All optical signal processing for conversion of the subcarriers of BPSK and QPSK digital signals

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Abstract:

A passive integrated unbalanced Mach Zehnder interferometer (UMZ) used in a frequency modulated fiber-optic link converts the microwave subcarrier frequencies of digital signals. As expected in theory, Bit Error Rate (BER) measurements for BPSK modulation format show better results using UMZ than for classical optical microwave mixing method using an active external optical modulator. Using the UMZ, conversions of microwave subcarrier of digital signals are reached for data rate of 500 Mbit/s. Measurements with QPSK modulation format show low BER and no IQ imbalance in the constellation diagram at 100 Mbit/s.

I. INTRODUCTION

In the new microwave (MW) digital optical transmission systems, the optical domain is not only used to transmit MW signals but provides also signal processing functions as optical MW frequency mixing. A great interest of optical MW mixing is to convert subcarrier frequencies of BPSK digital signals or of widely used QPSK digital signals [1].

An original technique for up and down-conversion of MW subcarriers of digital signals based on the insertion of a passive all-optical device (unbalanced Mach-Zehnder interferometer) in a frequency modulated (FM) fiber-optic link has been investigated. This technique has been successfully tested with CW signals [2]. In this presentation, BER measurements of digital transmission for BPSK and QPSK format are presented. The BPSK format measurements valid the principle of this optical MW mixing method, BER measurements using UMZ are compared with classical optical microwave mixing method using active external optical modulator. QPSK modulation format give information about resistance of vector modulations after optical microwave conversion through UMZ.

II. OPTICAL MICROWAVE MIXING WITH AN INTERFEROMETER

II.1 Original mixing method using a passive interferometer

A DFB laser diode (LD) operating at 1550 nm in the linear regime is directly modulated by two MW signals delivered by a RF combiner. A 100 Mb/s NRZ 2^{23}-1 pseudorandom bit sequence modulates the phase of the first subcarrier at a frequency f_{RF} with a BPSK format. The second subcarrier is a CW signal at the frequency f_{LO}. Optical power is coupled into an optical fiber, then injected into an unbalanced Mach-Zehnder interferometer (UMZ) and detected at its output by a photodetector (PD) part of the Hewlett Packard Lightwave test set 83420A. This PD is directly followed by a 30 dB broadband amplifier (130 MHz-20 GHz). The UMZ acts as a linear filter on the input optical field, its transfer function is periodic, with a period equal to the Free Spectral Range (FSR) of the UMZ. The UMZ was fabricated in commercial glass substrate by Tl^+/Na^+ ion exchange, it has been designed to have a FSR of 3 GHz. The global system is represented in Fig. 1.

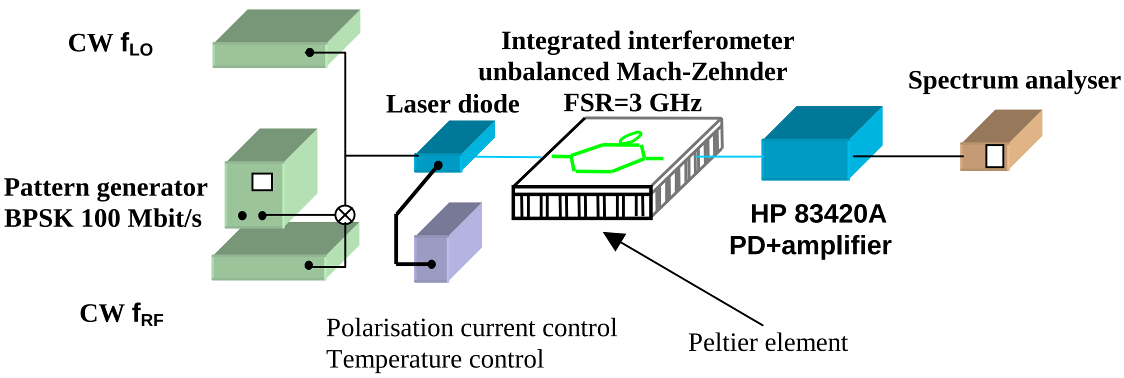

Fig. 1. Set up for up and downconversion of MW subcarrier of a BPSK digital signal using a passive UMZ

