical components have been reported previously. Usually, microwave mixing is obtained with optoelectronic modulating devices (direct or external modulation) working in a non-linear regime [2], or with non-linear photodetection [3].

An alternative method explored here and detailed in Ref [4], realizes up-or-down conversion on the optical link while the directly modulated LD is working in a linear regime. Direct modulation of the LD generates both frequency modulation (FM) and amplitude modulation of the field. A fully passive component, an Unbalanced Mach-Zehnder (UMZ) interferometer integrated on glass is used to convert FM into IM. For particular interference regime, the conversion is non linear and generates mixing. Here is presented a further step of this technique, where microwave mixing products are multiplexed on two optical carriers at 1308 and 1551 nm. Wavelength division multiplexing techniques have already been used for microwave signal processing [5,6]. The advantage of the method presented here is that it uses a unique component to process simultaneously and in parallel different information signals. The configuration is able to work at different wavelength ranges (here for example in the range around 1308 nm or 1550 nm) with the same device.

II. MULTICHANNEL PHOTONICS MICROWAVE MIXER

Our technique is based on the association of DFB LD each directly modulated by two microwave subcarriers (f_{LOi}, f_{RFi}) and an UMZ integrated on glass substrate by Tl+/Na+ ion-exchange as shown in Fig.1.

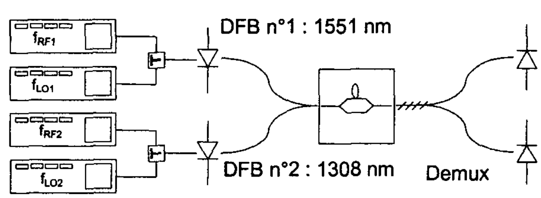

Fig. 1. Optical- microwave mixer set-up with multiplexed 1308-1550 nm carriers.

The passive interferometer is entirely fabricated in our laboratory, and a layout of this device is presented in

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Fig.2. The UMZ has a path difference ΔL between the two arms and when used in the incoherent interference regime, acts as a microwave frequency rejection filter as shown in Fig.3. Rejection frequencies are an odd integer of half free spectral range (FSR), with $FSR=c/(n\Delta L)$, and rejection period equals FSR. In the coherent regime, the two fields propagating on the two arms of the UMZ beat on a high-speed quadratic photodetector (PD), which leads to microwave mixing products $f_{LOi}\pm f_{RFi}$ in the spectrum of the PD current. An accurate control of the optical coherent interference regime allows to optimize the mixing response. The UMZ filters undesirable microwave frequencies of the optical field and, in consequence, a good rejection of the input signals can be obtained in the output detected spectrum.

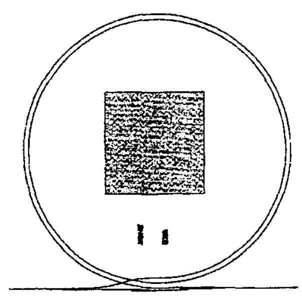

Fig. 2. : Layout of the UMZ interferometer integrated on glass substrate.

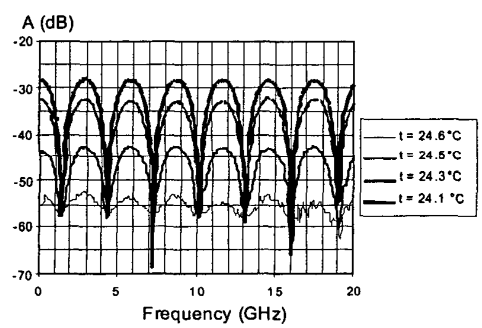

Fig. 3.: UMZ microwave frequency response, in the incoherent regime.

Finally, this microwave mixing technique in the optical domain can benefit from optical carriers multiplexing possibilities which is a specificity of photonics.

III. OPTIMIZATION OF THE OPERATION POINT ON THE DIFFERENT CHANNELS

Our integrated UMZ has a Free Spectral Range (FSR) of 3 GHz. Therefore, theoretical investigation shows that microwave subcarriers frequencies (f_{LO} and f_{RF}) have to be an odd integer of half FSR/2 [4] :

$$f_{LO} = \frac{FSR}{2} + k_{LO}.FSR$$
$$f_{RF} = \frac{FSR}{2} + k_{RF}.FSR \qquad (1)$$

This is the so called first condition.

For FSR=3 GHz, the input frequencies can be 1.5, 4.5, 7.5 GHz. In fact only the first two can be used because the resonance frequency of our LD approximates 6 GHz.

Performances of the microwave mixing depend on the Henry factor α (linewidth enhancement factor), which is the parameter measuring the chirp of a LD : the higher it is, the better is the microwave mixing in terms of converted power. The first LD emits about 2 mW of optical power at λ_{opt}=1308 nm and has a Henry factor of 7. The second LD emits about 5 mW at λ_{opt}=1551 nm and α is about 5.