In the coherent regime, interference converts Frequency Modulation due to the direct modulation of the LD into intensity modulation (IM) at the output of the interferometer. The interferometer/PD combination has a non-linear response as a function of the optical frequency (sinusoidal in the case of the UMZ). Consequently, MW mixing can be generated when operating at maximum or minimum of transmission, by controlling the interference regime either with bias current of LD, or by thermo-optic control of the LD and of the substrate of the UMZ. Maximum mixing power is then obtained when the input frequencies respect also condition 2, depending on the FSR value [3].

Condition 2: $f_{LO}=(2k+1)\frac{FSR}{2},\ k\in \mathrm{N}$ and $f_{RF}=(2k'+1)\frac{FSR}{2},\ k'\in \mathrm{N},$

Respecting these conditions, the converted digital signals are transmitted at the mixing frequencies $f_{mix}= f_{RF}\pm f_{LO}$ and the input frequencies are rejected.

Supposing that the power of the LO signal is chosen in order to maximise the mixing power and that the power of the RF signal is low, the power detected at the mixing frequencies after quadratic photodetection can be written as :

$$P_{mix} \approx R_{PD}\left(T_i P_0 m_{RF} \alpha 0.58\right)^2$$

where R_{PD} is the same term due to optical/electrical conversion and m_{RF} is the optical intensity modulation index which would be measured at the output of the LD. T_i is the insertion loss of the UMZ, α is the linewidth enhancement factor of the LD.

II.2 Advantages of UMZ compared to classical optical microwave mixing with external optical Mach-Zehnder modulator

To make a comparison between classical optical microwave mixing methods, an external optical Mach-Zehnder modulator (EOM) can be used at minimum transmission, adding digital signal around f_{RF} and the CW signal at f_{LO} at its electrical input [4]. In this case, the power at the mixing frequencies can be written as:

$$P_{mix} \approx R_{PD}\left(T_i P_0 m_{RF}\, 0.58\right)^2$$

Finally, the comparison of the two methods working in similar conditions, with the same intensity modulation index m_{RF} and with same insertion loss T_i (in fact, the insertion loss with a passive interferometer could easily be even better than the insertion loss of the external modulator), shows a mixing gain factor equal to α^2 in the case of the passive Mach-Zehnder interferometer.

As expected in theory, passive UMZ gives sensibly better BER values for the same optical input power and for equal intensity modulation index and no insertion loss than EOM (Fig. 2). For a 10^{-9} BER value, input optical power must be –7.5 dBm for EOM whereas it must be only –13 dBm for UMZ considering equal intensity modulation index and no insertion loss. Average difference between the two BER curves is about 6 dB that corresponds to $10\log(\alpha^2)=6.5$ dB expected in theory. Optical MW mixing with passive UMZ is optimized by a α^2 factor compared to EOM.

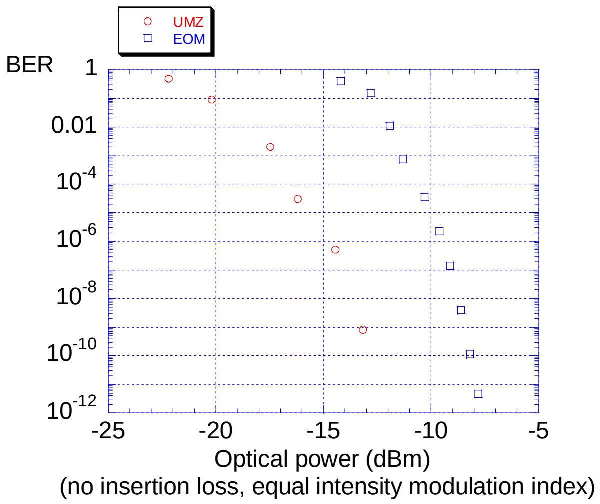

Fig. 2. BER function of the input optical power P_o (dBm)