A second condition (Rel. (2)) has to be verified for better microwave mixing performances. It is related to the optical interference figure, which has to be either a maximum, or a minimum :

$$\cos\left(\frac{2\pi c}{\lambda_{opt}.FSR}\right) = \pm 1 \qquad (2)$$

This optical condition gives the precision in positioning the operation point in terms of λ_{opt}. The variations $\delta\lambda$ are produced by the bias current of the LD. The measured power obtained at the output of the PD is the response of the system LD-UMZ-PD. The power of mixing products at $f_{LO}\pm f_{RF}$ is measured by a rapid PD, while the average optical power is measured by a slow PD. Fig.4 confirms Eq.(2), i.e. that maximum mixing power is obtained at maxima or minima of the interference figure. The authorised periodic shift $\delta\lambda$ for a given λ_{opt} between two consecutive optima of microwave mixing, maximum or minimum, is given by :

$$\delta\lambda = \frac{FSR.\lambda_{opt}^2}{2.c} \qquad (3)$$

It equals 8.5 pm at 1300 nm and 12 pm at 1550 nm.

Since the interference regime must respect condition (2), the temperature of the optical UMZ must be preliminarily fixed by a Peltier element. Then, the positioning of the operation point for each LD (Eq. (3)) can be theoretically adjusted independently by fine tuning of its temperature and/or bias. But in practice, the temperature precision is of ± 0.1°C only, which corresponds to a wavelength shift of $\delta\lambda$=8 pm. This precision is not sufficient for an optimized utilisation. It is preferable to control the bias of the LD, since the precision of ± 0.1 mA, corresponds to about $\delta\lambda$=0.65 pm. In this case, it is possible to optimize easily the positioning of the optical operation points independently at each multiplexed wavelength λ_{opt}.

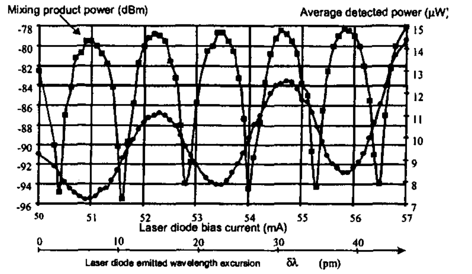

Fig. 4. : Measured power of the mixing products (square) compared with the interference regime (circle) : FSR=3 GHz, f_{LO}=1.6 GHZ, f_{RF}=1.4 GHz.

IV. EXPERIMENTAL RESULTS WITH WDM

A. Description of the optical microwave set-up

The measurement set-up is shown in Fig.1. The LDs No.1 (emitting at 1551 nm) and No.2 (emitting at 1308 nm) are modulated independently by frequency couples (f_{LO1}, f_{RF1}) and (f_{LO2}, f_{RF2}) respectively.

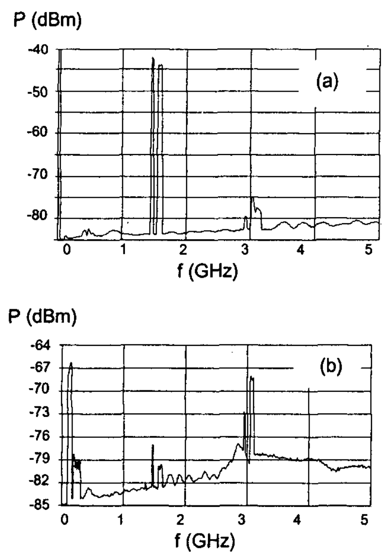

Fig. 6. : Detected microwave spectrum, on the 1551 nm channel, at the output of the LD (a) and at the output of the UMZ (b).

The microwave power measured before injection at the RF input of the LDs is of 0 dBm for each frequency. Through a 3dB-coupler, carriers No.1 and No.2 are injected simultaneously, with optical powers of 2.4 mW and 1.75 mW respectively. The UMZ is preceded by a cleaved single-mode fibre and followed by a lensed fibre to improve coupling. At the output of the UMZ, optical powers of 131 µW and 111 µW are measured at 1551 nm and 1308 nm respectively. From those values, an optical loss of 12 dB (24 dB electrical) can be derived. This loss is due to the mismatch between diameters of the fibres (∅ 9 µm) and that of the integrated waveguide (∅ 2 µm).

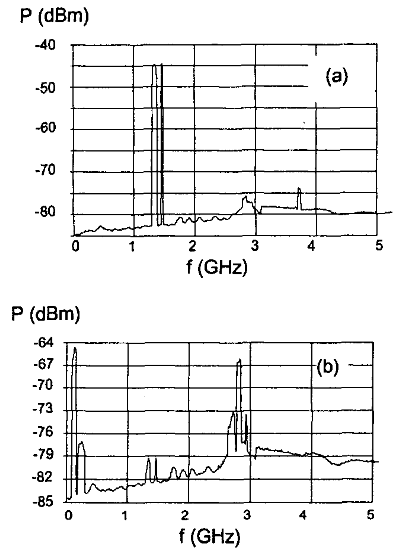

Fig. 7. : Detected microwave spectrum, on the 1308 nm channel, at the output of the LD (a) and at the output of the UMZ (b).

Fig.6a and Fig.7a exhibit the spectral powers at the output of the system LD+PD without the UMZ, while Fig.6b and Fig.7b show the spectral powers on the converted frequencies, at the output of the system LD+UMZ+PD after demultiplexing.

B. Results at 1551 nm after demultiplexing

A CW f_{LO1}=1.45 GHz was applied and combined with f_{RF1} swept from 1.6 GHz to 1.65 GHz (Fig.6a). Then, the desired frequency mixing products f_{RF1}-f_{LO1} and f_{RF1}+f_{LO1} are swept between [100 MHz - 150 MHz] and [3.05 GHz - 3.1 GHz] respectively (Fig.6b).

In the output spectrum, a 10 dB rejection of the fundamentals is observed (defined as the difference between the converted power and the detected power of the input frequencies).

The conversion gain L_{CVmix} is used to quantify microwave mixing performances. It is defined as the ratio between the detected powers measured for the mixing frequency after the optical UMZ and for the RF frequency without the UMZ. Theoretical investigation gives :

$$L_{CVmix}(dB) = \frac{(0.58\alpha)^2}{4} \tag{4}$$

In the case of LD No.1, the theoretical L_{CVmix} is about 2.1 dB. From the measurement results of Fig.6a, the detected power on the fundamentals is about –44 dBm, without mixing. From measurements of Fig.6b, the converted powers on the mixing products (f_{RF1}-f_{LO1}) and (f_{RF1}+f_{LO1}) are –66 dBm and –68 dBm respectively. Taking into account the –24 dB of electrical loss, the derived experimental conversion gains are on both mixing products :

$L_{CVmix}(f_{RF1}-f_{LO1}) = +2$ dB; $L_{CVmix}(f_{RF1}+f_{LO1}) = 0$ dB.

This is close to the theoretical value. Difference between up-and-down values of L_{CVmix} is due to the term of amplitude modulation, despite the influence of this term is low.

C. Results at 1308 nm after demultiplexing

On the second channel at 1308 nm, a CW f_{LO2}=1. 5 GHz was applied and combined with f_{RF2} swept from 1.35 GHz to 1.4 GHz (Fig. 7a). Then, the desired frequency mixing products f_{LO2}-f_{RF2} and f_{LO2}+f_{RF2} are swept between [100 MHz - 150 MHz] and [2.85 GHz - 2.9 GHz] respectively (Fig. 7b).

Here again, a rejection of about 15 dB of the fundamentals is observed. In this case, the theoretical conversion gain L_{CVmix} is about 4.1 dB.

From the measurement results of Fig. 7a, the detected power on the fundamentals is about –45 dBm, without mixing. From measurements of Fig. 7b, the converted powers on the mixing products (f_{LO2}-f_{RF2}) and (f_{LO2}+f_{RF2}) are –65 dBm and –66 dBm respectively. Taking into account the –24 dB of electrical loss, the derived experimental conversion gains are on both mixing products :

$L_{CVmix}(f_{LO2}-f_{RF2}) = +4$ dB; $L_{CVmix}(f_{LO2}+f_{RF2}) = +3$ dB.

Here again, measurements are in good agreement with theory.

Simultaneous conversions of microwave signal from 1.5 GHz to 3 GHz are experimentally demonstrated on two separated optical channels.

An important issue of mixing is the possibility to transmit microwave signals at frequencies higher than the bandwidth of the LD : when both frequencies f_{LO2}, f_{RF2} are swept around 4.5 GHz according to relation (1), the up-converted signal is around 9 GHz.

V. CONCLUSION

In this paper focused also on operation conditions and controls requested for good performances, multiplexing possibilities of a new photonic microwave mixing technique are experimentally demonstrated.

Two couples of microwave frequencies are mixed independently on two optical carriers at 1308 and 1551 nm. Both wavelengths are injected into a unique optical passive integrated component, an UMZ interferometer.

After demultiplexing, the measured conversion gains are 0 dB, +3 dB at 3 GHz, for powers at the output of the LDs about 2 mW. These values depend on the LD linewidth enhancement factor α. The higher α is, the higher the conversion gain is.

This WDM method is advantageously applicable to optical simultaneous processing of several multiplexed channels, such as those used in radar systems. This multiplexing technique of converted microwave signals is a specificity of microwave/photonics interactions and could not be used in the pure electrical domain.

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