III. APPLICATIONS OF OPTICAL MICROWAVE MIXING WITH UMZ FOR BPSK AND QPSK DIGITAL SIGNALS

III.1 Influence of data rate for BPSK modulation

BER function of input optical power was measured for different data rates of digital signal. Figure 3 shows that degradation of BER with higher data rate can be compensated by increasing the optical power P_o while keeping a low value for P_o, in the range of –18 dBm to –10 dBm. High data rate of 500 Mbit/s can be easily obtained with a low optical power. As shown in the inset of Fig. 3, the eye diagram is well open.

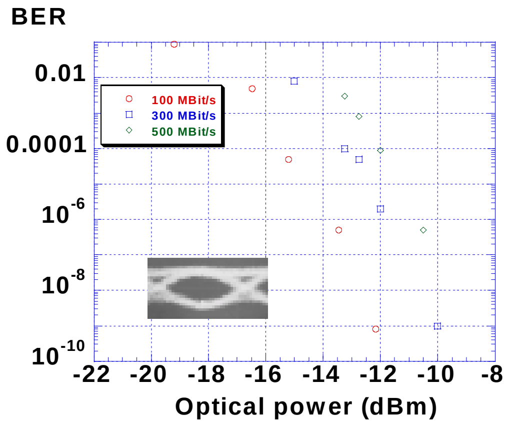

Fig. 3. BER function of input optical power P_o (dBm) for different data rates

III.2 QPSK modulation

A QPSK modulator is used to generate the IQ digital signal around 1.55 GHz. A QPSK demodulator is used at 6 GHz to recover the transmitted IQ data sequences after upconversion of the subcarrier of the digital signal. Both IQ recovered sequences are analysed with a high speed sampling scope. AS shown on Fig. 4, a low BER of 10^{-9} can be reached for optical power as low as -8 dBm at 100 Mbit/s.

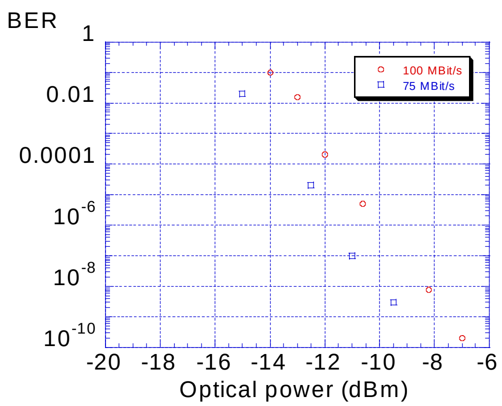

Fig.4. BER function of input optical power P_o

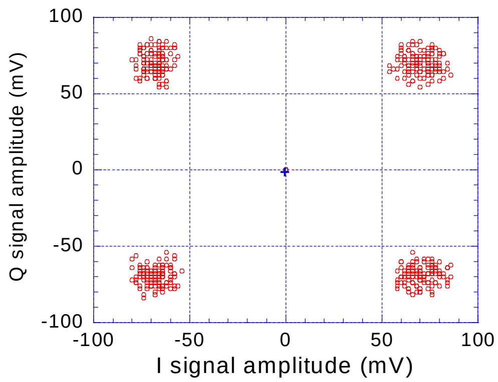

Fig.5. Constellation diagram

Fig. 5 shows a symmetrical constellation diagram that insures good transmission of QPSK signal without IQ imbalance. Accurate decision can still be made for each symbol.

IV. CONCLUSIONS

A technique for up and downconversion of MW subcarriers of digital signals has been successfully demonstrated for BPSK and QPSK digital signals. This technique uses a very low cost passive optical device that allows also to work with WDM and full duplex systems (1.3-1.5 μm)[2].

BER results are improved compared to the classical method using an EOM as far as the laser diode has a linewidth enhancement factor higher than 1. High data rate of 500 Mbit/s is possible for BPSK modulation format and good resistance of constellation diagram (no IQ imbalance) is obtained for QPSK modulation format at 100 Mbit/s.

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